

Immersive Onboarding: A Design and Evaluation Study in Industrial VR Training

Leonie Kopahs
University of Goettingen
leonie.kopahs@uni-goettingen.de

Tamino Marahrens
University of Goettingen
tamino.marahrens@uni-goettingen.de

Matthias Schumann
University of Goettingen
mschumal@uni-goettingen.de

Abstract

This study evaluates a Virtual Reality (VR) onboarding system grounded in digital twin principles for immersive industrial training. With 63 participants, we examine how onboarding features shape immersive learning and knowledge acquisition. Participants completed domain-specific tasks before and after training, yielding a substantial knowledge gain (Cohen's $d = 3.29$), with scores improving by nearly 50 percentage points. Qualitative findings reinforced the role of onboarding for technical training in enhancing engagement, orientation, and perceived clarity, while identifying usability limitations and cybersickness as barriers. By conceptualizing the onboarding system as a socio-technical artifact, this study contributes to IS research on human-centered design, experiential system use, and training in Industry 4.0 environments. It offers practical design implications for developing immersive learning systems to support users' onboarding, cognitive processing, and system adoption in digitally transforming workplaces.

Keywords: Virtual Reality, Immersive Learning, Digital Twin, Onboarding Systems, Industrial Training, Evaluation

1. Introduction

In this paper, 'onboarding' refers to the structured VR training introduction, not a broader HR introduction. This distinction is especially relevant in industrial manufacturing contexts, where onboarding requires learners to quickly acquire procedural knowledge, safety protocols, and operational skills without disrupting ongoing production processes (Carruth, 2017). Traditional methods often lack scalability and are limited by safety and equipment constraints (Carruth, 2017). Immersive technologies, particularly Virtual Reality (VR), have established

themselves as practical tools for delivering realistic and risk-free training environments (Makransky et al., 2019), which also represent important building blocks of the emerging metaverse

In a broader sense, such environments represent important building blocks of the emerging metaverse. In this persistent, shared, and immersive digital space, individuals can perform complex tasks such as work, collaboration, and training (Mystakidis, 2022). Industrial training, especially induction training in high-risk, equipment-intensive areas, is expected to become one of the most impactful enterprise applications in this evolving virtual landscape (Martínez-Gutiérrez et al., 2023).

VR-based learning environments enable users to engage in situated, interactive training experiences replicating industrial systems' logic, tools, and spatial configurations (Akpan & Offodile, 2024). This immersive approach promotes experiential learning through trial-and-error and active problem-solving, which improves procedural understanding and knowledge retention (Makransky et al., 2019). A central feature is immersion, the state of deep involvement, where users focus on the virtual experience (Slater & Sanchez-Vives, 2016).

Interactivity enhances immersion by allowing users to manipulate virtual objects and receive feedback, fostering spatial presence—the feeling of 'being there' in the virtual environment (Engeser & Rheinberg, 2008; Mütterlein, 2018; Slater, 2009).

Another critical determinant of practical VR training is usability, which encompasses clarity, control intuitiveness, and system responsiveness, especially during initial exposure (Abeele et al., 2020). When usability is low, due to interface complexity or technical bugs, users may experience cognitive overload, interfering with learning (Leppink et al., 2013; Sweller et al., 2011). Onboarding, the introductory phase during which users learn how to interact with the VR system and understand the training objectives, plays a key role in managing these

challenges (Makransky & Mayer, 2022). In industrial training contexts, onboarding must also be domain-specific, preparing users to operate complex equipment, follow safety protocols, and understand production logic (Makransky et al., 2019).

Recent work has also shown how immersive onboarding can be applied beyond industrial training, for example, in remote work contexts using metaverse-based introductions (Fernandes et al., 2024).

Structured onboarding sequences often use interactive tutorials, visual prompts, and scenario-based scaffolding to ease users into the VR experience (Howard, 2014). These design features improve usability and establish the conditions for immersion and presence, influencing how effectively learners process and apply the simulated content (Zambrano et al., 2020).

Despite these advances in VR training design, the specific contribution of onboarding sequences to users' immersive learning experience remains insufficiently understood. While the pedagogical value of VR in industrial education has been increasingly acknowledged, onboarding is often treated as a peripheral or purely technical necessity rather than a strategic design component in its own right (Makransky & Mayer, 2022). Broader reviews of immersive VR highlight its role in the metaverse as a socio-technical system of affordances, emphasizing how design decisions shape user engagement and outcomes (Dincelli & Yayla, 2022). However, users form critical first impressions during this early phase, develop interaction fluency, and establish cognitive frameworks for navigating complex virtual environments (Howard, 2014; Slater & Sanchez-Vives, 2016). A lack of research into how structured onboarding shapes psychological states such as presence, flow, and engagement limits our ability to optimize these systems for learning effectiveness (Engeser & Rheinberg, 2008; Zambrano et al., 2020).

While previous studies have demonstrated the theoretical benefits of VR for industrial training, few have systematically examined how onboarding design features influence immersion and perceived learning outcomes in such environments (Makransky & Mayer, 2022). Moreover, presence, flow, and usability in shaping subjective and objective learning remain underexplored (Engeser & Rheinberg, 2008; Slater & Sanchez-Vives, 2016).

This study addresses these gaps by evaluating a VR onboarding prototype as a socio-technical artifact embedded in a digital twin-based information system for industrial training (Martínez-Gutiérrez et al., 2023). It aims to empirically assess how onboarding design features such as interactivity and usability

influence immersion and learning, and how psychological states like presence and flow mediate these relationships (Abeele et al., 2020; Makransky et al., 2019). By empirically investigating how onboarding design impacts immersive learning in VR, this study contributes to understanding how enterprise training systems can be effectively integrated into Metaverse infrastructures.

To guide our analysis, we pose the following research questions (RQ):

RQ1: How does a digital-twin-based VR onboarding System influence users' immersive learning experience in an industrial training environment?

RQ2: What are the perceived strengths and limitations of the VR onboarding system in supporting subject matter learning outcomes?

2. Theoretical Background & Related Work

This section presents the theoretical foundations of immersive learning in industrial settings, focusing on VR-based training and the role of onboarding in supporting usability, presence, and cognitive readiness for task execution.

2.1. Immersive Learning in Industrial Training

Integrating immersive environments such as VR into industrial training reshapes how complex skills are acquired in production-oriented contexts. These environments leverage interactive virtual training scenarios—often developed using digital twins—to replicate operational workflows, machine handling, and safety-critical procedures (Akpan & Offodile, 2024; Martínez-Gutiérrez et al., 2023). By offering realistic, risk-free environments, these scenarios allow learners to rehearse actions in ways traditional training formats cannot provide, especially where equipment availability, cost, or safety constraints limit real-world practice (Carruth, 2017).

Core to the effectiveness of immersive learning is the concept of immersion, the psychological state of deep engagement, in which learners become cognitively and emotionally absorbed in the virtual task. Immersion is closely associated with user focus, emotional investment, and long-term memory retention. One of its strongest predictors is interactivity, defined as the extent to which users can influence virtual elements and receive meaningful feedback (Bowman & McMahan, 2007; Mütterlein, 2018).

When immersion is intense, learners are more likely to enter a flow state—an optimal learning condition marked by deep concentration, intrinsic motivation, and an ideal balance between task challenge and skill level (Engeser & Rheinberg, 2008). These psychological conditions are essential for promoting both subjective learning outcomes (e.g., learner confidence) and objective outcomes (e.g., task accuracy and knowledge retention) (Kalyuga, 2009; Mcdaniel et al., 2007).

To support this, gamified design elements such as performance scoring, visual progress indicators, and real-time corrective feedback are increasingly integrated into VR-based onboarding. These features do not just enhance motivation—they also scaffold the learning experience and help maintain cognitive engagement over time (Plass et al., 2015; Zainuddin et al., 2020).

Immersive learning systems use virtual environments and gamification to offer scalable, repeatable, high-fidelity training. They enable experiential learning without disrupting operations, especially in manufacturing, where tasks are complex, hazardous, or equipment-intensive.

2.2. The Role of Onboarding in Immersive Industrial Training

Within the broader context of immersive learning, onboarding in VR is a foundational phase, significantly shaping user experience and learning effectiveness (Makransky & Mayer, 2022). This phase introduces users to the system's interaction logic, spatial layout, and intended objectives (Makransky & Mayer, 2022). Effective onboarding is essential for novice users, as it lowers entry barriers and supports a smooth and confident transition into the virtual environment (Makransky et al., 2019).

During this early phase, a particular challenge is motion sickness—also called cybersickness—which can result from mismatches between visual stimuli and physical motion cues (Slater, 2009). If not proactively addressed, symptoms such as nausea, dizziness, and disorientation may severely hinder learner engagement and performance (Zambrano et al., 2020). To address this, effective onboarding routines often feature gradual exposure to motion, user-controlled navigation, and stable frame rates (Abeele et al., 2020). These design strategies help users acclimate physically and cognitively, laying the foundation for fluency in digital interaction and reducing the risk of early disengagement (Howard, 2014).

Onboarding modules commonly include interactive tutorials, guided walkthroughs, and procedural scaffolding to mitigate cognitive strain

(Abeele et al., 2020). These instructional tools help users build early mastery of control mechanisms and task procedures, enabling deeper immersion and increasing user autonomy during the core training experience (Howard, 2014). This is especially relevant for new users who face dual learning demands—acquiring system navigation skills and domain-specific knowledge, which can create elevated cognitive loads (Makransky et al., 2019). According to Cognitive Load Theory, learning effectiveness declines when mental demands exceed processing capacity, even if the instructional design is otherwise sound (Leppink et al., 2013; Sweller et al., 2011). Two constructs are particularly central to onboarding success: usability and presence (Slater, 2009). Usability refers to the perceived clarity, ease of use, and intuitiveness of the VR system's interface (Zambrano et al., 2020). Thoughtful onboarding improves usability by aligning feedback and interaction patterns with user expectations (Makransky & Mayer, 2022). Presence, particularly spatial presence, refers to the subjective experience of being “inside” the virtual world (Slater, 2009). This sense of presence is supported by consistent sensory cues and seamless, responsive interaction, both of which are reinforced during the onboarding phase (Zambrano et al., 2020).

In industrial training contexts, where VR systems often simulate highly technical, regulated, and safety-critical tasks, the importance of structured onboarding becomes even more pronounced (Makransky et al., 2019). Onboarding must go beyond basic interface training to prepare users for domain-specific actions such as operating complex machinery, assembling components, or following detailed safety procedures (Makransky et al., 2019). Without this contextually rich preparation, learners may face disorientation, frustration, or reduced learning efficiency, especially if they are unfamiliar with the system and the domain (Makransky et al., 2019). According to Cognitive Load Theory, instructional effectiveness is diminished when learners must simultaneously grasp system controls and domain knowledge under high cognitive strain (Leppink et al., 2013; Sweller et al., 2011). Therefore, onboarding in industrial VR environments is not merely a technical step but a pedagogical strategy (Howard, 2014). It bridges the gap between general VR interaction competence and specialized workplace skills by integrating procedural accuracy and contextual knowledge from the outset (Makransky & Mayer, 2022). As such, onboarding in industrial contexts actively shapes the success and transferability of the entire learning process (Makransky et al., 2019).

3. Artifact Overview: VR Onboarding

Building on the theoretical and methodological foundation, this section presents the VR onboarding prototype developed for this study. It outlines the practical training context, key design requirements, instructional scenario logic, and technical implementation.

3.1. Practical Training Context

Training new production employees in many global manufacturing companies is still heavily based on personal job shadowing. New employees typically shadow operators, providing authentic insight but disrupting production, reducing safety, and burdening trainers.

The company tested a VR training system based on digital twins replicating the physical production environment in a risk-free, immersive training format to address these issues. Before entering real-world operations, new employees complete a structured onboarding sequence in VR, where important processes such as material handling, machine operation, and troubleshooting are performed in a virtual environment. These training scenarios are based on actual process data and safety standards, ensuring high realism and consistent training quality.

The rollout is a collaboration between the human resources, health and safety, IT, and operational excellence teams. Integration with existing learning platforms enables centralized tracking of training completion, performance results, and behavioral metrics such as task efficiency and error rates. The system also supports iterative content updates, allowing teams to respond quickly to process changes or compliance updates.

By reducing reliance on live training, the company has significantly reduced the risks associated with onboarding and improved scalability across all locations worldwide. In addition, VR-based onboarding has shortened the time it takes for new employees to become proficient, while freeing up skilled employees for their core production tasks. This example shows how immersive onboarding systems can become an important factor in the digital transformation of the workforce by bridging the gap between operational training requirements and scalable, human-centered learning solutions.

3.2. Design Objectives and Requirements

Drawing on insights from Sections 2.2 and 2.3, the VR onboarding prototype was designed to tackle

key challenges in immersive industrial training—usability, cognitive load, and experiential engagement. These focus areas informed the system’s functional and instructional design. Table 1 outlines the core requirements.

Table 1: Core Requirements (R) of the VR Onboarding System

Functional Focus	No.	Requirement Description
Digital Twin & Object Presentation	R1	Realistic modeling of the production environment, including objects, textures, and equipment
	R2	Simulation of functional machine and tool behaviors
Interaction & Control Logic	R3	Natural manipulation of virtual objects (e.g., grab, place, operate)
	R4	System control over machine states and parameters
Immersion & Spatial Presence	R5	Integration of visual, auditory, and physical effects to enhance realism
	R6	Support for fluid movement via head and hand tracking in first-person perspective
Scenario-Based Learning	R7	Structured learning progression with selectable process complexity
	R8	Independent control of scenario flow (start, pause, resume, exit)
Instructional Support	R9	Step-by-step visual guidance with numbered action prompts
Performance Monitoring	R10	Tracking, analyzing, and visualizing user performance metrics
Multimodal Feedback	R11	Real-time feedback via visual, auditory, and haptic channels
Information Accessibility	R12	Context-sensitive pop-up information for self-directed learning

Area (1) **Digital Twin & Object Presentation** ensures visual and functional fidelity by accurately modeling machines, tools, materials, and layouts (R1). Simulated behaviors allow learners to experience realistic cause-and-effect processes (R2). Area (2) **Interaction & Control Logic** enables natural manipulation of virtual objects—grabbing, placing, or operating them (R3)—and includes system-level functions like toggling machines and adjusting settings (R4) to reinforce process understanding. Area (3) **Immersion & Spatial Presence** promotes cognitive and physical immersion through multimodal stimuli (R5). Full-body tracking and a first-person view support embodied interaction (R6). Area (4) **Scenario-Based Learning** provides structured yet self-directed tasks—orientation, basic, or complex—with options to start, pause, and resume freely (R7–R8), supporting autonomy and exploration. Area (5) **Instructional Support** delivers step-by-step visual prompts to guide learners through procedures and enhance navigational confidence (R9). Area (6) **Performance Monitoring** tracks user behavior—completion, errors, timing—and visualizes this data for formative feedback and progress evaluation (R10). Area (7) **Multimodal Feedback** reinforces behavior via real-time visual, auditory, and haptic cues, helping correct errors and confirm success (R11). Area (8) **Information Accessibility** offers contextual pop-ups for tools, tasks, or materials, supporting just-in-time learning without disrupting the flow (R12).

3.3. Training Scenario Walkthrough

The VR onboarding prototype features a modular and progressively structured training system to foster procedural understanding and user autonomy. As shown in Figure 1, the application begins with a start menu, where users can configure basic VR settings such as control preferences. Upon selecting “Select Training Scenario”, users can choose between three trainings: the **Orientation Scenario** for initial familiarization, the complete onboarding process encompassing up to 84 production steps, or individual subprocesses for focused practice. This flexible structure enables learners to repeat specific units, target previously misunderstood elements, or gradually work through the production workflow depending on their learning goals.

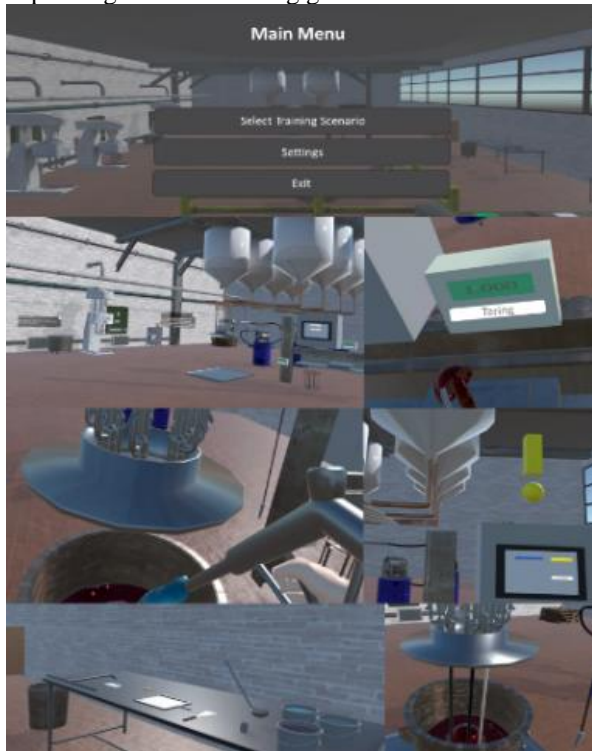


Figure 1: VR Training Environment

After setup, learners are guided through a structured sequence of training scenarios. The orientation scenario should be completed first to ensure a common understanding of the environment and task logic. It introduces users to the virtual workspace, the relevant machines, and the fundamental interaction mechanisms. This phase includes visual cues with explanations of the individual components of production to reduce entry barriers, especially for users with limited VR experience.

Learners then proceed with either the easy or advanced scenario, depending on their training requirements or level of knowledge. In the **Easy Scenario**, learners receive individual instructions for each step via a whiteboard and see a yellow exclamation mark in the room to let them know where the next task is located. As users interact with the system, they receive immediate feedback via audible signals indicating whether a step has been completed successfully or needs to be repeated. This helps to reinforce correct behavior and understanding of the processes in real time.

The **Advanced Scenario** challenges learners to complete the production process autonomously without instructional support. It consists of multiple subprocesses and device interactions requiring the precise, step-by-step application of previously learned procedures. As learners progress through the tasks, immediate feedback is provided via audio signals confirming the correct execution of each step. This real-time response reinforces procedural accuracy while allowing users to monitor their progress and performance.

All scenarios are repeatable, allowing users to adjust the pace and focus of their training. This design supports self-regulated learning by combining structured guidance with increasing complexity and preparing users for real-world tasks in industrial environments.

3.4. System Architecture and Implementation

The VR onboarding prototype was developed in Unity 3D using the XR Interaction Toolkit to ensure modularity, extensibility, and hardware compatibility. Core assets—machines, tools, and layouts—were modeled in Blender at a 1:1 scale with high-fidelity textures.

Custom scripts and state machines allow intuitive object manipulation and equipment operation via controllers or gestures, mirroring real-world logic. Instructional prompts are embedded within the training environment, guiding users through tasks while a tracking layer logs errors and durations for feedback.

Multimodal feedback—visual, auditory, and haptic—enhances engagement and error correction. Performance was optimized via object pooling and asynchronous loading, and a responsive UI with abstracted input ensures cross-device usability. The system supports flexible, location-independent deployment.

4. Research Design

Building on the artifact described in Section 3, the following section outlines our research design to empirically investigate how the onboarding system affects immersive learning experiences and perceived learning outcomes.

4.1. Study Design: Immersive Onboarding

An exploratory pre-post study was conducted using the VR training platform to investigate the effectiveness and user experience of the VR onboarding system. The study aimed to understand how onboarding-related design features shape learners' perceptions and behavior in immersive industrial training contexts.

The procedure consisted of three phases: (1) a pre-survey, (2) an individual VR training session using the full Easy Scenario, and (3) a post-survey. All sessions were conducted in a controlled laboratory environment to ensure consistent conditions. In the pre-survey, participants provided demographic data (e.g., age, gender, professional background) and reported prior experience with VR. Additionally, expectations regarding the onboarding experience and Digital training readiness were assessed. The study used Oculus Quest 2 with joystick locomotion, and participants stood and rotated physically, but couldn't walk freely. During the VR session, participants first engaged in the onboarding scenario designed to introduce navigation, interaction mechanics, and the virtual workspace. This was followed by a domain-specific training task recreating a typical production workflow. Participants completed the experience independently to reflect realistic, autonomous system use.

The post-survey included open-ended questions to gather qualitative feedback on system usability, realism, and perceived learning effects. Each session lasted approximately 45–60 minutes. Participation was voluntary and anonymized by ethical research standards.

Based on theoretical foundations in immersive learning, usability, and instructional design (e.g. Makransky & Mayer, 2022; Slater & Sanchez-Vives, 2016), the analysis focused on four core dimensions relevant to successful VR training (see Figure 2).

Learning Environment	Learning Scenario	Learning Outcome	Cybersickness
• usability, immersion, system clarity	• task logic, feedback, instructional design	• knowledge gains, transferability	• physical discomfort, navigation challenges

Figure 2: Core Evaluation Dimensions of the Onboarding System

These categories reflect pedagogical and ergonomic factors essential for effectively implementing VR onboarding systems in industrial settings.

4.2. Research Hypotheses

Drawing on prior research in immersive learning, instructional design, and VR usability, the following theoretically grounded hypotheses were formulated to guide the qualitative analysis of user experience within the VR onboarding environment (see Figure 3).

<p>Learning Environment</p> <p>•H1: A highly usable and immersive onboarding experience increases user engagement and fosters a more positive perception of the virtual learning environment. (Makransky et al., 2019; Slater & Sanchez-Vives, 2016)</p>
<p>Learning Scenario</p> <p>•H2: Structured, scenario-based onboarding with clear task logic and instructional support enhances perceived training effectiveness and user confidence in task execution. (Howard, 2014; Akpan & Offodile, 2024)</p>
<p>Learning Outcomes</p> <p>•H3: VR onboarding that reduces cognitive load and encourages reflective processing results in greater subjective learning gains and improved perceived transfer to real-world tasks, compared to onboarding approaches that lack such instructional design support. (Sweller et al., 2011; Kalyuga, 2009)</p>
<p>Cybersickness</p> <p>•H4: Onboarding systems with intuitive navigation and comfort-enhancing features reduce the likelihood and severity of cybersickness symptoms. (Abeele et al., 2020; Slater, 2009)</p>

Figure 3: Overview of research hypotheses across the four dimensions

5. Evaluation Results

This section presents the empirical findings from evaluating the digital twin-based VR onboarding system. Drawing from quantitative and qualitative data, the analysis aims to understand how the system influenced users' learning outcomes, engagement, and interaction quality in an industrial training context. The results are presented in three parts: (1) a descriptive overview of the participant sample and their background, (2) an analysis of the objective learning gains based on pre- and post-test scores, and (3) a thematic synthesis of users' subjective experiences regarding system usability, instructional clarity, immersion, and physical comfort. These findings provide a comprehensive view of the system's pedagogical and technical effectiveness in supporting onboarding through immersive training.

5.1. Descriptive Sample Insights

The sample comprised 63 participants, primarily students (over 80%), with a balanced gender distribution. The average age was approximately 24 years, ranging from 19 to 43.

The majority had limited or no prior exposure to virtual reality. About one-third had little VR experience; a smaller group used VR more frequently, mainly for gaming or projects. Some owned headsets, others accessed them via institutions.

This diversity in VR familiarity provides valuable contrast in evaluating onboarding effectiveness, particularly between novices and more experienced users. Exploratory checks showed that prior VR experience reduced navigation issues, suggesting moderating effects for future research (Makransky et al., 2019).

5.2 Quantitative Insights

To objectively assess the learning effectiveness of the VR onboarding system, participants completed a domain-specific knowledge test before and after the training session. The results demonstrate a substantial performance improvement. The average pre-test score was 1.87 (SD = 1.14) out of a maximum of 12 points, equivalent to 15.6% of the possible score. In contrast, the average post-test score rose to 7.81 (SD = 2.14), corresponding to 65.1%—a gain of approximately 49.5 percentage points. This represents a more than fourfold increase in correctly answered items and a mean difference of 5.94 points. The assessment covered factual recall and procedural steps (e.g., machine operation) but did not include affective or risk-awareness aspects.

Statistical analysis confirms the significance of this learning gain. A paired sample t-test revealed a highly significant difference between pre- and post-test scores ($t(61) = 25.87, p < 1.37 \times 10^{-34}$), indicating a strong training effect. As measured by Cohen's $d = 3.29$, the effect size reflects a considerable impact, well above the conventional threshold for practical significance ($d > 0.80$).

The increase in variance from 1.29 in the pre-test to 4.56 in the post-test suggests a wider spread in learning outcomes, which may be attributed to individual differences in prior knowledge, cognitive processing, or ease of interaction with the VR system. Despite this variability, the results strongly support the conclusion that users' objective knowledge acquisition was significantly enhanced through the digital twin-based VR onboarding environment.

5.3. Qualitative Insights

The qualitative results provide a detailed understanding of how users experienced the VR onboarding system and where they encountered friction or saw potential for improvement. Based on thematic analysis of open-ended responses, four core

areas were identified: the learning environment, the learning scenario, learning outcomes, and cybersickness.

In the learning environment, participants largely praised the presence of visual aids such as exclamation marks, whiteboards, and detailed spatial design. Many highlighted the engaging, game-like climate, motivating them to interact. However, usability concerns were prominent. Participants noted navigation and interaction issues (joystick, grabbing), often due to bugs and lack of guidance. Blurry textures and low resolution were also criticized. Sensory immersion was also perceived as incomplete due to the absence of ambient sounds or environmental feedback. For example, navigation difficulties were mentioned by 28 of 63 participants, while 34 participants highlighted visual clarity as a strength.

These findings suggest concrete improvements: add a structured onboarding with an interactive tutorial to explain controls; offer alternative navigation options like teleportation to reduce disorientation; improve visual and technical fidelity with higher resolution assets, bug fixes, and environmental sounds to boost realism. Users liked clear instructions and orientation features but faced technical issues during tasks like weighing or filling, causing frustration. Some wanted more autonomy, variation, or adaptive difficulty.

In response to these observations, the learning scenario should incorporate more robust error-handling logic and more precise system feedback when user actions deviate from the intended process. Introducing non-linear task paths or optional complexity levels could cater to diverse user preferences and expertise. Additionally, repeating steps or revisiting parts of the scenario could improve understanding and engagement.

Regarding perceived learning outcomes, most users reported a better understanding of technical processes and the use of relevant equipment. However, several responses also revealed a lack of deeper understanding, with limited background knowledge or contextual depth. A few users explicitly noted difficulties in transferring the experience to real-world scenarios.

Future iterations should incorporate reflective learning mechanisms to deepen learning outcomes. These could include embedded micro-quizzes, contextual tooltips explaining machine functions or process logic, and visual comparisons between virtual actions and real-world equivalents. Supplementary materials such as short videos or PDF manuals could reinforce learning and improve transferability.

Finally, cybersickness emerged as a substantial issue. More than half of the participants experienced

symptoms such as nausea, dizziness, and visual discomfort. These symptoms were typically associated with environmental movement and occurred more frequently among first-time VR users.

The default navigation mode should prioritize teleportation and minimize rapid visual transitions to mitigate these effects. Additional comfort features like field-of-view stabilization (e.g., vignette effect), clear ergonomic instructions, and modular scenario design with built-in breaks should be standard. Raising the frame rate and limiting camera movement could further reduce discomfort.

The qualitative evaluation revealed high user engagement and a positive perception of the VR system's educational value. At the same time, it highlighted recurring technical and ergonomic challenges that, if addressed, could significantly enhance the system's effectiveness, comfort, and accessibility. These insights serve as a valuable roadmap for iterative design and refinement in future development cycles.

6. Implications for Research and Practice

The findings of this study yield several important implications for both the IS community and practitioners designing immersive training solutions in industrial contexts.

6.1 Implications for IS Research

This study extends IS research by operationalizing a VR-based onboarding system as a socio-technical artifact integrating digital twin logic with immersive user interfaces. By empirically examining how design features such as interactivity, onboarding structure, and usability shape user experience and learning, the paper advances understanding of system affordances in human-centered industrial information systems. Results underscore onboarding as a learning-enabling mechanism beyond usability, enhancing perceived system quality and cognition. These insights contribute to IS subfields concerned with human-computer interaction, technology adoption, and experiential system design, especially under the growing umbrella of Industry 4.0 and cyber-physical systems.

Moreover, this work empirically bridges subjective (e.g., perceived immersion) and objective (e.g., performance gain) measures of system success, reinforcing calls within IS research for multi-method, user-centered evaluation frameworks. The substantial learning gain observed (Cohen's $d = 3.29$) highlights the potential of immersive systems to generate

meaningful performance outcomes beyond traditional system usage metrics. Future IS studies can build on this model to explore learning analytics, biometric feedback, or adaptive system architectures in digital training environments.

6.2 Implications for Practice

The results highlight the importance of onboarding for practitioners deploying virtual training systems for production. Designers and training developers should not treat onboarding as a peripheral add-on but as a central instructional strategy. Structured, scenario-based onboarding with interactive support systems significantly enhances user engagement, reduces cognitive load, and fosters faster system adoption, especially for first-time VR users. These outcomes are particularly relevant for manufacturing companies facing increasing demands for rapid, scalable workforce upskilling. Industry practice reflects this trend, as shown in Accenture's large-scale adoption of immersive onboarding for workforce training (Lacity & Mullins, 2025).

Furthermore, the findings point to concrete design priorities: systems should include adaptive tutorials, context-sensitive feedback, ergonomic navigation options, and support for reflective learning (e.g., embedded tooltips or post-task analytics). Addressing interaction fidelity and cybersickness is crucial for both user comfort and learning effectiveness. Future studies should also apply standardized measures such as the Simulator Sickness Questionnaire to quantify these effects.

Finally, these implications emphasize the relevance of aligning immersive system development with IS design science principles, encouraging a continuous loop of iterative design, stakeholder feedback, and empirical evaluation. As immersive technologies become mainstream in industrial IS portfolios, structured onboarding systems like the one evaluated here may become vital touchpoints in organizational digital transformation.

7. Discussion

The results advance IS research by showing how immersive training systems function as cross-border information systems, combining human cognition with machine logic and supporting coordination between digital tools and industrial work processes. The findings address the guiding research questions by combining subjective feedback and objective performance data. Concerning RQ1, the qualitative findings indicate successfully enhancing participants'

immersive learning experiences through the onboarding design.

Visual signals, scenario guidance, and spatial layout promoted clarity and confident interaction, confirming H1. The hypothesis posited that highly usable and immersive onboarding fosters positive perceptions and engagement (Makransky & Mayer, 2022; Slater & Sanchez-Vives, 2016). Participants found the VR environment motivating and intuitive, reinforcing experiential immersion in industrial VR.

However, technical limitations occasionally disrupted immersion. Complaints about joystick navigation, grip mechanics, visual fidelity, and the absence of ambient audio suggest even minor usability issues can fragment the immersive flow. This highlights the importance of seamless, multisensory interaction design for future system iterations.

Regarding RQ2, qualitative and quantitative data point to the system's effectiveness in improving users' understanding of subject matter. On a quantitative level, participants' knowledge scores significantly enhanced following the VR intervention. The average test score rose from 1.87 (15.6%) in the pre-test to 7.81 (65.1%) in the post-test, a gain of nearly 50 percentage points. A paired t-test confirmed this difference as highly significant ($t(61) = 25.87, p < 1.37 \times 10^{-34}$), and the corresponding Cohen's $d = 3.29$ indicates a huge effect size, far surpassing conventional benchmarks. These results strongly support H3, hypothesizing reduced cognitive load and improved learning through onboarding (Kalyuga, 2009; Sweller et al., 2011).

Qualitatively, participants felt more confident executing procedural steps after training and appreciated the clear logic of tasks and instructional prompts, thereby supporting H2. However, some reported that the learning remained shallow, with limited transfer to real-world situations due to the lack of contextual explanation. These responses underline the need for reflective scaffolding, such as tooltips or real-world analogies, to deepen conceptual understanding and enhance transferability.

A recurring challenge involved cybersickness, particularly among VR novices. Over half of the participants reported symptoms such as dizziness or nausea during the experience, especially in motion-intensive segments. These results empirically validate H4, proposing a critical influence of comfort and navigation design on cybersickness (Abeele et al., 2020). Teleportation and comfort settings were likely factors in the discomfort. Future designs should implement ergonomic modes, customizable movement styles, and system-initiated breaks.

VR's impact on learning significantly enhances learner orientation and knowledge acquisition in short interventions. However, there's room for improvement

in system comfort, interactivity, and instructional depth. Onboarding benefits may decline in repeated training and future designs should add adaptive features like skipping, personalization, or simplification (Howard, 2014; Makransky & Mayer, 2022).

8. Conclusion and Future Work

This study shows the potential of digital twin-based VR onboarding for safe, scalable industrial training. Grounded in instructional design and usability, the prototype measurably improved both subjective experience and objective performance. The combination of nearly 50 percentage points of learning gain and a huge effect size (Cohen's $d = 3.29$) affirms the educational efficacy of immersive onboarding. In parallel, qualitative insights revealed that well-designed onboarding promotes user confidence, presence, and motivation while highlighting areas requiring attention, such as ergonomic navigation, clarity of transfer, and technical consistency.

The study confirms onboarding's essential role and offers implications for IS research on usability, adoption, and experiential learning in industrial VR. However, several limitations should be acknowledged. First, the participant sample primarily consisted of students, which may affect the generalizability of findings to industrial employees. Future studies should include professional users to assess real-world applicability. Second, the short-term evaluation design does not account for long-term knowledge retention or transfer to physical task performance. Third, although a strong training effect was observed, cybersickness and usability concerns indicate the need for further ergonomic and technical refinement. Finally, data relied on self-reports and performance metrics, lacking physiological or behavioral analytics. Future work should include long-term studies assessing retention, performance in real-world tasks, and comparisons between immersive and traditional onboarding approaches. In addition, real-time adaptive onboarding and data-driven feedback mechanisms, such as eye-tracking or biometric inputs, could further tailor the learning experience to individual user profiles. A further limitation is the absence of a non-VR baseline condition. As such, the findings demonstrate the effect of VR onboarding itself, but not its relative advantage over traditional methods (Makransky & Mayer, 2022).

By refining the interplay between technology, pedagogy, and user experience, immersive onboarding can become a cornerstone of human-centered training strategies in Industry 4.0.

9. References

- Abeebe, V. V., Spiel, K., Nacke, L., Johnson, D., & Gerling, K. (2020). Development and validation of the player experience inventory: A scale to measure player experiences at the level of functional and psychosocial consequences. *International Journal of Human-Computer Studies*, *135*, 102370. <https://doi.org/10.1016/j.ijhcs.2019.102370>
- Akpan, I. J., & Offodile, O. F. (2024). The Role of Virtual Reality Simulation in Manufacturing in Industry 4.0. *Systems*, *12*(1), 26. <https://doi.org/10.3390/systems12010026>
- Bowman, D. A., & McMahan, R. P. (2007). Virtual Reality: How Much Immersion Is Enough? *Computer*, *40*(7), 36–43. <https://doi.org/10.1109/MC.2007.257>
- Carruth, D. W. (2017). Virtual reality for education and workforce training. In *2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA)* (pp. 1–6). IEEE. <https://doi.org/10.1109/ICETA.2017.8102472>
- Dincelli, E., & Yayla, A. (2022). Immersive virtual reality in the age of the Metaverse: A hybrid-narrative review based on the technology affordance perspective. *The Journal of Strategic Information Systems*, *31*(2), 101717. <https://doi.org/10.1016/j.jsis.2022.101717>
- Engeser, S., & Rheinberg, F. (2008). Flow, performance and moderators of challenge-skill balance. *Motivation and Emotion*, *32*(3), 158–172. <https://doi.org/10.1007/s11031-008-9102-4>
- Fernandes, C., Dias, M. S., & Costa, P. (2024). Virtual Onboarding: Using the Metaverse for Induction of New Employees on Remote Work. In *2024 International Conference on Graphics and Interaction (ICGI)*. <https://ciencia.iscte-iul.pt/publications/virtual-onboarding-using-the-metaverse-for-induction-of-new-employees-on-remote-work/110927>
- Howard, M. C. (2014). Creation of a computer self-efficacy measure: Analysis of internal consistency, psychometric properties, and validity. *Cyberpsychology, Behavior and Social Networking*, *17*(10), 677–681. <https://doi.org/10.1089/cyber.2014.0255>
- Kalyuga, S. (2009). Knowledge elaboration: A cognitive load perspective. *Learning and Instruction*, *19*(5), 402–410. <https://doi.org/10.1016/j.learninstruc.2009.02.003>
- Lacity, M., & Mullins, J. (2025). Modernizing Onboarding at Accenture with Immersive Learning. *MIS Quarterly Executive*, *24*(2). <https://aisel.aisnet.org/misqe/vol24/iss2/7>
- Leppink, J., Paas, F., van der Vleuten, C. P. M., van Gog, T., & van Merriënboer, J. J. G. (2013). Development of an instrument for measuring different types of cognitive load. *Behavior Research Methods*, *45*(4), 1058–1072. <https://doi.org/10.3758/s13428-013-0334-1>
- Makransky, G., & Mayer, R. E. (2022). Benefits of Taking a Virtual Field Trip in Immersive Virtual Reality: Evidence for the Immersion Principle in Multimedia Learning. *Educational Psychology Review*, *34*(3), 1771–1798. <https://doi.org/10.1007/s10648-022-09675-4>
- Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, *60*, 225–236. <https://doi.org/10.1016/j.learninstruc.2017.12.007>
- Martínez-Gutiérrez, A., Díez-González, J., Verde, P., & Perez, H. (2023). Convergence of Virtual Reality and Digital Twin technologies to enhance digital operators' training in industry 4.0. *International Journal of Human-Computer Studies*, *180*, 103136. <https://doi.org/10.1016/j.ijhcs.2023.103136>
- Mcdaniel, M. A., Roediger, H. L., & Mcdermott, K. B. (2007). Generalizing test-enhanced learning from the laboratory to the classroom. *Psychonomic Bulletin & Review*, *14*(2), 200–206. <https://doi.org/10.3758/BF03194052>
- Mütterlein, J. (2018). The Three Pillars of Virtual Reality? Investigating the Roles of Immersion, Presence, and Interactivity. In T. Bui (Ed.), *Proceedings of the Annual Hawaii International Conference on System Sciences, Proceedings of the 51st Hawaii International Conference on System Sciences*. Hawaii International Conference on System Sciences. <https://doi.org/10.24251/HICSS.2018.174>
- Mystakidis, S. (2022). Metaverse. *Encyclopedia*, *2*(1), 486–497. <https://doi.org/10.3390/encyclopedia2010031>
- Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of Game-Based Learning. *Educational Psychologist*, *50*(4), 258–283. <https://doi.org/10.1080/00461520.2015.1122533>
- Slater, M. (2009). Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1535), 3549–3557. <https://doi.org/10.1098/rstb.2009.0138>
- Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing Our Lives with Immersive Virtual Reality. *Frontiers in Robotics and AI*, *3*. <https://doi.org/10.3389/frobt.2016.00074>
- Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive Load Theory*. Springer New York. <https://doi.org/10.1007/978-1-4419-8126-4>
- Zainuddin, Z., Chu, S. K. W., Shujahat, M., & Perera, C. J. (2020). The impact of gamification on learning and instruction: A systematic review of empirical evidence. *Educational Research Review*, *30*, 100326. <https://doi.org/10.1016/j.edurev.2020.100326>
- Zambrano, J. I., Bermeo, D. A., Naranjo, C. A., & Andaluz, V. H. (2020). Multi-User Virtual System for Training of the Production and Bottling Process of Soft Drinks. In *2020 15th Iberian Conference on Information Systems and Technologies (CISTI)* (pp. 1–7). IEEE. <https://doi.org/10.23919/CISTI49556.2020.9141140>