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TPACK-XD: Expanding the TPACK Framework for Metaverse-Based Higher Education Learning Environments

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Abstract

The integration of immersive metaverse-based environments into higher education challenges existing conceptualisations of teacher knowledge. While the Technological Pedagogical Content Knowledge (TPACK) framework has guided technology integration in traditional and online settings, its sufficiency for immersive higher education metaverse-based learning environments (HEMLE) remains underexplored. Grounded in a design-based research (DBR) problem-analysis phase, this qualitative study draws on expert interviews with immersive education practitioners and platform developers to identify the knowledge domains required for effective curriculum design in HEMLE contexts. Using a hybrid thematic analysis informed by TPACK, findings reveal that immersive teaching demands expanded attention to Learner Knowledge (AK), Design Knowledge (DK), and strengthened Contextual Knowledge (XK), reflecting embodied interaction, experiential orchestration, and infrastructural constraints unique to immersive environments. Based on these insights, the study proposes TPACK-XD as an extended framework that accounts for the design-intensive, contextually embedded, and learner-centered nature of metaverse-based higher education. The findings contribute to the theoretical refinement of teacher knowledge models and offer guidance for curriculum development in immersive digital learning spaces.

Keywords: Metaverse, curriculum, TPACK, TPACK-XD, higher education

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1 Introduction

Higher Education Institutions (HEIs) worldwide undergo a profound transformation driven by internationalisation, student diversity, digitalisation, and the emergence of new pedagogies for an uncertain future (Devlin & Samarawickrema, 2022). These shifts happen alongside rapid societal changes and the emergence of advanced technologies, obliging HEIs to rethink how they prepare learners for a complex, technology-driven future.

Amongst these innovations, Virtual Reality (VR) offers immersive, computer-generated three-dimensional spaces that allow users to interact with virtual objects while blocking the physical world (Jensen & Konradsen, 2018; Velev & Zlateva, 2017 in Mills et al., 2022, p. 336). Augmented Reality (AR) is enriching reality, overlaying computer-generated data (Britannica, 2024; Sala, 2020, p. 50), while Mixed Reality (MR) merges real-time physical and digital, combining interactive virtual objects with real settings (Sobota & Cvetković, 2020, p. 100). These different systems, blending physical and virtual environments, fall under the umbrella term of Extended Reality (XR) (Vasarainen et al., 2021). When mixed with Artificial Intelligence (AI), enabler of automated content and code generation, XR technologies are shaping a new, immersive digital continuum: the Metaverse. AI contributes to shaping immersive environments at multiple levels: infrastructure (AI supports automated generation of code, adaptive system behaviour, and intelligent non-player agents that respond dynamically to user interaction), content (generative AI tools enable rapid production of learning materials, virtual assets, and simulated scenarios), organisation of learning (AI can structure learning pathways, provide real-time feedback, and personalise immersive experiences). These different layers of AI integration suggest that its influence extends beyond technical enhancement toward pedagogical structuring and experiential design within Higher Education Metaverse-based Learning Environments (HEMLE).

Etymologically, the term “Metaverse” is sharing its root with “universe”, which invites to a conceptual parallel between the two concepts. In modern physics, scholars distinguish the “observable universe,” the portion visible to humanity, from the vast and largely unknown whole (Britannica, 2023; Collins English Dictionary, 2023). By analogy, we might speak of a “metaverse” (lowercase) as the observable portion of the broader Metaverse, the part that currently exists and can be experienced. However, just as cosmology distinguishes between the observable universe and a vastly larger, partially unknown cosmos containing undiscovered formations, the broader Metaverse can be understood as including not only existing platforms but also a multiplicity of potential immersive configurations, architectures, governance models, and socio-technical arrangements that have not yet been materialised. The observable metaverse is therefore a provisional manifestation within a wider field of technological, organisational, and cultural possibility. The broader Metaverse includes, on the other hand, the evolving code architectures, infrastructural logics, institutional frameworks, economic models, and ideological imaginaries that shape what kinds of immersive environments are possible, scalable, or legitimate within specific contexts. In this sense, the metaverse currently implemented in a HEI represents just one realised configuration among many potential “metaverses” that could emerge as technologies, institutional cultures, and societal expectations continue to evolve.

In fact, like the observable universe, the metaverse is shaped by its own space–time laws and is in continuous change. Its dynamism reflects the broader transformation of today’s world. The ongoing Fourth Industrial Revolution, led by mixing digital, biological, and physical technologies

such as AI, the Internet of Things, robotics, and biotechnology, is rapidly reshaping economies and societies (Schwab, 2017, 2021). As industries evolve toward knowledge-intensive, innovation-focused, and globally interconnected processes (Trilling & Fadel, 2009), HEIs face the challenge of preparing graduates for quickly adapting to constantly changing technologies and roles.

In this context, the metaverse arises as a forward-looking learning environment that does not entirely replicate the real world, but simulates, augments, and reconfigures its socio-technical processes. Instead of functioning as a simple digital copy, immersive environments can model complex systems, compress temporal processes, and make visible the interactions between technological infrastructures, institutional structures, and human agency. Like this, the metaverse becomes a space in which learners can actively experiment with and navigate the extended reality of the modern world. This capacity to simulate and reconfigure socio-technical systems aligns with the metaverse's potential role as a pedagogical space for navigating current technological and societal transformations.

Research suggests that immersive, multisensory virtual environments could enhance students' engagement and learning in various educational contexts. They are capable of fostering behavioural, affective, and cognitive engagement, leading to richer interactions among students and improving collaborative learning outcomes (Bouta et al., 2012) so that HEI level students are more engaged and immersed in the subject matter (Rauch et al., 2009). Such platforms offer synchronous or asynchronous learning opportunities, allowing learners to practice their skills in simulated real-world scenarios (Chung, 2012; Sutherland & Ward, 2018) and have been proven effective in multiple domains like design education, supporting critical thinking, creative experimentation, generation of multiple solutions to design problems, etc. (Chandler & Ward, 2019).

These interaction modalities not only extend traditional communication channels. They entirely reshape the learning environment. Synchronous immersive interaction can intensify social presence and immediacy, making possible co-presence and collaborative problem-solving, while asynchronous engagement allows reflection, repetition, and personalised pacing within simulated contexts. Avatar-mediated participation can reduce performance anxiety and reconfigure identity expression, altering classroom dynamics and learner confidence. Spatial interaction and embodied manipulation of virtual objects shift learning from abstract representation to experiential modelling, influencing cognitive processes and conceptual understanding. Like this, interaction in the metaverse is more than communicative: it is embedded in the learning environment itself, affecting agency, authority, feedback structures, and the technical or pedagogical orchestration done by the teachers.

But, even if the pedagogical affordances and benefits of these technologies are evident (Obae & Alkhayat, 2023), careful design of such online resources and curricula is necessary to fully leverage their potential in HEI settings (Bouta et al., 2012; Chandler & Ward, 2019). Moreover, the negative effects of using these technologies, such as visual exhaustion or mental fatigue (Bermejo et al., 2023), and material challenges (e.g. issues with headsets, cost of technology, etc.) can represent serious barriers (Evans, 2019) in the implementation of such metaverse-based learning environments in HEIs.

As immersive higher education environments remain emergent and not everywhere institutionalized, expertise in their design and implementation is concentrated currently within

early adopters, platform developers, and community leaders who actively shape these ecosystems. Unlike established pedagogical domains, immersive teaching practices are not yet widely standardized within HEIs, so individuals who designed, implemented, or architected metaverse-based learning environments possess situated and practice-based knowledge that is critical for being able to identify the competencies required for effective integration. Sampling "metaverse experts" in this study was therefore epistemologically aligned with the research aim of mapping emergent teacher knowledge domains, rather than privileging technological perspectives. This positioning provides a theoretical foundation for the study's methodological choices.

In fact, in this paper, the literature gap identified is that a specific knowledge framework for teachers wanting to implement metaverse technology into HEI learning environments hasn't yet been developed. The current investigation aims to explore this aspect and develop it further.

The primary goal of this qualitative research is to identify the key teacher knowledge domains necessary for such integration and to outline some of the elements that a teacher should be aware of when planning a curriculum tailored for a Higher Education Metaverse-based Learning Environment (HEMLE).

2 Key concepts

2.1 Higher Education Metaverse-based Learning Environment

A HEMLE is a complex learning environment based on metaverse technologies that incorporates pedagogical, social, cultural, psychological, physical, and digital aspects into a HEI context.

The metaverse has multiple definitions in the scientific literature and even more in the non-scientific one. Its meaning has evolved since its 1990s first appearance (Weinberger, 2022, p. 3) and is now seen as an expansive network of interconnected virtual environments that blend physical and digital realities, allowing millions of users and AI-driven agents to interact in real time through immersive, extended-reality experiences (Slater, 2025)**.** It can be accessed through XR devices, computers or phones, enabling human activities such as social interaction, work, education, and entertainment. A VR-accessed virtual environment is simply one part of the metaverse, much like a planet is part of the universe. VR constitutes one of metaverse's possible gateways, alongside AR/MR headsets, computers, or phones.

HEIs have already started exploring this new multi-faceted space, embedding it in the education process (Elgamal, 2022), so the HEMLE concept can be brought into discussion.

HEI learning environments comprise multiple interconnected elements such as physical spaces, digital resources, psychological and social aspects, and institutional culture (Rusticus et al., 2023). They are complex systems, where learning theories (Guney & Al, 2012), pedagogy and space (Imms & Kvan, 2021) are deeply connected and can be analysed from several viewpoints: physical, digital, psychological, social, cultural, and pedagogical.

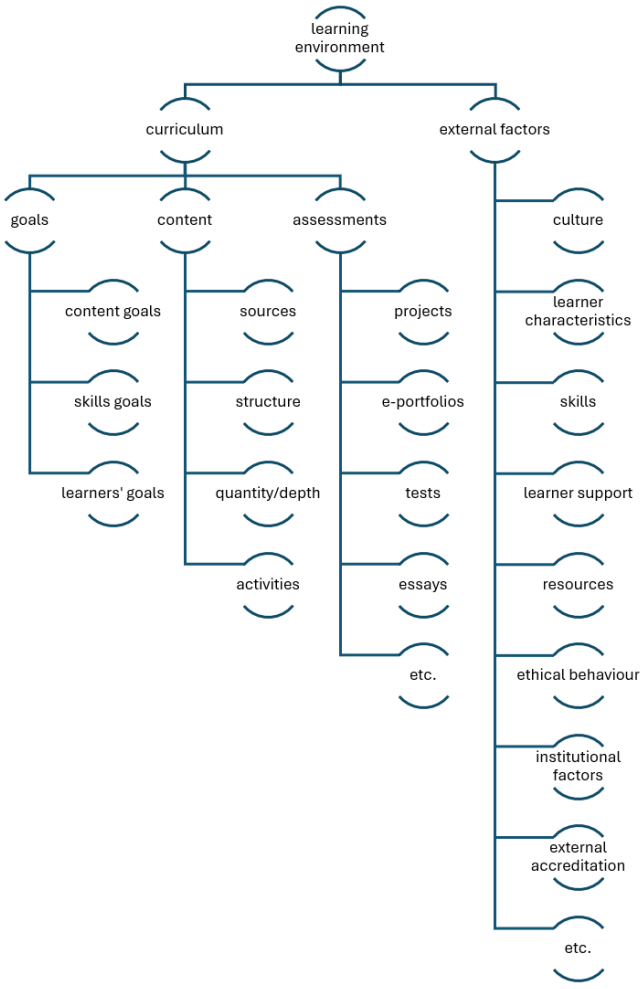
When the metaverse is used as a virtual learning environment, the HEMLE adds a supplemental layer of complexity to the HEI learning environment by including both real-world and virtual elements, blurring the limits between physical and digital. From a technological and practical point of view, including, for example, VR in a face-to-face learning experience, imposes certain

adaptations, like the usage of large amounts of physical space (Marwecki et al., 2018). Even though the learners are feeling embodied, the avatar choice has a clear impact on the prosocial behaviours (Herrera & Bailenson, 2021), self-presence, realism, synchrony and nonverbal behaviours (Han et al., 2023). This brings new elements to consider in the social-psychological aspects of such an HEMLE. Moreover, the *culture influences content design, acceptance and use by instructors and learners* (Buliva, 2018), so a HEMLE has its own characteristics and differs from face-to-face learning environments. The traits of the curriculum to be built for HEMLE need to be specified.

2.2 Curriculum

Despite the large number of definitions given over the decades for the concept of "curriculum" (Marsh, 2004), two core common elements can be observed: learning objectives and content (Glatthorn et al., 2018; Posner, 1992; Trilling & Fadel, 2009). In this paper, the curriculum is understood, following Bates (2022), as an integral part of the HEI learning environment. As illustrated in FIGURE 1, curriculum is built on three foundational components (goals, content, and assessment) and interacts dynamically with a set of external contextual factors such as learner characteristics, institutional policies, resources, and technological infrastructure. This interdependence between internal and external elements highlights the need for a comprehensive framework of teacher knowledge capable of guiding curriculum design within HEMLEs.

FIGURE 1

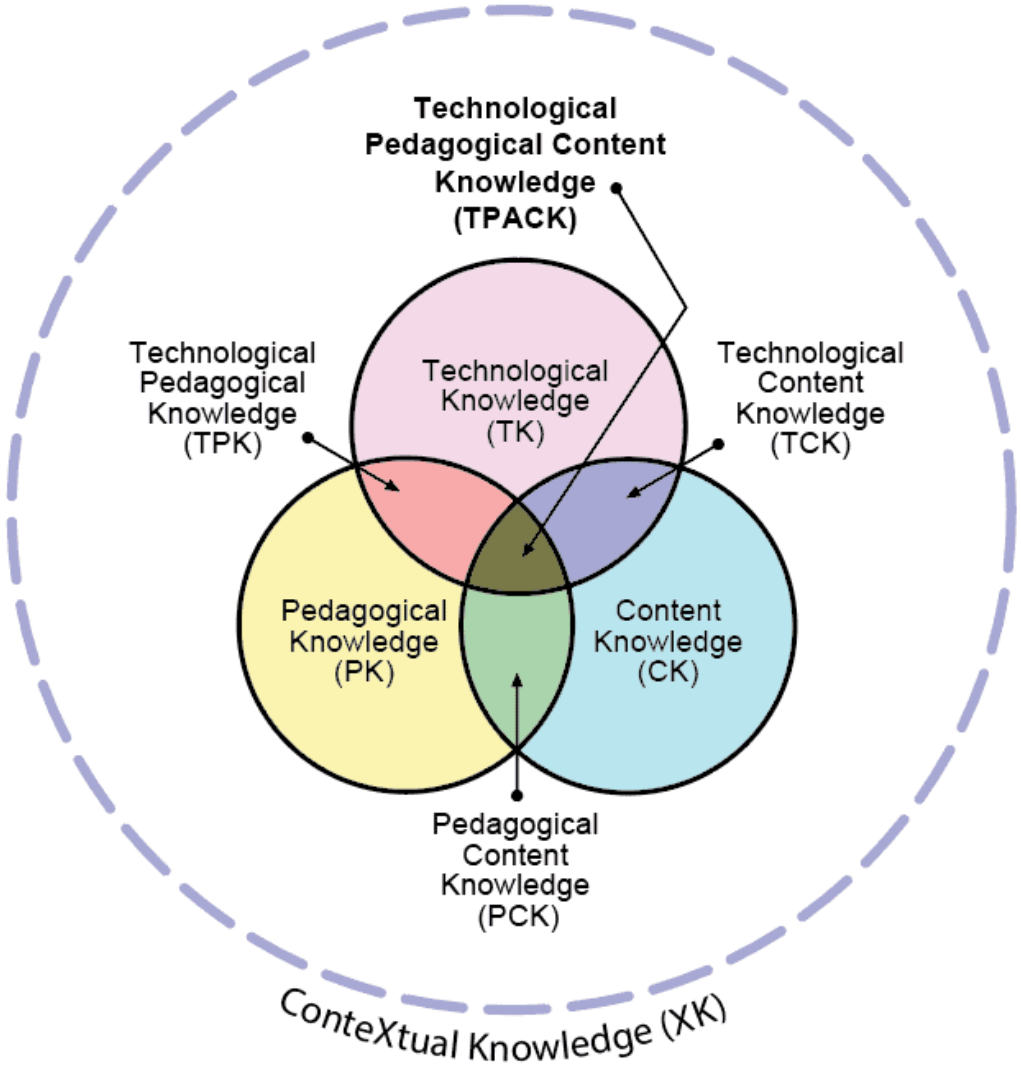


Learning environment and curriculum hierarchy adapted after Bates (2022)

2.3 TPACK

The Technological Pedagogical Content Knowledge (TPACK) framework, (FIGURE 2) is a conceptual model that *describes the kinds of knowledge needed by a teacher for effective technology integration* (Koehler et al., 2014). It was first introduced by Mishra and Koelher in 2006 and it consists of three overlapping knowledge domains: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), embraced by Contextual Knowledge (XK) (Mishra, 2019; Warr & Mishra, 2022). TPACK emphasises that successful technology use in education requires a balance between these domains (Padmavathi, 2017).

FIGURE 2



The TPACK Framework (Mishra, 2019)

TPACK has been widely researched, with studies showing positive results in enhancing teachers' ability to integrate technology in instruction (Chai et al., 2013). It has been adapted and applied over the years to analyse online HEI learning environments, which opens the possibility of

adapting it for HEMLE. However, while TPACK has been proven effective in describing technology integration in traditional and online learning environments, HEMLE contexts introduce conditions that challenge its original assumptions. TPACK conceptualizes contextual knowledge (XK) even in recent studies as a key surrounding layer (Brianza, 2022; Brianza et al., 2024) but does not explicitly theorize learner embodiment, spatial cognition, or interaction design in three-dimensional environments. In HEMLEs, teachers must navigate immersive affordances, embodied presence, infrastructural constraints, and experiential design decisions that extend beyond conventional TK, PK, and CK intersections. These emerging demands raise the question of whether TPACK, in its current form, captures well enough the complexity of teacher knowledge required in HEMLE.

3 Methodology

3.1 Research aims and questions

This paper constitutes the initial phase of a broader design-based research (DBR) project situated in HEI context. At this stage, the study aims to establish a foundation for the next DBR phases, addressing the following core research question: What are the essential components of teacher knowledge required to integrate metaverse technologies into a higher education learning environment?

3.2 Research context

The study was initiated at the University of Lapland, as part of the author's PhD research. It represents the first phase of a DBR process aimed at defining a conceptual framework and guiding principles for adapting HEI curricula to HEMLEs.

This phase focuses on relevance, looking at *problem identification* and *needs assessment*. It will be followed by a *design development and implementation* phase, highlighting consistency and practicality, and an *evaluation* phase focused on effectiveness. Based on an extensive literature review and aiming at developing a preliminary research framework, this initial stage used Metaverse experts' online interviews (see Sections **Feil! Fant ikke referansekilden.** and 0).

3.3 Research process and data collection

Following the seven steps to conducting, analysing, and reporting semi-structured interview data (Adeoye-Olatunde & Olenik, 2021) participants recruitment and sampling were performed, resulting in five interviews with specialists representing organisations that provide technological, pedagogical, content, and context expertise related to the HEMLE (**Feil! Fant ikke referansekilden.**).

Participants (I1-I5) were identified through the Educators in VR network, a global community of educators, researchers, and trainers exploring educational XR usage. All participants were contacted via email and informed about the purpose of the study beforehand.

The sampling strategy was purposive, aiming to gather diverse but complementary perspectives on teacher knowledge for metaverse integration in HEIs. Even though only two participants were currently employed as university teachers, the remaining experts have extensive background in educational technology development, curriculum design, contextual metaverse implementation or teacher training within HEIs. Their roles provide insider expertise on the knowledge teachers

require when designing and implementing learning experiences in HEMLE. This combination of practitioners and organisational leaders was thus aiming to capture both pedagogical and systemic dimensions of teachers' TPACK for HEMLEs.

In fact, this study adopts a design-based research (DBR) framework aligned with Reeves (2006) and further elaborated by McKenney and Reeves (2019), which conceptualizes DBR as an iterative process involving: (1) analysis of practical problems, (2) development of informed design principles, (3) iterative testing and refinement, and (4) reflection leading to theoretical contributions. The present study corresponds to the initial problem-analysis phase, focusing on identifying and conceptualising main teacher knowledge domains relevant to HEMLEs. In this framework, the objective is not statistical representativeness, but the generation of theoretically grounded design insights that can be refined and validated in the following DBR cycles.

Given the exploratory character of this DBR phase, representativeness was not targeted statistically. Instead, the focus was on selecting information-rich cases capable of bringing light on different areas of the knowledge domains applied to metaverse-based teaching and learning. The expert sample was intentionally brought together to address the objectives of the DBR problem-identification phase. At this stage, the aim was not to measure teachers' competence directly but to map the conceptual and practical foundations of teacher knowledge necessary for integrating metaverse technologies in HEIs. Involving experts from both pedagogical and technological domains provided a holistic perspective on challenges, affordances, and systemic conditions that shape teachers' knowledge domains, laying the ground for following DBR phases.

Interviews were conducted online, by the author, via Teams and Google Meet, between November 2023 and February 2024. Each interview lasted between 19-38 minutes (**Feil! Fant ikke referansekilden.**) and was video recorded with prior consent. Transcriptions were generated using tl;dv and Microsoft Teams AI transcription tools and securely stored on University of Lapland's OneDrive with access limited to the author. They were manually verified and anonymised before being imported into ATLAS.ti for qualitative analysis.

TABLE 1

no	Duration	Date	Interviewee	Interviewee's job at the moment of the interview	Organization type	Provides expertise in
1	25:35 min	21.11.2023	I1	Director of research	Metaverse-access platform provider	TCX
2	24:55 min	5.12.2023	I2	Director of all projects in the higher education space	Metaverse-access platform provider	TCX
3	19:45 min	19.01.2024	I3	Adjunct Faculty	University	TPX
4	19:27 min	25.01.2024	I4	Executive Director	Metaverse community	TPCX
5	38:00 min	09.02.2024	I5	Academic coordinator	University	TPX

Interviews details

Two interviewees represented metaverse-access platform providers, contributing with insights into the technological (TK), contextual (XK), and content (CK) aspects of implementing metaverse technologies in HEI. Two participants were university lecturers with direct teaching experience in metaverse environments, providing practical perspectives on technological (TK), pedagogical (PK), and contextual (XK) knowledge. The fifth participant, from an international metaverse community, provided expertise across technological, pedagogical, content, and contextual domains (TPCX), particularly in teacher professional development and immersive curriculum design.

Interview questions were developed in alignment with the conceptual and theoretical framework (Green, 2014) integrating participants' technological, pedagogical, and content knowledge. To activate CK, all participants were asked to define the metaverse and describe its core features. As illustrated in "8 Annex 1 – interview guide", questions about "metaversities" or "metaverse-based courses" targeted TK and XK dimensions, while inquiries into pedagogical methods and tools addressed PK. The concept of "curriculum" was explored in the interviews through its main components (FIGURE 1): objectives, content (the learning activities), and assessment, trying to identify the teachers' knowledge domains for effective HEMLE design.

Although the interview guide was not formally pilot-tested with an external sample, it was reviewed and initially discussed with the author's doctoral supervisors to ensure conceptual alignment with the TPACK framework and the aims of the study. Minor refinements in wording and sequencing were made after the first interview to improve clarity, reduce potential ambiguity, and enhance the flow of the semi-structured dialogue. In line with the Connectivity, Humanness, and Empathy principles (Brown & Danaher, 2019), the order and wording of questions were flexibly adapted during the interviews to preserve a dialogic, participant-centred approach while

maintaining alignment with the conceptual framework. These adjustments were limited to phrasing and did not alter the conceptual focus of the questions. As this study represents the initial problem-identification phase of a broader design-based research (DBR) project, such iterative refinement of the instrument is consistent with DBR's flexible and responsive methodological principles.

In fact, as first stage of the larger DBR research, the current investigation focused on identifying the knowledge domains HEI teachers need regardless of institutional context. A special emphasis was put on the transition of face-to-face curriculum to a HEMLE, as this was expected to activate participants' TPACK domains and reveal current understandings and gaps in metaverse-related teacher competence.

Given the exploratory nature of the present study and its positioning within the broader DBR process, the aim was not to exhaustively map all possible immersive teaching competencies. The objective of this phase was rather to identify core knowledge domains and recurring patterns across expert discourse. The inclusion of two university teachers provided a practice-grounded insight into classroom-level competencies. The current sample does not claim representativeness of the full population of immersive educators. Following the concept of "information power" (Malterud et al., 2016), the depth of participants' expertise and the specificity level of the research aim allowed for a meaningful conceptual mapping at this stage. Further empirical validation with larger teacher cohorts is planned in the following DBR phases.

3.4 Data analysis

Data was analysed using a hybrid thematic analysis approach (Braun & Clarke, 2006), combining deductive and inductive coding strategies. Following a first open thematic coding that generated 103 codes and remained mainly descriptive, preserving participants' denotations, the TPACK framework and the key concepts (curriculum, HEMLE) were used as analytical lens. Six principal code groups were established at this stage: Curriculum, HEMLE, CK, PK, TK, and XK. Their relationship was afterwards examined using the co-occurrence function in ATLAS.ti. In this analysis, co-occurrence refers to the frequency with which two or more codes appear together in the same fragment, indicating how interviewees linked different knowledge domains conceptually in their responses.

TABLE 1 presents these co-occurrences, showing that the strongest relationships occurred between PK and Curriculum (54 instances) and between CK and Curriculum (40 instances). This highlights that participants most frequently associated their understanding of curriculum design with pedagogical and content considerations (e.g. teaching strategies, learning objectives, and subject-specific adaptations in metaverse environments). Moderate overlaps between TK and both Curriculum (23) and HEMLE (22) suggest that technology integration was seen as equally relevant to both instructional design and the creation of immersive learning spaces. Meanwhile, XK showed fewer links with Curriculum (4) but stronger ties to HEMLE (18), reflecting that participants value the situational and institutional aspects of implementing a metaverse-based education.

TABLE 1

		curriculum 42	HEMLE 30
CK	37	40	11
PK	46	54	10
TK	39	23	22
XK	19	4	18

Co-occurrences of key concepts and the TPACK framework

These co-occurrence patterns directly support the research question by clarifying how various teacher knowledge domains interact while integrating metaverse technologies in HEI. So, Table 2 serves not only as a visual summary of coding results but also as analytical evidence demonstrating that effective curriculum design for HEMLEs relies on the interdependence of pedagogical, content, technological, and contextual knowledge.

Co-occurrence analysis was used to identify thematic intersections between knowledge domains, but it did not function as a metric of pure frequency or sentiment. All coded segments were first interpreted qualitatively, making sure for contrasting or critical statements (e.g., expressions of limitation, dissatisfaction, or comparison) to be analysed contextually. Co-occurrence captured conceptual proximity between themes, regardless of whether the relationship was framed positively or critically. During interpretive analysis, the focus was on the rhetorical function of statements, allowing distinctions between endorsement, critique, and tension to inform the refinement of categories.

In this deductive thematic analysis guided by the TPACK framework several codes emerged as not aligning with the six predefined categories. These were kept as inductive insights and later analysed separately. They were identified as representing possible new dimensions of teacher knowledge within HEMLE, not fully captured by the existing TPACK domains. Their presence in the interviews suggested the possibility of having emergent knowledge categories when discussing a HEMLE design and implementation (see Sections 4.2 and 4.3).

In summary, the overall data analysis followed a deductive–inductive continuum, where theory guided categorisation and participants' data informed theory refinement, leading to extension of the theoretical framework. The following section presents the results of the thematic analysis organised according to the TPACK knowledge domains and the emergent categories identified during coding.

4 Findings

Building on the thematic analysis, this section presents the key findings derived from the five expert interviews. Results are organised according to the TPACK framework, highlighting how different knowledge domains intersect when integrating metaverse technologies in HEIs (Section 4.1) and how knowledge domains guide the curriculum design process for HEMLEs.

Each subsection below discusses cross-data patterns and insights, illustrating shared understandings and distinctive perspectives relevant to the evolving role of teacher knowledge in metaverse-based education. Moreover, two emergent knowledge domains are identified as particularly relevant for curriculum design in HEMLEs. These new domains are examined in Sections 0 and 0, followed by a proposed extension of the TPACK framework in Section 0.

4.1 Technological-Pedagogical-Content-conteXt Knowledge for Higher Education Metaverse-based Learning Environments

The metaverse, as I4 so well characterises it, is "*what anthropologists call presentist terms"* for which it is *"premature to give a definition*". Despite its continuously evolving nature, all interviewees (I1-I5) emphasised that it is already being implemented in HEI contexts, functioning as a learning environment shaped by emerging and interconnected technologies. This integration into HEIs requires teachers to develop a nuanced form of TPACK that will be further developed and described below.

4.1.1 Technological-Pedagogical knowledge

As the interviews pointed out, even if the metaverse is not fully in place yet (I3, I1) due to financial and security issues (I2, I3), it can be seen as a parallel of the universe and, like the latter, doesn't have clear boundaries, being in constant expansion. There are, for example, nowadays parts of the metaverse that are well in place and functioning. Virtual Worlds accessed through VR technology are one example that all experts used as a synecdoche for the "metaverse". In fact, the metaverse goes beyond VR/AR worlds: "*It might extend to mixed reality*" (I3), linking *the virtual and physical world through AI-generated content* (Sun et al., 2022, p. 2) as in the future "*there will be a merge between virtual and mixed reality*" (I3). The metaverse is, in fact, a series of *interconnected web of ubiquitous virtual worlds* (Weinberger, 2022, p. 13), "*like a world that connects these virtual worlds together, and you can go there without a password without a username*" (I3). It "*is an abstract concept that doesn't have any unified platform*", "*a space that's created in the digital sphere that allows people for fully immersive three-dimensional experience to achieve whatever goals that might be*" (I2).

As I4 was phrasing it, the metaverse allows for creating new tasks, previously inconceivable, as *"you can bend space and time, you can alter the interactions, the actual physics in those spaces*" (I2). It changes the way we perceive essential concepts as time and space (I4) since *the spatial properties of the VR environment […] produce significantly different time estimations* (Read et al., 2021, p. 913). "*The whole idea of a metaverse is that anything is possible*" (I4), so it could act as a "redefinition" technology (see Puentedura, 2013 SAMR model) if a mindful selection of the best adapted access platform (I1) is done based on the learning goals and HEI-specific contextual limitations.

Software for a HEMLE thus needs to be carefully selected. It must have all the necessary teaching functions required by each organisation. Writing and reading, for example, are not activities easily

doable in a 3D environment (I1), and if a language teacher needs to work on those, they should rather choose a 2D learning environment than an immersive one. But if the learning goal is speaking, immersive simulations might be the best-adapted solution. Alongside AI-powered avatars, these can stimulate oral interaction or even function "*as a form of self-assessment*" (I1), allowing for asynchronous and authentic practice of oral skills.

The HEMLE technological-pedagogical knowledge (**TPK**) for teachers to acquire needs to consider these aspects. When teaching in the metaverse, learning goals are kept, and the "*modality of instruction*" (I2) is shifted. This raises the necessity of a HEMLE-adapted learning activities design framework, combining pedagogical and content knowledge (**PCK**).

4.1.2 Technological-Content Knowledge

Technology is one of the biggest challenges of a HEMLE. When looking at the intersection between TPACK and HEMLE in TABLE 1 TK has the highest degree of co-occurrences. It becomes obvious that there are "still tech issues that come about" as "it's a big setup to use VR at […] the scale of a classroom of 25 students" (I1). Moreover, the limitations that different platforms have are directly impacting the pedagogical choices of HEI teachers (I1, I2, I3) or even the length of the learning experience (I5), indicating that technological-content knowledge (TCK) has to be considered when integrating the metaverse in a HEI learning environment.

Being mindful about the selection of the metaverse access platforms is essential, and knowing different technology selection frameworks (e.g. Bates, 2022; Chugh et al., 2023; Rhode & Krishnamurthi, 2017, etc.) can become useful in this situation. The ease of use must be considered since the beginning of the planning process, alongside the costs of hardware and software necessary to access the HEMLE. Technological and contextual knowledge go hand in hand.

4.1.3 Technological-conteXt Knowledge

For an immersive experience, VR, AR or MR headsets are essential. In certain HEIs these devices might already be acquired, while in others, they might need to be bought. Even if prices decreased, they are still expensive and with all the budget cuts higher education institutions are facing (I1), teaching in the metaverse can be challenging depending on the financial context of the HEI. But funding can be found (I2), and there are even multiple platforms that facilitate metaverse access through a phone, tablet, or computer. The main cost to consider when integrating metaverse technology in HEI learning environments is that of teacher time and software, so technical-contextual (TXK) is essential to have.

Each HEI has specific logistical, spatial or time restrictions besides the financial ones. When considering a HEMLE, "there is some organisational planning that you need to go through and there are other people that you have to bring into the equation" (I2), like technicians, funding specialists, etc. The complexity of a HEMLE makes it "necessary to have at least an assistant worrying of the technical part and helping with the interaction. […] To teach in the metaverse is not an individual [work]. This is another difference from the regular class1, with the physical classes" (I5) and needs to be considered when planning a metaverse-based activity. Moreover, "hardware and software alignment" (I2), storing space for the headsets, the physical setting of an immersive laboratory, access to such a setting and even the Internet speed are important

[1] "regular classes", based on the apposition the interviewee used, can be understood as face-to-face classes where the teacher and students meet in a physical space owned by the HEI.

elements that put extra pressure on the HEI. Scholars have emphasised that the operation and realisation of the metaverse depend fundamentally on advanced wireless communication systems and high-speed network infrastructures, notably 5G and emerging 6G technologies (Zhang et al., 2022, p. 4). However, these technologies remain costly and, in many regions, are not yet entirely implemented, making from the metaverse as fully functional learning environment still a projection for the near future.

But alongside these different technologies that are part of a HEMLE, security and privacy are a must to consider. Alignment of the different platforms (I4), interoperability (I3), not yet in place due to „liability issues" (I4) and "security issues among websites" (I3), are the main obstacles to a fully functional metaverse. Adding to this, AI integration in different platforms raises new concerns regarding users' data privacy in this environment not yet enough studied and regulated. This makes TXK essential for any professor looking to integrate the metaverse technology into HEI learning environment.

Contrary to many more streamline technology-enhanced environments where contextual variables remain peripheral to instructional design, HEMLEs are materially constrained by the organisational infrastructure (e.g., bandwidth, hardware availability, spatial configuration). XK refers thus not only to. It directly limits or enables pedagogical and design choices. In this way, contextual knowledge becomes structurally intertwined with technological and design decision-making in HEMLE.

4.2 Comparative perspectives: Teaching practitioners vs. organisational experts

The thematic analysis above presents patterns across interviews, but some differences emerged between participants with direct teaching responsibilities (I3 and I5) and those occupying organisational or platform-development roles (I1, I2, and I4). These differences add nuance to the interpretation of teacher knowledge domains in HEMLE contexts, as illustrated in the table below:

TABLE 3

Role	Interviews Included	Technological Scalability	Interoperability	Infrastructure Requirements	Platform Affordances	Total Mentions
Platform providers	I1, I2	8	6	16	21	51
University teachers	I3, I5	10	9	21	22	62
Systemic thinker	I4	8	6	8	12	34

Distribution of Scalability, Interoperability, Infrastructure, and Affordance References by Role

The aggregated role-based comparison (Table 3) reveals the differences in emphases between the participant groups, highlighting the patterns identified in the thematic analysis. University teachers (I3, I5) generated the highest overall number of references (n = 62), with accentuating on infrastructure requirements (n = 21) and platform affordances (n = 22). Their speech was based on

practical experience, focusing on instructional design decisions, technical setup, learner management, embodiment constraints, and the pedagogical organisation of HEMLE. Platform providers (I1, I2) also pointed out the infrastructure (n = 16) and platforms affordances (n = 21), but they talked more frequently about institutional-level scalability and compatibility between hardware–software. The I4 interviewee, which was oriented towards a systemic viewpoint, underlined technological scalability (n = 8) and platform affordances (n = 12) at a macro-structural level. He was discussing educational transformation, paradigms shifts, and fluidity of processes rather than details of the classroom implementation.

Across all roles, platform affordances appeared as the most frequently discussed dimension (n = 55), followed by infrastructure requirements (n = 45). However, the nature of these references was different: teachers interpreted affordances through design and learner experience, providers through system integration and scalability, and the systemic thinker through educational transformation. These role-based differences suggest that immersive teaching requires not only technological and pedagogical alignment, but also design-oriented mediation (DK), contextual navigation (XK), and attention to embodied learner dynamics (AK). This comparative evidence strengthens the argument for extending traditional TPACK toward a TPACK-XD framework.

4.3 The leArner Knowledge (AK)

When analysing the codes that couldn't be included in the 6 main groups during the 2nd coding phase of the qualitative research, elements like age-related specificities, avatar embodiment, space-time individual perception, skills, learning, and social aspects stood out. These are all related to the learner characteristics and were grouped in the "learner" code group. With 51 occurrences over the interviews, it became obvious that it represents an important knowledge area when integrating the metaverse technology in HEIs. For simplification purposes and alignment with the 2019 TPACK naming system, this code group name was changed to "AK", where the "A" refers to the "learner" characteristics and "K" to knowledge.

Going deeper into analysing the AK theme, **Feil! Fant ikke referansekilden.** shows that age is the most prominent element in all the interviews (14 occurrences), followed by space-time perception and learning. This highlights that teachers wanting to integrate metaverse technologies into an HEMLE need to keep in mind primarily these three learners' characteristics. Nevertheless, embodiment into the avatar and different skill levels are all psychological aspects of the HEMLE to be considered. The social aspect seems to be the least mentioned, as it appeared only once in I1 interview. It is nevertheless deeply interconnected with the "interaction" mentioned by I1, I2, I3, and I5. So, age, time-space perception, learning characteristics, social interaction, avatar embodiment and student skills are all essential knowledge domains for teachers wanting to integrate metaverse technology in HEI learning environments.

TABLE 4

Code	Occurrences
Age	14
Time	13
Space	10
Learning	9
Social Interaction	8
Avatar embodiment	4
Skills	3

Occurrences of the AK code group elements

When choosing a technology, such as a metaverse access platform, variables like students' characteristics must be considered alongside the HEMLE traits. There is a "*learning curve for some users to learn how to use VR and learn how to interact with the environment*" (I1). This impacts the curriculum as time must be considered for learning how the technology functions when planning for an activity in the metaverse, but also the organisational aspects, as the devices need to be booked for a longer time or training space allocated before the actual start of the metaverse-based course.

Besides these physical, pedagogical, technical, or organisational aspects, the networking itself must be taken into consideration. A HEMLE holds the technical possibility of offering closed or open spaces. It is up to the instructor to reflect on which type of learning environment best suits the course objectives. Networking is possible in certain VR applications (e.g. Engage VR, ImmerseVR, Frame VR, RecRoom, VRChat, Spatial, etc.) while others don't have this affordance (WondaVR, StellarX, Flow immersive, etc.). With the number of universities using VR expected to double each year (I2), with AR being used in sports, gaming, and entertainment (Kipper & Rampolla, 2012), social networking is making its way in the metaverse, and teachers must take it into consideration when designing courses for a HEMLE.

The metaverse holds promise of a reality-like 3D learning environment, "*very relationship-based*" (I4), with ease of access, interactivity, 24/7 availability, synchronous and asynchronous real-life situations simulations, gamification and experiential learning (I4, I5) affordances. There are "*some things that you can do in virtual reality that you literally cannot do in the real world*" (I2). Students become less anxious (I3) as they are represented by an avatar and can communicate through voice or text simultaneously. So, learner knowledge combines with other domains, resulting in a TP**A**CK-X knowledge that seems essential for successful integration of metaverse technology in HEIs.

Unlike traditional learner characteristics typically included into PK, the learner knowledge (AK) in HEMLE contexts includes embodied interaction, avatar-mediated identity construction, spatial perception, and physiological constraints such as VR fatigue/sickness. These dimensions affect directly how learning activities can be designed, structured, and implemented. Their operational

impact on curriculum design suggests that learner-related immersive variables function not only as contextual background, but also as an active knowledge domain shaping instructional decision-making.

4.4 The Design Knowledge (DK)

Another set of codes that couldn't fit into the 6 groups during the 2nd stage of coding was related to design and thus grouped under the "DK" = design knowledge group. I3 spoke about "*interaction design*" and "*instructional design*" processes and models, while I5 mentioned careful planning of the "*storytelling or the script*". These are elements that find themselves at the overlap between pedagogical knowledge and design knowledge, depending on their focus and application. Interaction design primarily focuses on usability and user experience, which belong to DK. When adapted for educational goals, it incorporates pedagogical principles, connecting to PK. Similarly, instructional design is rooted in pedagogy but often utilises design processes. Storytelling, on the other hand, mixes narrative creativity (design) with learning strategies (pedagogy) when applied to education. I1 and I2 linked the affordances and limitations of the VR space to a certain "*order of operations*" (I2) as teachers can achieve the objectives in different ways, and the specific learning activities "*need to be reimagined*" (I1), once more highlighting the importance of a close connection between DK and PK.

The metaverse is a set of interconnected 3D, interactive virtual spaces. This is an essential characteristic that sets it apart from the 2D websites with which teachers and learners are used, but also from the reality people live and learn in since they are born. If in a 2D learning environment, the lack of interaction is perceived as a negative element by the I2, "*understanding interaction design in VR*" (I3) is a problem HEI teachers face. Moreover, with new technologies like haptic gloves (Chan & Torah, 2022) simulating tactile sensations of virtual objects or olfactory displays (Niedenthal et al., 2019) four of the five human senses can be involved in the perception of the metaverse: sight, touch, smell, and hearing. This makes the experience much more realistic than just watching a 2D video or looking at a picture from a book, which "are perceptually impoverished" (Barr, 2013, p. 206) stimulating only sight and hearing. This paradigmatic shift in information perception, combined with the fact that many users do not understand 3D interfaces, creates, as I3 explained, difficulties in designing for a HEMLE and makes teaching in the metaverse different from teaching in 2D online, but at the same time not identical to teaching in face-to-face either.

As all the participants made it clear, when teaching in an HEMLE, the teacher has "*to use instructional design models in order to align the curriculum with whatever you feel appropriate or suitable for virtual reality*" (I3). This means that DK has a direct connection with the TPK. It includes the different existing instructional design models (Seel et al., 2017), more specifically, those for online learning and an authentic learning environment (Herrington & Oliver, 2000) as a HEMLE can simulate real-life situations, but it is simultaneously a virtual space functioning online.

The interactions that need to take place during the learning process are, in fact, another essential criterion for selecting the metaverse access technology. Not all platforms have the same technical affordances (I1, I2, I3) and qualities: some might be less intuitive, less easy to build into than others. "*Understanding interaction design in VR*" is one of the main struggles teachers have when starting to teach in a HEMLE (I3). Assuming that 3D software are the same as 2D ones makes it "*hard for them* [teachers] *to navigate and build inside 3D interfaces, and what happens is that it*

takes them a lot of time to understand that, and how to find things that they built before, and also what's challenging is that sometimes they are clueless." (I3) "When VR is done well, the results are brilliant and pleasurable experiences that go beyond what we can do in the real world [are created]. When VR is done badly, not only is the system frustrating to use, but it can result in sickness" (Jerald, 2016), neck pain, headache, or lower attention span (I5). More than "*45 minutes, one hour, one hour and a half is too much* [making it] *really difficult*" (I5) to use VR from a physical point of view. In fact, there is "a multi-faceted characteristic of VR sickness" (Chang et al., 2020, p. 1678) and it has different causes due to hardware, content or human factors. With all the different hardware and software available on the market, the selection must be very rigorous and "it is required to consider the various components of the virtual environment simultaneously to design a user friendly VR scenario." (Chang et al., 2020, p. 1678). For this purpose, "*training for the teachers is needed*" (I2), but this raises new organisational issues that must be addressed, so DK combines with the other TPACK-X domains in a HEMLE context.

While instructional design models have traditionally been situated within PK, the characteristics of HEMLEs require additional expertise in interaction design, spatial composition, affordance alignment, and experiential sequencing. These design decisions are not reducible to pedagogy alone; they involve understanding user-interface constraints, sensory limitations, and embodied interaction logic. DK therefore emerges as a mediating knowledge domain between technological affordances and pedagogical intent.

The analysis suggests that XK, AK, and DK function as three complementary dimensions that extend the traditional TPACK configuration in immersive environments. XK refers to the institutional, technological, and organisational conditions that enable or constrain the implementation of metaverse-based learning environments, such as infrastructure, hardware availability, network capacity, and institutional support structures. AK captures the specific characteristics of learners interacting within immersive environments, including embodiment through avatars, spatial perception, cognitive load, technological familiarity, and social interaction patterns. DK, on the other hand, mediates between technological affordances and pedagogical intentions, including interaction design, experiential sequencing, spatial composition, and the adaptation of instructional design models to HEMLEs. While XK shapes the feasibility and operational context of immersive learning, AK informs how learners experience and engage with the environment, and DK structures how learning activities are designed within these constraints and possibilities. Together, these three domains operate as interdependent layers that influence how technological, pedagogical, and content knowledge are mobilised when designing curricula for HEMLEs.

Together, these findings indicate that immersive learning environments require knowledge domains beyond those conceptualised in the traditional TPACK model.

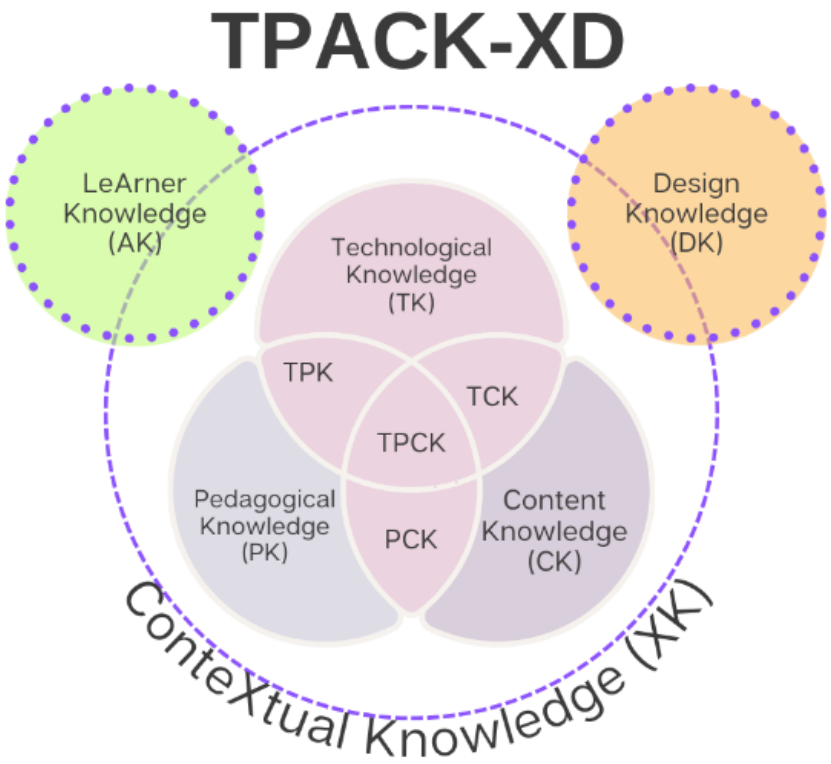
4.5 TPACK-XD

The empirical findings of this investigation suggest that HEMLEs generate knowledge requirements that cannot be fully accommodated by the original TPACK configuration. While TPACK puts in relation technology–pedagogy–content domains intersections, it does not explicitly theorize immersive design mediation (DK), embodied learner dynamics (AK), or infrastructural conditioning (expanded XK) as distinct domains of teacher expertise. In HEMLEs contexts, these elements operate not as marginal influences but as structuring forces shaping curricular implementation,

interaction design, and experiences organisation. The TPACK-XD model thus represents not a replacement, but an expansion that responds to the epistemic and material shifts introduced by immersive technologies.

Analysing all the different themes identified throughout the interviews leads to the conclusion that the main aspects of teacher knowledge for integrating metaverse technology into an HEI learning environment expand beyond the TPACK framework. In fact, in a HEMLE, it is important to be aware of the context and learner characteristics, but also have design knowledge. As illustrated in **Feil! Fant ikke referansekilden.**, these elements intersect with the contextual knowledge and serve as a background for the HEMLE technical-pedagogical-content knowledge.

FIGURE 4



Aspects of teacher knowledge for integrating metaverse technology in HEI learning environments

TPACK-XD is a conceptual proposition emerging from qualitative insights, not a validated framework yet. This will be done in the following phases of the DBR research.

4.6 Elements to consider when creating curriculum for a HEMLE

Curriculum is a core component of any learning environment. When analysing the interviews through the lens of curriculum design for HEMLEs, it became obvious that various domains of teacher knowledge intersect and complement each other in different ways. Following data analysis, PK emerged as the most prominent domain, indicating its central role in curriculum development for metaverse-based learning. However, CK and TK also proved essential in shaping effective teaching within HEMLEs. These patterns suggest that, beyond the established TPACK framework, an extension that incorporates Learner Knowledge (AK) and Design Knowledge (DK) is

necessary. So, when teachers prepare curriculum for HEMLEs, the following elements seem to be important considerations:

- Use a design thinking approach (DK+CK+XK+curriculum). The starting point is the course guiding idea, the general planning of the activity, the objectives, follows the storytelling or the script, and then "thinking how many assistants do I need even for the creative part" (I5). A design thinking approach is essential for being able to plan and teach in the metaverse.
- Keep in mind the context, problem and learning goals (DK+XK+ AK+CK+curriculum). As in any design thinking situation, the teacher needs to start with understanding the context, defining the problem, and the need, "making sure that overall learning goals of the course are still kept at the forefront" (I1). Deciding which are the "learning objectives and what problems would the teachers want to solve" (I3) are one of the first steps in the teaching process.
- Choose the appropriate learning environment (XK+CK+HEMLE+ curriculum). Deciding which type of learning environment is the most appropriate to the context and will support best achievement of the learning objectives is the following step. In certain cases, face-to-face, hybrid or fully online might be better adapted.
- Choose the most appropriate technology. (TK+ CK+ HEMLE+curriculum) If the decision is taken for a hybrid learning environment, choosing which technology is the most appropriate for the learning goals is essential as a 2D application might be more beneficial than a 3D one in certain contexts.
- Select the most appropriate metaverse-access platform (TK+HEMLE+ CK curriculum). Once the metaverse is found suitable to achieve the learning goals, a technology selection framework can be applied to select the most appropriate app for achieving the curricular goals.
- Plan for training time (AK+HEMLE+curriculum). It is essential to check "first of all, whether the participants are familiar with the VR or not, and how am I going to approach this" (I3). Therefore, planning for training time in the curriculum is a must.
- Choose the instructional design model to follow (DK+AK+CK+ PK+HEMLE+curriculum). Instructional designs models have to be used to align the curriculum with the HEMLE. The design of the activity itself must be considered so that it is interesting and meaningful for the students, the assets carefully chosen and built "in order to make them understand" (I3) and reach the learning goals. Instructional design frameworks can provide a solid foundation for building such activities and knowledge about pedagogical approaches to be used in a HEMLE is essential for any teacher to have prior to starting planning curriculum.

5 Conclusion

It is important to remember that curriculum can be aligned with a HEMLE (I3), and the decision-making that takes place at the very beginning of the planning process will greatly help the educator. HEI teachers are bound to use existing learning goals from their current curriculum, but it is possible to adapt the pedagogies, the way the learning experiences are delivered.

Using a HEMLE, HEI professors find themselves in a moment of “paradigmatic change” that requires “to disassemble some of the structures that were created for the purposes of reinforcing that paradigm” (I4). The Metaverse is a technology that changes the way we teach and learn, the way we perceive time and space. But “technology is a tool and not a totem” (I2), and teachers need to use it wisely.

Planning and designing curriculum for HEMLE requires a slightly different set of knowledge than the face-to-face one. The TPACK-XD framework coined in this paper is still to be developed through experimentation, leading to a definitive list of the knowledge domains for educators to master when integrating metaverse technology into a HEI learning environment.

As all the participants pointed out, we can adapt an existing curriculum to be used in a HEMLE or build it from scratch, but there will always be one element that will remain immutable: the learning goals. Consequently, building a curriculum based on the seven above-identified elements and the HEI course-specific learning goals will allow for a clear definition of the steps to be followed in adapting current HEI curricula for delivery in a HEMLE.

This study has limitations that must be acknowledged, and they relate mainly to the number of interviews used in the qualitative research process. Even though 2 questions were specifically targeting the PK, a comprehensive description of the HEMLE PCK couldn’t be extracted, so further investigations need to be done in this area, as well as on the elements to consider when designing curriculum for HEMLE. In fact, the participants focused on the VR-accessed metaverse, so inquiry on AR or MR-access points needs to be made. Adding to this, the usage of AI in generating 3D objects or spaces wasn’t approached during the interviews. Due to this, it is not clear if knowledge about such a technology would be something that teachers would need for successfully integrating the metaverse in HEIs' learning environment.

While the study identifies recurring knowledge domains across expert interviews, it does not claim to have exhaustively defined the full set of competencies required for HEMLE teaching. The inclusion of two university teachers provided in-depth practitioner perspectives but does not allow for claims of complete competency definition across disciplinary contexts. The findings represent therefore a theoretically informed and empirically grounded conceptual mapping rather than a finalized competency framework. Subsequent phases of the DBR project will involve broader teacher sampling and iterative refinement to validate, extend, or adjust the proposed TPACK-XD model.

The TPACK-XD model therefore provides an initial conceptual framework for understanding teacher knowledge in immersive higher education environments and offers a foundation for future empirical validation within iterative DBR cycles.

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7 References

Adeoye-Olatunde, O. A., & Olenik, N. L. (2021). Research and scholarly methods: Semi-structured interviews. *JACCP: JOURNAL OF THE AMERICAN COLLEGE OF CLINICAL PHARMACY*, *4*(10), 1358–1367. https://doi.org/10.1002/jac5.1441

Barr, R. (2013). Memory Constraints on Infant Learning From Picture Books, Television, and Touchscreens. *Child Development Perspectives*, *7*(4), 205–210. https://doi.org/10.1111/cdep.12041

Bates, A. W. (Tony). (2022). *Teaching in a Digital Age: Third Edition - General*. Tony Bates Associates Ltd. https://pressbooks.bccampus.ca/teachinginadigitalagev3m/

Bermejo, B., Juiz, C., Cortes, D., Oskam, J., Moilanen, T., Loijas, J., Govender, P., Hussey, J., Schmidt, A. L., Burbach, R., King, D., O'Connor, C., & Dunlea, D. (2023). AR/VR Teaching-Learning Experiences in Higher Education Institutions (HEI): A Systematic Literature Review. *Informatics*, *10*(2), 45. https://doi.org/10.3390/informatics10020045

Bouta, H., Retalis, S., & Paraskeva, F. (2012). Utilising a collaborative macro-script to enhance student engagement: A mixed method study in a 3D virtual environment. *Computers & Education*, *58*(1), 501–517. https://doi.org/10.1016/j.compedu.2011.08.031

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brianza, E. (2022). *Situating TPACK: A Systematic Literature Review of Context as a Domain of Knowledge*.

Brianza, E., Schmid, M., Tondeur, J., & Petko, D. (2024). Is contextual knowledge a key component of expertise for teaching with technology? A systematic literature review. *Computers and Education Open*, *7*, 100201. https://doi.org/10.1016/j.caeo.2024.100201

Britannica. (2023). *Observable universe*. https://www.britannica.com/topic/observable-universe

Britannica. (2024, March 15). *Augmented reality | Definition, Examples, & Facts | Britannica*. https://www.britannica.com/technology/augmented-reality

Brown, A., & Danaher, P. A. (2019). CHE Principles: Facilitating authentic and dialogical semi-structured interviews in educational research. *International Journal of Research & Method in Education*, *42*(1), 76–90. https://doi.org/10.1080/1743727X.2017.1379987

Buliva, N. (2018). *Does Culture Impact Learning For Students Who Use Virtual Reality (VR) Tools? A Review of Literature*. https://www.academia.edu/64303387/Does_Culture_Impact_Learning_For_Students_Who_Use_Virtual_Reality_VR_Tools_A_Review_of_Literature

Chai, C., Koh, J., & Tsai, C.-C. (2013). A Review of Technological Pedagogical Content Knowledge. *Educational Technology & Society*, *16*, 31–51.

Chan, J., & Torah, R. (2022). E-Textile Haptic Feedback Gloves for Virtual and Augmented Reality Applications. *The 3rd International Conference on the Challenges, Opportunities, Innovations and Applications in Electronic Textiles*, 144. https://doi.org/10.3390/engproc2022015001

Chandler, L., & Ward, A. (2019). Immersed in Design: Using an Immersive Teaching Space to Visualise Design Solutions. *International Journal of Art & Design Education*, *38*(2), 314–327. https://doi.org/10.1111/jade.12191

Chang, E., Kim, H.-T., & Yoo, B. (2020). Virtual Reality Sickness: A Review of Causes and Measurements. *International Journal of Human-Computer Interaction*, *36*, 1–25. https://doi.org/10.1080/10447318.2020.1778351

Chugh, R., Turnbull, D., Cowling, M. A., Vanderburg, R., & Vanderburg, M. A. (2023). Implementing educational technology in Higher Education Institutions: A review of technologies, stakeholder perceptions, frameworks and metrics. *Education and Information Technologies*, *28*(12), 16403–16429. https://doi.org/10.1007/s10639-023-11846-x

Chung, L.-Y. (2012). Virtual Reality in College English Curriculum: Case Study of Integrating Second Life in Freshman English Course. *2012 26th International Conference on Advanced Information Networking and Applications Workshops*, 250–253. https://doi.org/10.1109/WAINA.2012.198

Collins English Dictionary. (2023, September 17). *Visible universe*. https://www.collinsdictionary.com/dictionary/english/visible-universe

Devlin, M., & Samarawickrema, G. (2022). A commentary on the criteria of effective teaching in post-COVID higher education. *Higher Education Research & Development*, *41*(1), 21–32. https://doi.org/10.1080/07294360.2021.2002828

Elgamal, Y. S. (2022). A New Dimension to University Education The Metaversity. *2022 32nd International Conference on Computer Theory and Applications (ICCTA)*, 1–2. https://doi.org/10.1109/ICCTA58027.2022.10206345

Evans, L. (2019). Barriers to VR use in HE. In *Proceedings of the Virtual and Augmented Reality to Enhance Learning and Teaching in Higher Education Conference 2018* (pp. 3–13). IM Publications Open LLP. https://doi.org/10.1255/vrar2018.ch2

Glatthorn, A. A., Boschee, F., Whitehead, B. M., & Boschee, B. F. (2018). *Curriculum leadership: Strategies for development and implementation* (Fifth Edition). SAGE.

Green, H. E. (2014). Use of theoretical and conceptual frameworks in qualitative research. *Nurse Researcher*, *21*(6), 34–38. https://doi.org/10.7748/nr.21.6.34.e1252

Guney, A., & Al, S. (2012). Effective Learning Environments in Relation to Different Learning Theories. *Procedia - Social and Behavioral Sciences, 4th WORLD CONFERENCE ON EDUCATIONAL SCIENCES (WCES-2012) 02-05 February 2012 Barcelona, Spain*, *46*, 2334–2338. https://doi.org/10.1016/j.sbspro.2012.05.480

Han, E., Miller, M. R., DeVeaux, C., Jun, H., Nowak, K. L., Hancock, J. T., Ram, N., & 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. https://doi.org/10.1093/jcmc/zmac031

Herrera, F., & Bailenson, J. N. (2021). Virtual reality perspective-taking at scale: Effect of avatar representation, choice, and head movement on prosocial behaviors. *New Media & Society*, *23*(8), 2189–2209. https://doi.org/10.1177/1461444821993121

Herrington, J., & Oliver, R. (2000). An instructional design framework for authentic learning environments. *Educational Technology Research and Development*, *48*(3), 23–48. https://doi.org/10.1007/BF02319856

Imms, W., & Kvan, T. (Eds). (2021). *Teacher Transition into Innovative Learning Environments: A Global Perspective*. Springer Nature Singapore. https://doi.org/10.1007/978-981-15-7497-9

Jerald, J. (2016). *The VR book: Human-centered design for virtual reality*. Morgan & Claypool.

Kipper, G., & Rampolla, J. (2012). *Augmented reality: An emerging technologies guide to AR*. Syngress.

Koehler, M. J., Mishra, P., Kereluik, K., Shin, T. S., & Graham, C. R. (2014). The Technological Pedagogical Content Knowledge Framework. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds), *Handbook of Research on Educational Communications and Technology* (pp. 101–111). Springer New York. https://doi.org/10.1007/978-1-4614-3185-5_9

Malterud, K., Siersma, V. D., & Guassora, A. D. (2016). Sample Size in Qualitative Interview Studies: Guided by Information Power. *Qualitative Health Research*, *26*(13), 1753–1760. https://doi.org/10.1177/1049732315617444

Marsh, C. J. (2004). *Key concepts for understanding curriculum* (3rd ed). RoutledgeFalmer.

Marwecki, S., Brehm, M., Wagner, L., Cheng, L.-P., Mueller, F. 'Floyd', & Baudisch, P. (2018). VirtualSpace—Overloading Physical Space with Multiple Virtual Reality Users. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–10. https://doi.org/10.1145/3173574.3173815

McKenney, S., & Reeves, T. C. (2019). *Conducting educational design research* (Second edition). Routledge, Taylor & Francis Group. https://doi.org/10.4324/9781315105642

Mills, K. A., Scholes, L., & Brown, A. (2022). Virtual Reality and Embodiment in Multimodal Meaning Making. *Written Communication*, 07410883221083517. https://doi.org/10.1177/07410883221083517

Mishra, P. (2019). Considering Contextual Knowledge: The TPACK Diagram Gets an Upgrade. *Journal of Digital Learning in Teacher Education*, *35*(2), 76–78. https://doi.org/10.1080/21532974.2019.1588611

Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge. *Eachers College Record*, *108*(6), 1017–1054.

Niedenthal, S., Lundén, P., Ehrndal, M., & Olofsson, J. K. (2019). A Handheld Olfactory Display For Smell-Enabled VR Games. *IEEE International Symposium on Olfaction and Electronic Nose*, 1–4. https://doi.org/10.1109/ISOEN.2019.8823162

Obae, C., & Alkhayat, A. (2023). Language Learning Pedagogical Affordances of the Metaverse. *Conference Papers*. https://tccpapers.coe.hawaii.edu/archive/2023/Obae.pdf

Padmavathi, M. (2017). Preparing Teachers For Technology Based Teaching-Learning Using TPACK. *I-Manager's Journal on School Educational Technology*, *12*(3), 1. https://doi.org/10.26634/jsch.12.3.10384

Posner, G. J. (1992). Analizing the Curriculum. *McGraw-Hill*.

Puentedura, R. R. (2013). *SAMR: Moving from Enhancement to Transformation*.

Rauch, U., Cohodas, M., & Wang, T. (2009). The Arts 3D VLE Metaverse as a Network of Imagination. *Innovate: Journal of Online Education*. https://www.semanticscholar.org/paper/The-Arts-3D-VLE-Metaverse-as-a-Network-of-Rauch-Cohodas/e3010504015d2bc63be33de5544ec2fc021062da

Read, T., Sanchez, C. A., & De Amicis, R. (2021). Engagement and time perception in virtual reality. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *65*(1), 913–918. https://doi.org/10.1177/1071181321651337

Reeves, T. C. (2006). Design research from a technology perspective. In K. Gravemeijer, S. McKenney, & N. Nieveen (Eds), *Educational design research*. Routledge. https://www.researchgate.net/publication/285854675

Rhode, J., & Krishnamurthi, M. (2017). From Frameworks to Practice: Selecting Technology Tools for Instructional Integration. *Proceedings of the 5th International Conference on Information and Education Technology*, 11–15. https://doi.org/10.1145/3029387.3029396

Rusticus, S. A., Pashootan, T., & Mah, A. (2023). What are the key elements of a positive learning environment? Perspectives from students and faculty. *Learning Environments Research*, *26*(1), 161–175. https://doi.org/10.1007/s10984-022-09410-4

Sala, N. (2020). Virtual Reality, Augmented Reality, and Mixed Reality in Education: A Brief Overview. In D. H. Choi, A. Dailey-Hebert, & J. S. Estes (Eds), *Advances in Higher Education and Professional Development* (pp. 48–73). IGI Global. https://doi.org/10.4018/978-1-7998-4960-5.ch003

Schwab, K. (2017). *The fourth industrial revolution* (First U.S. edition). Crown Business.

Schwab, K. (2021, March 23). *The Fourth Industrial Revolution* [Encyclopedia]. Britannica. https://www.britannica.com/topic/The-Fourth-Industrial-Revolution-2119734

Seel, N. M., Lehmann, T., Blumschein, P., & Podolskiy, O. A. (2017). Models of Instructional Design. In N. M. Seel, T. Lehmann, P. Blumschein, & O. A. Podolskiy, *Instructional Design for Learning* (pp. 45–107). SensePublishers. https://doi.org/10.1007/978-94-6300-941-6_3

Slater, M. (2025). *A Metaverse for the Good: Exploring the Intersection of AI and the Metaverse, 2nd International Congress*. https://doi.org/10.5281/ZENODO.15847422

Sobota, B., & Cvetković, D. (Eds). (2020). *Mixed Reality and Three-Dimensional Computer Graphics*. IntechOpen. https://doi.org/10.5772/intechopen.77405

Sun, Y., Xu, Y., Cheng, C., Li, Y., Lee, C. H., & Asadipour, A. (2022). *Travel with Wander in the Metaverse: An AI chatbot to Visit the Future Earth*. https://doi.org/10.1109/MMSP55362.2022.9950031

Sutherland, K., & Ward, A. (2018). Immersive simulation as a public relations pedagogical tool. *Asia Pacific Public Relations Journal*. https://www.semanticscholar.org/paper/Immersive-simulation-as-a-public-relations-tool-Sutherland-Ward/7d649657a2a49127b663596b80aec7a1c3bdf0ea

Trilling, B., & Fadel, C. (2009). *21st Century Skills: Learning for Life in Our Times*. Jossey-Bass.

Vasarainen, M., Paavola, S., & Vetoshkina, L. (2021). A Systematic Literature Review on Extended Reality: Virtual, Augmented and Mixed Reality in Working Life. *International Journal of Virtual Reality*, *21*(2), 1–28. https://doi.org/10.20870/IJVR.2021.21.2.4620

Warr, M., & Mishra, P. (2022). TPACK. *EdTechnica*. https://doi.org/10.59668/371.9034

Weinberger, M. (2022). What Is Metaverse?—A Definition Based on Qualitative Meta-Synthesis. *Future Internet*, *14*(11), 310. https://doi.org/10.3390/fi14110310

Zhang, X., Chen, Y., Hu, L., & Wang, Y. (2022). The metaverse in education: Definition, framework, features, potential applications, challenges, and future research topics. *Frontiers in Psychology*, *13*.

8 Annex 1 – interview guide

The main questions used in the interviews were the ones illustrated in the table below. Contextual adaptations of the phrasing or order of the questions were made during each interview.

Interview Question	Relevant TPACK Domains	Related Concepts	Purpose of the Question
1. How do you define the "metaverse"?	CK, XK	Metaverse, HEMLE	To explore participants' conceptual understanding of the metaverse and its characteristics as an educational environment.
2. Can you describe how a metaversity/course in the metaverse works?	TK, CK, XK	Metaverse, HEMLE	To explore the structural and technological features of metaverse-based courses and how they function in HEI.
3. How is teaching in the metaverse different from face-to-face teaching?	PK, XK, TK	HEMLE, Curriculum	To identify pedagogical, technological and contextual differences between immersive and other, more traditional instructional settings.
4. When you designed your metaverse-based course, did you adapt an existing curriculum or build a new one from scratch?	PCK, TCK, XK	Curriculum, HEMLE	To investigate how curriculum design practices evolve when transitioning from traditional to metaverse-based learning environments.
5. What are the key challenges you have encountered when transitioning a traditional face-to-face curriculum to the metaverse learning environment?	TK, PK, XK	Curriculum, HEMLE	To understand obstacles in adapting existing curricula for immersive, technology-enhanced settings.
6. How did you overcome them?	PK, TK, XK	Curriculum, HEMLE	To identify effective strategies and practices used

Interview Question	Relevant TPACK Domains	Related Concepts	Purpose of the Question
			to address possible implementation challenges.
7. In your opinion, what are the essential components of a curriculum that must be retained when adapting it to the metaverse?	CK, PK, CPK	Curriculum, HEMLE	To examine which foundational curricular elements remain relevant in HEMLEs.
8. Could you share specific examples of successful pedagogical methods or tools you have used to engage students effectively in the metaverse for learning purposes?	PK, TK, TPK	HEMLE, Curriculum	To identify effective pedagogical strategies and technology use for student engagement in metaverse learning environments.
9. Can you share your insights on the balance between synchronous and asynchronous learning activities in the metaverse, and how this balance affects the effectiveness of the curriculum?	PK, XK, TPK	Curriculum, HEMLE	To explore time-based interaction models and their pedagogical implications in HEMLE.
10. How have you assessed and evaluated the learning outcomes and student performance in a metaverse-based curriculum?	PCK, TPK	Curriculum, HEMLE	To understand possible assessment methods and tools used to measure learning in HEMLE.
11. Which assessment challenges have you encountered while teaching in the metaverse?	PK, TK, XK	Curriculum, HEMLE	To identify barriers and contextual constraints affecting assessment in HEMLE.
12. In your opinion, what are the key future trends or developments in metaverse teaching in higher education, and how do you think they will impact curricula?	TPACK	HEMLE, Curriculum	To explore anticipated TPACK developments and their implications for future curriculum design.