Factors For The Successful Implementation Of Extended Reality In General Nursing Education: A Qualitative Expert Study Based On The Extended TPACK Model

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Abstract
Persistent global shortages of qualified nursing professionals and increasing clinical complexity place substantial pressure on nursing education systems. Extended Reality (XR), including Virtual Reality, Augmented Reality, and Mixed Reality, enables immersive and repeatable simulation of complex clinical scenarios within psychologically safe learning environments. Despite growing evidence regarding learning effectiveness, structural conditions for sustainable institutional implementation remain insufficiently examined.
This qualitative study investigates enabling factors and barriers influencing the integration of XR in general nursing education. Eight semi-structured expert interviews were analysed using structured qualitative content analysis guided by an extended Technological Pedagogical Content Knowledge (TPACK) framework incorporating ethical and organisational dimensions.
Findings indicate that sustainable XR implementation depends on systemic alignment between technological infrastructure, pedagogical integration, disciplinary authenticity, organisational capacity, ethical governance, and long-term financing. Faculty qualification, stable institutional support structures, transparent data protection frameworks, and innovation-oriented organisational cultures emerged as decisive implementation conditions. Ethical considerations, particularly regarding data governance and learners' psychological safety, function as foundational structural requirements rather than peripheral concerns.
By extending the TPACK framework to include ethical and organisational knowledge domains, this study provides an empirically grounded implementation model for immersive healthcare education. XR is conceptualised as a governance-related transformation process with implications for workforce resilience, patient safety, and the strategic digital development of nursing education systems.

Introduction

Background

Healthcare systems worldwide face persistent shortages of qualified nursing professionals, intensified by demographic change, rising multimorbidity, and increasing care complexity (BibliomedPflege, 2025; BIBB, 2022). Nursing education must therefore prepare learners for complex and high-risk clinical situations while maintaining patient safety and educational quality. However, training opportunities in real-world care settings remain limited, as critical or rare scenarios cannot be practiced repeatedly without exposing patients to potential risk.
Simulation-based and digital learning environments have gained importance in competence-oriented healthcare education. Extended Reality (XR), encompassing Virtual Reality, Augmented Reality, and Mixed Reality, enables immersive simulation of clinical procedures, communication scenarios, and decision-making processes in controlled and psychologically safe environments. Empirical evidence indicates positive effects on learner engagement, procedural competence, and self-efficacy (Aebersold & Dunbar, 2020; Logeswaran et al., 2021; Fernández Cerero et al., 2024). European initiatives such as VReduMED and ViReTrain further illustrate the feasibility of XR-supported nursing education (Bade et al., 2023; Fries et al., 2023).
Despite promising findings, technology alone does not guarantee educational impact. Sustainable integration requires reliable infrastructure, structured pedagogical embedding, disciplinary authenticity,

and systematic curricular anchoring. The alignment of technological, pedagogical, and content-related knowledge has been conceptualised within the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006; Koehler et al., 2013).
Emerging research suggests that immersive technologies also introduce organisational and ethical challenges, including faculty qualification, data governance, maintenance planning, and psychological safety considerations. These structural dimensions remain insufficiently integrated into existing implementation models.
Against this background, the present study investigates enabling factors and barriers influencing the sustainable implementation of XR in general nursing education. By applying and extending the TPACK framework, it conceptualises XR integration as a systemic institutional transformation with relevance for workforce development and patient safety.

Introduction
While immersive technologies are increasingly discussed as promising tools in healthcare education, existing research predominantly concentrates on short-term learning outcomes, user satisfaction, and technical feasibility. Less attention has been devoted to the structural conditions that determine whether XR becomes sustainably embedded within nursing education systems.
Implementation in this context extends beyond classroom-level adoption. It requires alignment between technological infrastructure, curricular integration, educator competencies, institutional strategy, and governance frameworks. Without such systemic coordination, XR initiatives risk remaining isolated pilot projects rather than evolving into stable curricular components.
The Technological Pedagogical Content Knowledge (TPACK) framework conceptualises the interaction between technological, pedagogical, and disciplinary knowledge as a prerequisite for meaningful technology integration (Mishra & Koehler, 2006). However, immersive healthcare technologies introduce additional structural demands, including data governance, psychological safety, organisational capacity, and long-term financing. These dimensions are insufficiently represented in existing implementation models.
Against this background, the present study investigates the prerequisites, enabling factors, and barriers influencing the sustainable implementation of XR in general nursing education. Guided by an extended TPACK framework incorporating ethical and organisational knowledge domains, the study seeks to develop an empirically grounded implementation model that conceptualises XR integration as a systemic institutional transformation.

Theoretical Framework
The Technological Pedagogical Content Knowledge (TPACK) framework provides a conceptual model for analysing the integration of technology in educational contexts (Mishra & Koehler, 2006; Koehler et al., 2013). It conceptualises meaningful technology use as the interaction between technological, pedagogical, and disciplinary knowledge domains. Educational value arises from the alignment of technological affordances with pedagogical design and disciplinary content.
In nursing education, this alignment is particularly complex due to the integration of cognitive, psychomotor, and affective competence dimensions. Immersive simulations require structured reflection, curricular embedding, and clinical authenticity to support competence-oriented learning.
However, immersive technologies in healthcare education introduce structural conditions that extend beyond the classical TPACK model. XR systems involve data processing, governance requirements, institutional investment, infrastructure management, and exposure to emotionally demanding scenarios. These characteristics suggest that ethical and organisational dimensions function as structural preconditions for sustainable integration.
The present study therefore applies an extended TPACK framework that integrates Ethical Knowledge and Organisational Knowledge as cross-cutting domains shaping the interaction between technology, pedagogy, and content. This extension conceptualises XR implementation not as a classroom-level intervention but as a systemic institutional process.

Objectives
The study aims to identify structural prerequisites, enabling factors, and barriers influencing the sustainable implementation of XR technologies in general nursing education. Guided by an extended

TPACK framework, it examines technological, pedagogical, disciplinary, ethical, and organisational dimensions of implementation.
The central research question is:
Which structural conditions facilitate or hinder the sustainable integration of XR in nursing education?

Methods
A qualitative research design based on semi-structured expert interviews was employed to examine structural conditions influencing the implementation of Extended Reality (XR) in nursing education. The extended Technological Pedagogical Content Knowledge (TPACK) framework served as the analytical orientation and informed both interview guide development and data analysis.
Eight experts were purposively selected to ensure diverse professional perspectives relevant to XR implementation, including nursing education, educational management, XR development, digital learning systems, and nursing research. Inclusion criteria comprised professional expertise in digital education, involvement in XR-related initiatives, and institutional decision-making experience.
Interviews were conducted online between February and March 2025 using a piloted semi-structured guide aligned with the dimensions of the Extended TPACK framework. All interviews were audio-recorded with informed consent and transcribed verbatim.
Data were analysed using structured qualitative content analysis following Kuckartz (2019). A deductive category system derived from the Extended TPACK framework was applied, encompassing technological, pedagogical, disciplinary, ethical, and organisational dimensions. Categories were inductively refined to capture emerging themes related to economic sustainability and governance conditions.
Coding and data management were conducted using MAXQDA. Cross-case comparison identified convergent and divergent implementation patterns.
Participation was voluntary and anonymised. Data protection regulations were strictly observed. Sensitive institutional statements were handled confidentially in accordance with applicable legal standards.

Results
XR implementation in nursing education emerged as a systemic institutional process rather than a technological intervention. Across interviews, participants described implementation as dependent on the interaction of technological, pedagogical, disciplinary, organisational, ethical, and economic conditions. This multidimensional perspective corresponds with broader findings on digital transformation in education systems (OECD, 2024).

Technological Conditions
Reliable infrastructure emerged as a fundamental prerequisite. Stable internet connectivity, compatible hardware, and user-friendly systems were consistently described as essential for sustained use. Technical instability and system complexity reduced educator acceptance and limited long-term implementation. Similar infrastructural challenges have been reported in European XR initiatives such as VReduMED and ViReTrain (Bade et al., 2023; Fries et al., 2023).
Data protection requirements were perceived as structurally relevant. XR systems often generate performance analytics and movement-related data, raising governance concerns. Participants identified legal uncertainty and compliance requirements as potential barriers, reflecting ethical challenges described in immersive learning research (Kourtesis, 2024).

Pedagogical Integration
Participants emphasised that XR applications were effective only when embedded in structured simulation-based learning designs. Clear learning objectives, guided immersion, and systematic debriefing were described as necessary for competence development. This aligns with established simulation pedagogy principles in nursing education (Aebersold & Dunbar, 2020; Logeswaran et al., 2021).
Immersive experiences lacking reflective integration were perceived as motivational but pedagogically limited. Faculty qualification emerged as a decisive factor; educators required both technical handling skills and media-pedagogical competence, consistent with TPACK assumptions regarding integrated

knowledge domains (Mishra & Koehler, 2006; Koehler et al., 2013). Curricular anchoring was regarded as essential for sustainability, as project-based initiatives were described as vulnerable to discontinuation.

Disciplinary Authenticity

Clinical realism and practice relevance strongly influenced perceived educational value. Participants stressed the importance of involving practicing nursing professionals in scenario development to ensure workflow accuracy and competence alignment. International studies similarly highlight authenticity as a determinant of transferability to real clinical settings (Skryabina et al., 2022; González et al., 2022).
Technologically advanced simulations lacking disciplinary depth were considered insufficient for competence-oriented learning. The alignment between technological design and professional requirements emerged as a central interface, reflecting the core interaction proposed by the TPACK model (Mishra & Koehler, 2006).

Organisational Capacity

Organisational structures significantly shaped implementation trajectories. Leadership support and strategic integration into broader digitalisation processes facilitated continuity. Comparable dynamics have been described in analyses of institutional digital transformation (OECD, 2024).
Recurring costs for maintenance, licensing, and professional development were identified as structural challenges. Participants reported that institutions lacking stable financial planning tended to restrict XR to pilot initiatives, a pattern also observed in European implementation studies (Bade et al., 2023).
An innovation-oriented organisational culture encouraging experimentation and reflective practice was described as supportive of sustained adoption.

Ethical and Governance Dimensions

Ethical considerations functioned as cross-cutting implementation conditions. Safeguarding learners' psychological well-being in high-intensity simulations was regarded as essential, consistent with evidence that immersive environments may induce stress or cognitive overload (Kourtesis, 2024).
Transparent data governance structures were considered necessary to establish institutional trust. Ethical safeguards were not perceived as secondary regulatory constraints but as foundational structural requirements for sustainable integration.

Economic and Policy Context

Economic sustainability was identified as decisive for long-term implementation. While initial hardware costs were described as increasingly manageable, recurring expenditures required institutional commitment. Participants emphasised the importance of regulatory clarity and supportive funding frameworks to reduce uncertainty and enable structural embedding, echoing broader policy analyses of digital education systems (OECD, 2024).

Implementation Logic

Overall, sustainable XR integration was described as dependent on coordinated alignment across technological infrastructure, pedagogical design, disciplinary authenticity, organisational commitment, ethical governance, and economic stability. Weaknesses in one domain were perceived as destabilising the overall process. The extended TPACK framework proved analytically useful in structuring these interdependencies.

Table 1: Results - Success Factors and Challenges in the Implementation of Extended Reality (XR) in Nursing Education.

Area	Success Factors	Challenges
Techno-logical (TK)	Stable technical infrastructure, user-friendly devices, data protection-compli-ant solutions, maintenance and updates	High technical complexity, regular software updates, data protection concerns regarding biometric data, acquisition costs

Pedagogical (PK)	Didactically grounded reflection phases, clear curricular integration, motivation through realistic scenarios, teacher qualification	Lack of media-pedagogical qualification, insufficient curricular integration, missing feedback mechanisms
Disciplinary (CK)	Practice-oriented development in close cooperation with nursing professionals, clear learning objectives, practice-relevant scenarios	Selective curricular anchoring, risk of disciplinary misalignment, lack of practical relevance in development
Interfaces	Integration of technological, pedagogical, and disciplinary knowledge, aligned scenarios, holistic learning process	Complexity of integrating knowledge domains, overload due to multidimensional requirements, high coordination effort
Ethics & Organization	Data protection-compliant processes, protection of psychological health, barrier-free access, innovation-friendly culture, supportive organizational structures	Legal uncertainties regarding data protection, psychological stress caused by technology, barriers due to lack of technology acceptance, lack of support and quality management

Table 1: Overview Experts

Pseudonym	**Field**	**Function/Role**	**Brief Description of Expertise**
E1	Digital Educational Development & Sales	Managing Director	Sales and didactic use of XR in nursing education
E2	Publishing & XR Management	Project Management	XR project coordination within a publishing house and interface to education
E3	Nursing Pedagogy & Skills Lab	Learning Facilitator / Project Lead	Development of simulation-based learning formats with XR
E4	Nursing Education & XR Project Coordination	Educational Consultant / Project Lead	Development of curricular XR learning scenarios
E5	XR Development & Corporate Management	Managing Director / Developer	Technical implementation and design of VR simulations
E6	E-Learning & VR/AR System Integration	System Integration / Lecturer / Developer	Integration of XR into learning management systems
E7	Nursing Research & Higher Education	Professor / Laboratory Head	Scientific evaluation of XR in nursing education
E8	Digital Innovation & University Projects	Innovation Developer	Digitalization of teaching and learning processes using XR

Recommendations for Practice

The findings suggest that XR integration in nursing education requires coordinated action across institutional, pedagogical, technological, and policy levels.

At the institutional level, sustainable implementation depends on stable technical infrastructure, structured maintenance planning, and systematic curricular embedding. XR applications should be integrated into competency frameworks and supported by structured debriefing formats. Continuous

professional development in media pedagogy, simulation design, and data governance represents a central enabling condition (Bade et al., 2023).

At the educator level, implementation requires the development of integrated technological and pedagogical competencies, consistent with TPACK assumptions (Mishra & Koehler, 2006). Educators play a critical role in mediating immersive experiences through structured reflection and psychologically safe learning environments (Bartolles & Kamin, 2021).

From a governance perspective, regulatory clarity regarding data protection and analytics use is essential. Given the financial implications of licensing, maintenance, and training, long-term funding models are required to prevent fragmentation into short-term pilot initiatives (OECD, 2024; Drossel et al., 2024). Financial barriers remain a documented obstacle to technology adoption in nursing education (González et al., 2022).

For technology developers, user-centred design, interoperability, and compliance with data protection standards are central. Collaboration with nursing professionals during scenario development enhances disciplinary authenticity and practical relevance.

Overall, XR implementation should be conceptualised as a strategic institutional development process rather than a technological acquisition decision. Without structural alignment across governance, curriculum, infrastructure, and professional development, immersive technologies risk remaining peripheral innovations.

Discussion

This study demonstrates that the implementation of Extended Reality (XR) in nursing education represents a systemic institutional transformation rather than a technological intervention. While existing research primarily focuses on learning effectiveness and user satisfaction (Aebersold & Dunbar, 2020; Fernández-Cerero et al., 2024), the present findings highlight structural conditions that determine sustainable integration.

The results confirm the core assumption of the TPACK framework that meaningful technology integration depends on alignment between technological, pedagogical, and disciplinary knowledge (Mishra & Koehler, 2006; Koehler et al., 2013). However, empirical evidence indicates that this alignment alone is insufficient. Ethical governance and organisational capacity emerge as decisive structural dimensions.

Ethical considerations, particularly data protection, psychological safety, and inclusive access, function as enabling conditions rather than peripheral regulatory concerns (Kourtesis, 2024; Harrasko-Kocmann et al., 2021). Similarly, organisational factors such as leadership commitment, strategic embedding, and sustainable financing determine whether XR remains confined to pilot initiatives or evolves into a stable curricular component (OECD, 2024; Drossel et al., 2024).

The integration of Ethical and Organisational Knowledge extends TPACK into a governance-sensitive implementation framework for immersive healthcare education. The Extended TPACK perspective conceptualises XR implementation as a governance-related process shaped by infrastructural stability, professional development, and institutional strategy.

From a public health perspective, XR may contribute to workforce preparedness by enabling safe rehearsal of high-risk and rare clinical scenarios. In contexts of nursing shortages and increasing care complexity (BIBB, 2022), immersive simulation can strengthen competence development without compromising patient safety. However, this contribution depends on structural embedding and long-term financial sustainability.

A recurring tension identified in the interviews concerns the gap between short-term innovation funding and ongoing maintenance requirements. Without stable funding models and regulatory clarity, immersive technologies risk remaining fragmented innovation projects rather than supporting systemic workforce development.

Conclusion

Extended Reality holds substantial potential for competence-oriented nursing education. However, sustainable integration depends on more than technological functionality. This study demonstrates that successful implementation requires coordinated alignment across technological infrastructure, pedagogical embedding, disciplinary authenticity, ethical governance, and organisational capacity.

By extending the Technological Pedagogical Content Knowledge framework to include ethical and organisational knowledge domains, the study advances a structurally grounded implementation model for immersive healthcare education. XR implementation emerges as a governance-related transformation process rather than a classroom-level innovation.
When structurally embedded and supported by sustainable funding and regulatory clarity, XR can enhance workforce preparedness and patient safety.In the context of global nursing shortages and increasing care complexity, XR integration represents a relevant component of the broader digital transformation of healthcare education systems.

Limitations
The study is based on qualitative expert interviews and allows analytical rather than statistical generalisation. The European focus may limit transferability to other healthcare contexts. Given the rapid development of immersive technologies, implementation conditions may evolve over time.
Future research should examine longitudinal implementation trajectories, cost-effectiveness, and cross-national applicability of the Extended TPACK framework.

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