Exploring Mental Workload Across Different Levels of Immersion: Augmented Reality for Assembly Training within the Industrial Metaverse

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Abstract

Recently, the metaverse has gained attention as the next evolution of the internet by merging the real and virtual world, with the potential to transform work, business, and social interactions. Even though immersive technologies for the metaverse, including augmented and virtual reality, offer great potential for collaboration, training, or simulation, there are indications that this could be at the expense of mental effort. Therefore, our study examines the impact of the immersion level on mental workload and performance. We conducted a within-subject design experiment with 30 participants who engaged in a training task across different environments (real world, computer, and metaverse). Our findings indicate no significant difference in mental workload. This suggests that the metaverse can serve as a viable, cost-effective training environment, particularly for complex and high-risk activities. These results highlight the potential of metaverse in work and especially industrial applications, providing new avenues for training and process optimization.

Keywords: Metaverse, mental workload, performance, immersion.

1. Introduction

Emerging technologies and innovations in the context of technical progress have always led companies to evaluate their potential to stay competitive (Lokuge et al., 2019). As the next generation of the internet, the metaverse has become popular recently (Dolata & Schwabe, 2023; Jacquemin et al., 2023). By merging the real world with the virtual world, it is intended to disrupt the way of working and conducting businesses as well as how people communicate, interact, and socialize both in their professional and private life (Dincelli & Yayla, 2022; Dwivedi et al., 2022). While the consumer metaverse focuses on new experiences regarding entertainment, gaming, shopping, or socializing, the industrial metaverse enables industrial processes within the virtual space in real-time, e.g., by mirroring or interacting with machines, factories or supply chains, where also virtual maintenance and training due to immersive human-machine interaction is of great interest (Cao et al., 2023; Kshetri, 2023). By 2026, it is predicted that 25% of people will spend at least one hour per day in the metaverse, both for business and leisure activities (Gartner Inc., 2022). Given this disruptive potential, organizations draw their attention to the metaverse to stay competitive and to evaluate new ways of creating value, conducting businesses, and improving processes and tasks (Dincelli & Yayla, 2022; Dwivedi et al., 2022; Jacquemin et al., 2023).

The metaverse, as an upcoming new digital ecosystem, integrates various emerging technologies like blockchain, non-fungible tokens (NFTs), cryptocurrencies, or immersive technologies like AR (Augmented Reality) and VR (Virtual Reality) (Dincelli & Yayla, 2022; Dolata & Schwabe, 2023; Jacquemin et al., 2023). Especially the latter enables new ways of interaction and new forms of experiences due to a high level of immersion (Dwivedi et al., 2022; Marabelli & Newell, 2023), which refers to how deeply the user is engaged with the digital environment (Schuemie et al., 2001). Even though VR and AR have existed and been researched for several years, the metaverse has brought renewed attention to these and further pushed the development of AR and VR devices (Dwivedi et al., 2022). Numerous studies show the positive impact of VR and AR, especially in increasing learning and working efficiency (e.g., Bednar & Welch, 2020; Lee, 2012; Zhang et al., 2017). While they support users in their activities through perceptual and cognitive advantages, such as the display of information that is not available in the real world, there is also the indication that this is at the expense of mental workload and not generally superior (e.g., Neguţ et al., 2016; Xi et al.,

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2023). But there are also signs that experiences with immersive technologies can decrease learning outcomes (e.g., Ahn et al., 2022). Especially in the metaverse, where social presence and real-time interaction with other users is an essential characteristic (Ball, 2022; Davis et al., 2009; Rosenberg, 2022), mental workload can be amplified, which can have a negative impact on employees and organizations that use training scenarios in the industrial metaverse.

Against this background of the evolving concept of the metaverse with conflicting predictions regarding the impact of the metaverse (based on AR/VR technology) on learning and working efficiency, more nuanced research is needed. Therefore, our study investigates how the level of immersion influences the mental workload during activities in the metaverse compared to the real world and the computer, exemplary in the context of the training of machine part assembly for the industrial metaverse. Therefore, we examine the following research question: *"How does the level of immersion in different environments influence the performance and mental workload?"*

We conducted a laboratory experiment with 30 participants. In a randomized sequence of environments with different levels of immersion (real world, computer, and metaverse), participants were asked to explore a LEGO model and assemble it in the real world. With this approach, we investigate the effects of the different immersion levels on mental workload within the training context. Our results show that there is no significant difference in mental workload. Thus, this indicates that the metaverse is an appropriate, cost-effective alternative learning environment for complex activities in the real world.

2. Theoretical background

2.1 Mental workload

The research on mental workload has been of interest for several decades and across disciplines like cognitive psychology, education, or information system (IS) research, where, for example, the mental workload for machine learning-based decision support systems in aviation (Ellenrieder et al., 2024) or in social media (Dang et al., 2020) is examined. Especially from the view of cognitive ergonomics, it is essential for work success as well as well-being to find a balance and the right level of mental workload that both underload and overload are prevented and, at the same time, a certain performance level is maintained (Cegarra & Chevalier, 2008). Technologies can have an effect in both directions: While they can facilitate, improve, or make the performance of tasks more efficient to support the user, they can also lead to an increase in mental workload, as the user has to invest additional cognitive or physical resources in interacting with the technology or in processing and utilizing its information (Gregor & Benbasat, 1999). Individuals cannot permanently fulfill their tasks quickly, accurately, and reliably due to their limited physical and mental capabilities, only at a very high and unacceptable level of human costs such as stress, illness, fatigue, or accidents. Therefore, the concept of mental workload is of particular interest in IS research, due to the technological advancements and upcoming systems since designers, managers, manufacturers, operators, and researchers need answers to the workload for users caused by technologies and systems being used (Hart, 2006; Xi et al., 2023).

The construct of mental workload is extensive, so there is no single, generally accepted definition and a debate about how it should be approached (Cegarra & Chevalier, 2008; Hart, 2006; Xi et al., 2023). In principle, the term mental workload describes that cognitive processes are required to complete a task, which inevitably results in effort (e.g., physical, mental, or emotional) that is finite and drawn from a limited pool of cognitive resources (Cegarra & Chevalier, 2008; Hart, 2006; Xi et al., 2023). Therefore, the mental workload is defined as the cost an individual incurs while achieving a certain level of performance on a task (Dang et al., 2020; Hart & Staveland, 1988; Sweller et al., 1998), thus specified "as the ratio between the demands of the task and the human resources available" (Cegarra & Chevalier, 2008, p. 988).

2.2 Metaverse and immersion

As the metaverse concept has constantly evolved over the past decades, there is no consensus about a clear and general definition (Dolata & Schwabe, 2023; Olt et al., 2024). The metaverse is assumed to be the next generation of the internet, based on digital environments and experienced through immersive technologies like AR or VR (Dwivedi et al., 2022), where AR refers to the integration of virtual content into the real world and VR describing fully virtual environments and objects (Dwivedi et al., 2022; Jacquemin et al., 2023).

As a new digital ecosystem that is based on the interplay of different emerging technologies, the metaverse is expected to change the way people work, communicate, socialize, and entertain (Dincelli & Yayla, 2022), mainly due to the fundamental transition of interaction from the traditional ecosystem of flat media to an ecosystem grounded in immersive technologies (Rosenberg, 2022). As a persistent, massively scaled, and immersive simulated world or an interoperable network of worlds, many users can share experiences synchronously and in real-time, allied with a sense of mutual presence (Ball, 2022; Rosenberg, 2022). With highly immersive technologies like VR, users can experience a completely virtual metaverse in virtual environments and are usually represented as fully controllable avatars (Jacquemin et al., 2023; Rosenberg, 2022). With AR, users can experience an augmented metaverse, where the real world is extended by virtual content (Jacquemin et al., 2023; Rosenberg, 2022).

This integration of different technologies offers new experiences and forms of interaction for users as well as new opportunities for organizations to interact with customers, develop new business models, and how processes and workflows are carried out within an organization (Dincelli & Yayla, 2022; Dwivedi et al., 2022; Jacquemin et al., 2023). Particularly in the organizational context, the shift of meetings from tools like Zoom or MS Teams into the metaverse (e.g., Olt et al., 2024) or the opportunities for immersive education and training scenarios (e.g., Siyaev & Jo, 2021) have gained attention (Dwivedi et al., 2022; Kshetri, 2023). This promising area is often referred to as the industrial metaverse where—in contrast to the consumer metaverse for entertainment, experiences, social activities, or gaming (Dwivedi et al., 2022)—mirroring of, e.g., real machines, factories, processes, or supply chains and virtual maintenance and training is in focus (Kshetri, 2023). Training and education for machines and processes are of great interest, especially as immersive technologies can increase learning success (Kshetri, 2023). Through immersive experiences with AR or VR, workflows can be trained in detail and realistically. It is no longer necessary to train, for example, maintenance steps on a real machine but on a detailed digital object in augmented or virtual reality, where digital machines can be connected to real machines. This includes numerous advantages such as cost-saving mechanisms, minimizing issues or risks, and shortening process or delivery times (Kshetri, 2023; Siyaev & Jo, 2021; Xi et al., 2023).

While there is a consensus in academia and practice that immersive technologies like AR or VR play a crucial role in a flourishing metaverse (e.g., Dincelli & Yayla, 2022; Dolata & Schwabe, 2023; Jacquemin et al., 2023), some consider mainly VR to be essential (e.g., Marabelli & Newell, 2023) while others expect the metaverse, both with VR and AR, named the virtual metaverse and the augmented metaverse (e.g., Jacquemin et al., 2023; Rosenberg, 2022).

The phenomenon of *immersion* plays a central role in the experience and learning of content (Choi et al., 2022), especially in the metaverse (Dwivedi et al., 2022). Immersion refers to how deeply the user is engaged with the virtual environment (Schuemie et al., 2001) with a feeling of being disassociated from the awareness of the real world (Agrawal et al., 2020; Choi et al., 2022). Immersion is conceptualized in two different ways: User-focused immersion “reflects a psychological immersion state when a user interacts with the mediated environment” (Choi et al., 2022, p. 1760) and is also a matter of content (Schultze, 2010). It is based on the individual feelings and interactions with the mediated environment (Daassi & Debbabi, 2021). System-focused immersion describes the ability of a technology to provide an immersive environment (Schultze, 2010) and describes therefore the quality of a technology to provide an immersive environment to interact with (Daassi & Debbabi, 2021). These two perspectives are complementary and build on each other where user-focused immersion follows system-focused immersion (Daassi & Debbabi, 2021). Immersion can be influenced by various factors, which is why Slater & Wilbur (1997) propose five environment-related features (surrounding, inclusive, vivid, extensive, and matching) for the objective measurement of immersion. Devices can enable different degrees, which is why there are several levels of immersion ranging from low (e.g., computer screen) to high (e.g., VR headset) (Miller & Bugnariu, 2016). As this study examines different technologies that enable different levels of immersion, we adopt the system-focused immersion approach.

2.3 Mental workload in the metaverse

Immersive technologies like AR and VR form a fundamental pillar of the metaverse (Dincelli & Yayla, 2022; Dolata & Schwabe, 2023; Jacquemin et al., 2023). These technologies can facilitate the execution of tasks by being immersed in the respective environment and providing perceptual and cognitive cues to support cognitive processing, mental elaboration, and imagery (e.g., Fan et al., 2020; Heller et al., 2019; Xi et al., 2023) by, for example, overlaying the names of machine parts during maintenance (Siyaev & Jo, 2021). Despite these facilitations, these advantages appear to come at the expense of additional mental workload (Xi et al., 2023).

Both AR and VR generate mental workload that is not required when performing tasks purely in reality. For VR, it can be assumed that the workload is only marginally to slightly higher, as users only have to mentally process the virtual reality, similar to the perception of only the real world (Xi et al., 2023). Since users are completely engaged with the virtual environment through high immersion (Schuemie et al., 2001), the VR world appears naturally as the only environment, requiring less mental effort (Xi et al., 2023). In contrast, AR—which is the focus of this paper—can lead to more mental effort and cognitive work (e.g., Dunleavy et al., 2009) since the user has to process both the reality and augmented virtual objects (Xi et al., 2023). Focusing on the task with little distraction and little mental workload is essential, especially for important and critical tasks such as machine maintenance (Siyaev & Jo, 2021) or training operations in the medical field (Barré et al., 2019). In the metaverse, where social presence and real-time interaction with other users are essential characteristics (Ball, 2022; Davis et al., 2009; Rosenberg, 2022), the mental workload can be amplified.

3. Methodology

To evaluate the impact of the immersion level within the training environment on mental workload, we conducted a within-subject design lab experiment in our metaverse laboratory as a state-of-the-art research facility focused on the exploration of immersive digital environments and technologies where participants had to train a LEGO model in each of the three training environments (real world, computer, metaverse), followed by a real-world assembly of this LEGO model. The three environments embody the different levels of immersion, with computer as low level, augmented metaverse as medium immersion, and real world as the reality. We are focusing on AR as this is widely applied for training and educational purposes within the context of industrial metaverse. To achieve a comparable and consistent level of difficulty for the LEGO models across all immersion levels, we chose models with a similar level of difficulty from the LEGO website (LEGO, 2018). As a final set of models, we selected a cactus, a castle, and an aircraft from the LEGO collection as models for our experiment (see Figure 1).

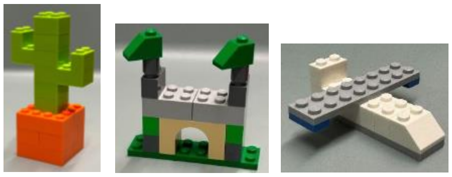

Figure 1. Real-world models of cactus, castle, and aircraft.

The environment was first prepared for all three settings (real world, metaverse, and computer). In the real world, the LEGO model was assembled once and served as a template. Participants were allowed to pick up the model, turn it, and disassemble it. The CADDY app (Meta, 2024) was used as a representative prototype for the metaverse. This app was developed specifically for the Meta Quest 3 glasses, which were used for this experiment. The app allows the import of custom models and offers functions that can be activated using specific hand gestures. The model can be rotated, zoomed, and disassembled in the virtual environment, and individual parts can be picked up. In addition to differ from pure VR research and applications, CADDY allows the typical characteristics of the metaverse: Social presence, immersion, connectivity, and real-time interaction (Ball, 2022; Davis et al., 2009; Jacquemin et al., 2023; Olt et al., 2024), in that several people can collaboratively work on the model at the same time. We created a Computer Aided Design model (CAD) for every model using LeoCAD, which we imported into CADDY for the training in the metaverse and used at the same time for the training on the computer. LeoCAD also has similar functions to CADDY, such as rotating the model, zooming, selecting, and moving individual bricks. This ensures the consistency of interaction options across the different environments. Figure 2 shows the cactus exemplary in the three environments.

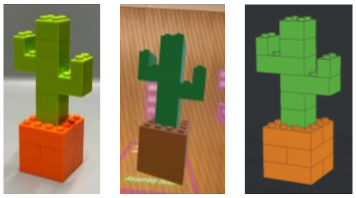

Figure 2. Cactus model in A: the real world, B: the metaverse, and C: the computer.

3.1. Structure, measurements, and variables

Our lab experiment was structured as follows (see Figure 3): First, participants agreed to a privacy policy. Afterward, every participant started with a practice session. Here, each participant was presented with the same model (elephant) within all three environments and was required to try out all the functions once in the real world, in the metaverse, and on the computer, where the study instructor and participants explored the model together. The experiment began with three consecutive rounds of learning a LEGO model, where a model was randomly assigned to an environment. After the learning phase, the participants were asked to move to the real model to the side (when training in the real world), take off their VR headsets (when training in the metaverse), or turn away the computer (when training on the computer). Now, the participants had to assemble the model in the real world, similar to assembling machine parts in a company. Each round concluded with a questionnaire on mental workload using the NASA-TLX with the dimensions recommended for IS research: mental demand, temporal demand, performance, effort, and frustration (Chen et al., 2009; Ellenrieder et al., 2024). All questions were answered on a 7-point Likert scale, listed in Table A in the appendix. The experiment concluded with questions on demographic data (the age and gender of the participants, their experience with the metaverse (adapted from Flynn & Goldsmith, 1999), and their attitude toward it (adapted from Schepman & Rodway, 2020).

A measurement that covers the complex concept of mental workload with all its multidimensional facets is the NASA Task Load Index (TLX) (Hart & Staveland, 1988). It is a well-known and widely applied measurement across scientific disciplines and established in IS research (Ellenrieder et al., 2024; Xi et al., 2023). The multidimensional rating scale is a subjective tool for measuring the subjective perceived workload, more precisely, the cost for the user to perform a task at a specific level of performance. It consists of six dimensions, namely mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). While within the original NASA-TLX users can rate the dimensions from 0 to 100, current (IS) research adopted a 7-point Likert scale and recommends excluding the physical demand (Chen et al., 2009). We followed these recommendations for our research. In addition, the time a person required to learn the model in interaction with the study leader and rebuild it was measured during the experiment. The number of errors and times a person had to rebuild the real LEGO model were also recorded. In case of errors and rebuilding, we added penalty points (10 seconds each) to the total time to calculate an overall objective performance measure. While the NASA TLX measures subjective performance (Hart & Staveland, 1988), the combination of subjective and objective performance offers complementary perspectives, whereby the objective measurement eliminates the possibly biased perception of the participants.

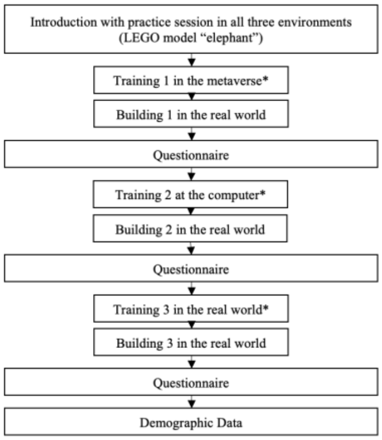

Figure 3. Experiment structure (* indicates the order of environments was randomly assigned).

3.2. Hypotheses

Following the literature, we propose the following hypotheses: Research on AR/VR comes to different conclusions about performance and error rates (e.g., Daling et al., 2023; Kaplan et al., 2021). However, the constant development of AR/VR devices enables a continuous improvement in user-friendliness and human-machine interaction. Thus, we hypothesize **H1**: A higher level of immersion has a positive effect on training outcomes (and thus on assembling performance). While the literature on mental workload shows a higher workload for immersive technologies like AR/VR (e.g., Dunleavy et al., 2009; Xi et al., 2023), the improvement of technologies, especially current rapid developments in the field of AR/VR devices, also can help to reduce the mental workload through technical improvements over time. Thus, we hypothesize **H2**: A higher level of immersion has no effect on mental workload for training. This hypothesis will be supported by the NASA-TLX as described in the methodology. Thus, our second hypothesis is divided in **H2a**: A higher level of immersion has no effect on the mental aspect of mental workload for training; **H2b**: A higher level of immersion has no effect on the temporal aspect of mental workload for training; **H2c**: A higher level of immersion has no effect on the performance aspect of mental workload for training; **H2d**: A higher level of immersion has no effect on the effort aspect of mental workload for training; and **H2e**: A higher level of immersion has no effect on the frustration aspect of mental workload for training.

3.3. Pretest and data collection

First, a pretest was performed for the selected LEGO models. Three people tested all three models once in each world. The assembly time was similar, allowing the models to be classified as equally complex (1:06, 0:56, and 1:01 minutes, respectively). In addition, a pretest for the questionnaire was conducted with three metaverse experts (two to six years of experience within their profession). Only the wording and some clarifying aspects of the questions were adjusted here. Subsequently, 30 participants were invited to our metaverse lab. The only requirement was that they already had experience with VR-/AR-headsets to avoid participant dropouts due to motion sickness or participants being too enthusiastic about the new environment and thus distorting the results. As a result, there was no need to eliminate participants retrospectively, so all 30 samples were used. The experiment lasted, on average, 40 minutes. The average age of the participants was 32, and slightly more men than women participated (see Table 1). Additionally, the participants were asked about their experience (*M* = 4.35, *SD* = 1.73) and attitude toward the metaverse (*M* = 5.32, *SD* = 1.09) on a 7-point Likert scale.

Table 1. Demographic data of participants.

Demography	**Categories**	**N**	**%**
Age	18-24	8	26.67
	25-34	15	50.00
	35-44	4	13.33
	<45	3	10.00
Gender	Female	12	40.00
	Male	18	60.00

4. Results

To answer our research question of whether the level of immersion in the training environment has an influence on mental workload, the reliability and validity assessments were calculated using SPSS and are presented below, followed by a repeated measures ANOVA ($p < .05$) to test for differences in performance and mental workload between our three environments.

4.1. Reliability and validity

Table 2 shows the values for Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE) to measure internal consistency for our measures of mental workload (Fornell & Larcker, 1981). For this purpose, the constructs were considered individually, and the mean value across all five constructs was calculated. For Cronbach's alpha, CR, and AVE, all constructs are above the thresholds of 0.7, 0.7, and 0.5, respectively. Thus, we can assume internal consistency (Hair Jr. et al., 2006). Furthermore, we assessed the overall mental workload by calculating the mean of all items. Here, Cronbach's alpha is 0.839, also above the threshold. Furthermore, all factor loadings for each variable are higher than those on all other constructs. Therefore, we can assume convergent and discriminant validity. Table 3 shows the square root of AVEs being greater than all inter-construct correlations, confirming the latter (Fornell & Larcker, 1981). The correlations are all significant and positive except between temporal and performance.

Table 2. Factor loadings, Cronbach's Alpha, CR, and AVE for mental workload.

Construct	Factor loadings	Cronbach's Alpha	CR	AVE
Mental	0.780-0.888	0.883	0.891	0.700
Temporal	1.000	1.000	1.000	1.000
Performance	0.797-0.893	0.910	0.896	0.743
Effort	0.854-0.854	0.928	0.826	0.758
Frustration	0.694-0.879	0.856	0.810	0.628

Table 3. Correlation matrix (bold numbers are the square root of AVEs; significant correlations ($p < .05$) are marked with *).

Construct	1	2	3	4	5
1. Mental	**0.837**				
2. Temporal	0.590*	**1.000**			
3. Performance	0.356*	0.205	**0.862**		
4. Effort	0.709*	0.531*	0.411*	**0.871**	
5. Frustration	0.650*	0.623*	0.459*	0.691*	**0.793**

4.2. ANOVA

To examine the influence of the level of immersion on the mental workload and performance, we performed a repeated measures ANOVA ($p < .05$). As our sample size is 30, we can assume a normal distribution for our data set (Stone, 2010). Levene's Test for homogeneity of variances showed that equal variances could not be assumed ($p < .05$). Thus, we performed a robust Welch-ANOVA and Games-Howell post-hoc tests.

Table 4 shows the results of the Welch-ANOVA, which shows that the mental workload does not significantly differ for all training environments ($p = .306$). This also extends to all components of the mental workload (mental $p = .435$, temporal $p = .146$, subjective performance $p = .446$, effort $p = .463$, and frustration p = .099). Also, Games-Howell post-hoc tests (see Table 5) confirm these findings, as no significant differences can be found between the three groups. However, for the performance measurement (time needed plus penalty time for mistakes and rebuilding), Table 4 shows a significant difference ($p = .003$). Games-Howell post-hoc tests further clarify that there is no difference between metaverse and computer regarding performance ($p = .064$) and no difference between computer and real world ($p = .472$). However, there is a significant difference between the metaverse and the real world, where the metaverse takes significantly longer (difference of mean: 0:01:11 [0:00:13, 0:02:09]; $p = .012$). Looking more into the detail, the main difference is in the time needed to train the model in the metaverse (Post hoc test: training time: $p = .005$, building time: $p = .218$, mistakes: $p = .981$, rebuild: $p = .844$).

Table 4. Results of Welch-ANOVA for mental workload and performance of the different training environments (* 7-point Likert scale; **time with penalty for mistakes and rebuilding).

Training Environment	Mental workload*	Objective performance**
Computer	mental: 3.700 temporal: 3.330 performance: 2.283 Effort: 2.783 Frustration: 3.100 Overall: 2.910	0:01:43
Metaverse	mental: 3.267	0:02:38

	temporal: 2.630 performance: 2.183 Effort: 2.350 Frustration: 2.542 Overall: 2.545	
Real World	mental: 3.327 temporal: 3.100 performance: 1.883 Effort: 2.467 Frustration: 2.733 Overall: 2.599	0:01:26
Welch-ANOVA	mental: F(2, 87) = 0.841, p = .435, η^2 = .019 temporal: F(2, 87) = 1.970, p = .146, η^2 = .043 performance: F(2, 87) = 0.816, p = .446, η^2 =.018 Effort: F(2, 87) = 0.777, p = .463, η^2 = .018 Frustration: F(2, 87) = 2.372, p = .099, η^2 = .052 Overall: F(2, 87) = 1.199, p = .306, η^2 = .027	F(2, 87) = 6.393, p = .003, η^2 = .128

Table 5. Results of Games-Howell post-hoc analysis.

Hypothesis	Training Environment	Games-Howell p	Mean Difference; Std;95%CI[lower, upper limit]
Mental Workload - Mental	Metaverse vs. Computer	.465	-0.433; 0.365; [-1.310, 0.444]
	Metaverse vs. Real World	.985	-0.060; 0.358; [-0.921, 0.801]
	Computer vs. Real World	.563	0.373; 0.363; [-0.501, 1.247]
Mental Workload - Temporal	Metaverse vs. Computer	.092	-0.700; 0.328; [-1.490, 0.090]
	Metaverse vs. Real World	.406	-0.467; 0.361; [-1.340, 0.410]
	Computer vs. Real World	.818	0.233, 0.386; [-0.690, 1.160]
Mental Workload - Performance	Metaverse vs. Computer	.959	-0.100; 0.262 [-0.972, 0.772]
	Metaverse vs. Real World	.610	0.300 0.315 [-0.461, 1.061]
	Computer vs. Real World	.377	0.400, 0.297; [-0.318, 1-118]
Mental Workload - Effort	Metaverse vs. Computer	.416	-0.433; 0.341; [-1.253, 0.386]
	Metaverse vs. Real World	.946	-0.117; 0.267; [-0.999, 0.766]
	Computer vs. Real World	.672	0.317; 0.371; [-0.576, 1.210]
Mental Workload - Frustration	Metaverse vs. Computer	.079	-0.558; 0.253; [-1.167, 0.051]
	Metaverse vs. Real World	.743	-0.192; 0.260; [-0.818, 0.434]
	Computer vs. Real World	.364	0.367; 0.268; [-0.278, 1.011]
Overall Mental Workload	Metaverse vs. Computer	.328	-0.365; 0.254; [-0.972, 0.242]
	Metaverse vs. Real World	.976	-0.054; 0.254; [-0.660, 0.553]
	Computer vs. Real World	.443	0.311, 0.254; [-0.294, 0.918]
Objective Performance	Metaverse vs. Computer	.064	0:00:55; 0:00:23; [-0:00:02, 0:01:53]
	Metaverse vs. Real World	.012*	0:01:11; 0:00:23; [0:00:13, 0:02:09
	Computer vs. Real World	.472	0:00:16; 0:00:13; [-0:00:16, 0:00:48]

5. Discussion

The metaverse offers new and exciting possibilities for experiences both in private and professional life (Dwivedi et al., 2022). It will impact how people work, socialize, and interact (Dincelli & Yayla, 2022). Thus, utilizing the metaverse in the context of work, for example, in training, meetings, or collaborations, is promising (Dwivedi et al., 2022; Olt et al., 2024; Siyaev & Jo, 2021). Especially the industrial metaverse offers use cases regarding machine assembly and maintenance as a cost-effective and suitable solution for training and education (Kshetri, 2023; Xi et al., 2023). Thus, the metaverse offers additional opportunities compared to the real world and computer but still has differences regarding the level of immersion of these environments. Therefore, we examined the impact of the level of immersion on performance as well as mental workload, two factors that affect the overall adoption of new technologies (Xi et al., 2023).

To answer our research question of whether the level of immersion influences objective performance and mental workload, we performed a lab experiment with 30 participants. Each participant had to assemble a LEGO model after training with the study instructor in the three environments (real world, metaverse, and computer). Our results show a significant increase in performance (H1) between real world and metaverse, however not between computer and metaverse. Although participants had experience with VR/AR, they took significantly more time to train the LEGO model.

A reason for this could be—since the experiment offered us to listen and watch the participants—that they were excited to try out all features of the metaverse environment. The measurement of the mental workload showed no significant differences between all three environments (H2). Meaning that the metaverse did not ease the work but did not make it more difficult.

5.1. Theoretical and practical contributions

Our experiment provides several theoretical contributions: First, although the literature suggests a significant difference in the objective performance for different environments, we can only confirm a difference between the metaverse and the real world and not between the metaverse and computer. In addition, the difference was in the time needed for training, where the participants stated that they were just amazed by the features offered by the metaverse prototype. Thus, when the metaverse is more established, we predict the difference to become less and the metaverse a valid alternative for training, especially in dangerous situations, with expensive machines or which cannot easily or cost-efficiently be repeated. Second, in line with research on the mental workload, we cannot find a significant difference between our three level of immersion environments. This holds true if we examine the distinct measurements of mental workload, namely the dimensions mental, temporal, performance, effort, and frustration. Thus, regarding the mental workload, the metaverse is a valid alternative already as it does not wear the user. Finally, compared to other similar studies (e.g., Daling et al., 2023; Xi et al., 2023), we not only compared two different environments but three—the real world, the metaverse, and the computer. Thus, we provide a more holistic approach to this topic by evaluating the differences more comprehensively.

We also offer practical contributions. With our findings that the metaverse offers a valid alternative to other training environments by offering a similar performance and not influencing the mental workload, we recommend organizations to try and use the metaverse (currently prototypes) in their daily work especially as alternative for high-risk or expensive trainings on machines. Nevertheless, the benefits must be weighed against the costs of, e.g., relevant infrastructure. Rather, the metaverse is currently more of an investment in the long term to become familiar with concepts, technologies, and use cases at an early stage, which could pay off in the long term. This can be transferred at least to some extent to other use cases, such as team meetings or collaborative work, as Olt et al. (2024) also indicate. Especially for tasks where 3D replicas of objects are needed, the metaverse offers additional functions and opportunities to explore.

5.2. Limitations and future research

While our study offers valuable insights, it is also subject to some limitations. First, the number of participants is limited as each participant had to join us in the lab and spend a relatively long time for the experiment. In addition, with the LEGO models, we simplified the task, which is typical for lab experiments but does not necessarily represent real use cases in organizations. Thus, we recommend future research to utilize field experiments or case study approaches to examine the effect of the level of immersion more realistically. In addition, future research should examine the reasons behind having no difference in mental load but objective performance. Finally, we are limited to the three training environments chosen for this study. While we used the latest technology for the metaverse environment, we believe that future headsets will be more comfortable to wear, offer even more possibilities, and thus reduce the mental workload. Therefore, future research should keep up with technological developments and use our experiment setup to examine these relationships again. Overall, our experiment provides insights into the influence of the level of immersion on objective performance and mental workload, which can impact future research on the metaverse. While some studies have shown immersive environments to be very promising for training purposes (e.g., Siyaev & Jo, 2021), there are also signs that the experience of presence in virtual environments can decrease learning outcomes (e.g., Ahn et al., 2022). Future research should, therefore, examine these phenomena more closely since research on the impact of Extended Reality and, therefore, AR/VR for metaverse is still in its infancy (Xi et al., 2023).

6. Appendix

Table A. Measured constructs and their respective items following Dang et al. (2020).

Construct	Item
Mental Workload - Mental	A large amount of thinking was required when using the real-world model / the computer / the metaverse to complete the tasks. A large amount of deciding was required when using the real-world model / the computer / the metaverse to complete the tasks. I had to remember a large amount of things to use the real-world model / the computer / the metaverse to complete the tasks. Overall, using the real-world model / the computer / the metaverse to complete the tasks was: easy / demanding. Overall, using the real-world model / the computer / the metaverse to complete the tasks was: simple / complex.

Mental Workload - Temporal	I felt a lot of time pressure when using the real-world model / the computer / the metaverse to complete the tasks. When using the real-world model / the computer / the metaverse to complete the tasks, the pace was: relaxed leisurely / extremely hurried. When using the real-world model / the computer / the metaverse, I had spare time to complete the tasks: very often / almost never.
Mental Workload - Performance	Using the real-world model / the computer / the metaverse, I successfully achieved the task goals. I was successful in accomplishing the goals of the tasks using the real-world model / the computer / the metaverse. I was satisfied with my performance in accomplishing the tasks using the real-world model / the computer / the metaverse. I was pleased with the results of my task performance using the real-world model / the computer / the metaverse.
Mental Workload - Effort	I needed to work very hard to get familiar with the real-world model / the computer / the metaverse to complete the tasks. I needed to work very hard to get satisfactory performance when using the real-world model / the computer / the metaverse to complete the tasks.
Mental Workload - Frustration	When using the real-world model / the computer / the metaverse to complete the tasks, I felt: gratified / discouraged. When using the real-world model / the computer / the metaverse to complete the tasks, I felt: relaxed / irritated. When using the real-world model / the computer / the metaverse to complete the tasks, I felt: content / stressed. When using the real-world model / the computer / the metaverse to complete the tasks, I felt: complacent / annoyed.

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