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VR-Based Workplace Training and Spaces of Learning: A Social Space Study of VR Training for Apprentice Electricians

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Abstract

Context: This study uses a social space approach to investigate Virtual Reality (VR)-based workplace learning in the context of apprenticeship training in the electronics industry in Switzerland. It was one part of a project which developed a prototype VR environment that enables apprentices to practice testing an electrical installation in a virtual garage using VR headsets. The study uses a spatial theory perspective to understand how the apprentices use the VR environment to develop their vocational competence and how spaces of learning are created through this process.

Approach: The study applies a socio-spatial perspective to a triangulation of the results of a qualitative content analysis of structured interviews with 16 apprentices and their 11 trainers and a quantitative analysis of a close-ended apprentice survey questionnaire (N = 16).

Results: When a VR environment is used for workplace learning, spaces of learning are created from the interplay of four spatial dimensions: The regulation and practices of use of the

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VR environment, the locality of use, the educational potential of the VR environment, and a mental representation of the real workplace represented in the VR environment. The VR headset acts as a boundary object in the training relationship. Other important findings of the study are: Automated access to learning opportunities reduces pressure on the teaching-learning relationship; the haptic dimension of work is important for competence development; the VR environment enables personalized learning with unlimited opportunities for practice; the lack of variety in the operational scenario enables apprentices to focus on practicing and perfecting procedures but does not reflect the complexity of the real world.

Conclusion: Our socio-spatial analysis shows that when VR environments are used in workplace training the interplay of physical, mental, and virtual spatial dimensions leads to the emergence of learning spaces. The access to the VR environment, the location where it is used, and the active use of its learning features interact with the mental representations of the depicted environment. Spaces of learning created using a VR environment can complement traditional workplace training by facilitating the development of specific aspects of vocational competence.

Keywords: Workplace Learning, Educational Technology, Communities of Practice, Learning Activities, Learning Process, VET, Vocational Education and Training, Social Space

1 Introduction

Virtual reality (VR) technology is increasingly used in vocational education and training (VET) as an adjunct to traditional locations such as schools and universities (Dobricki et al., 2020; Radianti et al., 2020). It is also being used in workplace training, which opens a new area of study for researchers (see Sec. 2.1). This study analyses the use of a VR learning environment that enables apprentices to run a final inspection of an electrical installation in a virtual garage, an important vocational competence in this field. Competence in this context includes the "knowledge, skills and attitudes" necessary to successfully perform a vocational task (Mulder, 2017, p. 1080).

A VR learning environment can be a useful "tool to support the instructional process" (Geana et al., 2024, p. 395) providing the environment is specifically designed for the purpose of achieving defined educational objectives (Geana et al., 2024). It opens up 'the opportunity for a 'sphere of possibility' (Brooks et al., 2012a, p. 4) and offers opportunities to acquire vocational competence. It is important for researchers to better understand how apprentices make use of these new learning environments and the opportunities they offer. Therefore, this study uses a social space theory approach which provides "an effective means of exploring the relationship between structure and agency" (Brooks et al., 2012a, p. 4). This is a new approach to understanding the active contribution of learners in the use of VR environments in VET. It recognizes that "spaces of learning" (Fuller et al., 2012, p. 261) are social spaces in which learning takes place through the agency of all actors involved in interaction with given framework conditions.

This article examines how these spaces of learning are created when a VR environment is used as part of workplace training. The process of creating spaces of learning is reconstructed using an empirical mixed-methods approach. The study aims to fill gaps in vocational education and workplace learning research and to show how new theoretical approaches can be used to analyze learning processes.

2 Theoretical Framework and Research Review

There are two theoretical approaches used in this study and these are detailed in sections 2.1 and 2.2.

2.1 Immersive VR Learning Settings in Vocational Education and Training

In immersive VR, learners are completely audio visually immersed in a technically generated three-dimensional (3D) world where, shielded by a VR headset, they can look around, move and interact with objects in 360-degree space (Freina & Ott, 2015). The use of and research into immersive VR in education has been increasing in recent years (Kavanagh, 2017; Pellas et al., 2021; Radianti et al., 2020; Wu et al., 2020). It has been shown to have great potential provided that is used in suitable fields and in line with pedagogical models and methods (Mulders et al., 2020; Zinn et al., 2020). It can be used to develop procedural-practical knowledge (Radianti et al., 2020), which can be used to develop skills (Radhakrishnan et al., 2021; Xie et al., 2021) and for vocational workplace training (Babu et al., 2018; Kim et al., 2020; Ravichandran & Mahapatra, 2023).

The effect of immersive VR on learning depends on an authentic experience of the virtual (learning) space. According to the cognitive affective model of immersive learning (CAMIL) this is based on the sense of presence (the feeling of being there) and the sense of agency (the feeling of generating and controlling actions) created by VR technology that have an impact on affective and cognitive factors (e.g., interest, motivation, self-regulation, cognitive load) (Makransky et al., 2021). The psychological affordances of presence and agency are produced by various aspects of the VR experience that govern the design and evaluation of VR environments: *Immersion* - the psychological state in which the individuals perceive themselves as part of a vivid version of reality and interact with it (Slater & Wilbur, 1997; Witmer & Singer, 1998); *flow* - the pleasurable sense of being in control and an altered perception of time (Heutte & Fenouillet, 2010); *usability* - how easy and intuitive it is for the user to interact with and move within the virtual environment (International Organization for Standardization

[ISO] 9241-11:2018 [en]); *emotional impact* - the type and intensity of feelings experienced by the user of the virtual environment (Pekrun et al., 2011); *judgement* - the user's general impression of how pleasant and useful (hedonic and pragmatic) their experience of VR was (Hassenzahl et al., 2003); and *side-effects* such as nausea or headaches (Kennedy et al., 1993).

In the context of workplace training in VET, these aspects of the VR experience determine how motivating and effective a learning experience in a virtual learning environment can be (Berger et al., 2022) and influence how spaces of learning are created in the learning process (Brooks et al., 2012b; Kraus, 2010). To date, however, researchers have not applied social space theory, which is based on the reconstruction of the emergence of social spaces, to investigating how spaces of learning emerge as a specific type of social spaces when VR technology is used in workplace training.

2.2 Theory of Social Space

The theory of social space has its origins in discussions about space and society in human geography (Harvey, 2002; Massey, 2007; Soja, 1971). Here space is understood as being "constructed through social processes" (Brooks et al., 2012a, p. 2), which is conceptualized as a process of "doing space" (Jucker et al., 2018, p. 86). Space is created when individuals interact with other human and non-human actors under certain material, cultural, and social conditions. Research on the emergence of social spaces reconstructs these interaction processes and their preconditions in different places (Schäfer & Everts, 2019). The spatial turn, the adoption of ideas of space by the social sciences, has been espoused by educational researchers (Baustien Siuty, 2019; Brooks et al., 2012b; Gómez-Gonzalvo et al., 2022; Kraus, 2010; Larsen & Beech, 2014; Middleton, 2017; Peters & Kessl, 2009; Weiland & Poling, 2022). To date, researchers have studied space in the real-world contexts of informal learning and in schools and universities. They have also investigated the effects of virtual space on accessibility, communication, and user behavior in higher education (Domingo & Bradley, 2018; Zeichner & Zilka, 2016; Zilka & Zeichner, 2019). The results have demonstrated that the spatial dimension is important for every form of learning and that spaces of learning are created through the agency of all actors involved, especially the learns. However, research on the emergence of social spaces of learning in VET is not yet available, although the learning environment is a key aspect of VET (Billett, 2022) and the spatial structure of learning environments in VET is undergoing profound change with the introduction of VR learning.

One of the few empirical works to apply this approach to the field of education and work is reported in the article *new places of work, new spaces of learning* by Felstead and Jewson (2012). They highlight that "technology opens up a range of possibilities, but the specific ways in which they are used reflect the constraints and opportunities embedded in social relationships" (Felstead & Jewson, 2012, p. 154). This insight led to our decision to focus our analysis on how VR environments are being used in vocational education. Our aim is to investigate how apprentices create spaces of learning when they use and experience the VR environment as part of their training.

2.3 Research Questions

This study is an empirical investigation of the spaces of learning that emerge as a specific type of social spaces when a VR learning environment is used in workplace training. The process is explored in the framework of the following research questions (RQ):

- RQ1: How do the apprentices use the VR environment and what experiences do they have while using it?

- RQ2: How do the apprentices experience the dimension of space while using the VR environment?

- RQ3: What contribution do trainers make to the use of VR in workplace training?

3 Methods

The following chapter describes the field of research and the empirical methodology.

3.1 Field of Research

This study was part of a research project which involved developing and evaluating a VR environment for workplace training (Berger et al., 2022). The primary objectives when developing the VR environment were (1) to ensure the simulation satisfied pedagogical requirements as much as possible given existing technological limitations and (2) to create an appropriate pedagogical framework for the simulation to incorporating concepts such as scaffolding. The VR environment allowed apprentices to learn and practice a complex procedure that is a required skill for qualified electricians (*making final acceptance test measurements*). They were able to run the procedure in a virtual garage environment without any outside help (see fig. 1). In March 2022 fourteen trainers, working in fourteen different companies, were given VR headsets so that a total of 35 apprentices could each use them at least four times before their final exams started in May 2022.[1] Several apprentices could interact with the system independently, each using their own VR headset (Meta Quest 2, no headphones, no auditory shielding). The evaluation of the VR environment showed that it was an effective tool for teaching apprentices how to conduct final acceptance test measurements (Berger et al., 2022).

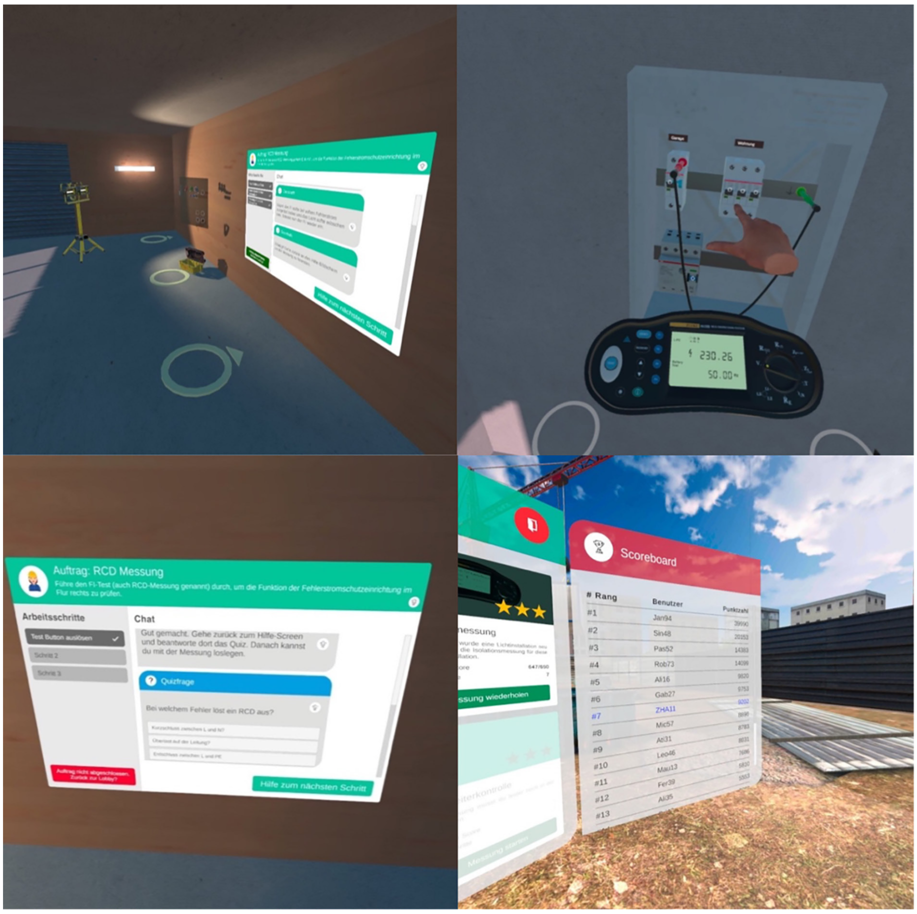

Figure 1: Images Seen by Apprentices in the VR Environment

Note. Top left panel: Apprentices find themselves in a realistic working environment in which they can teleport to different places (shown as circles on the floor). A screen projected on the wall guides them through the measurements and provides visual and aural help. Top right panel: The distribution box, on which some measurements are done, is in an adjacent room. The apprentices practice using the same measuring device that the company uses. Bottom left panel: The apprentices are asked relevant theoretical questions during the process. Bottom right panel: After successfully completing the acceptance test, accessing support, and answering questions, the apprentices are given a score and see how their performance ranks compared to their peers on a leaderboard.

1 The VR application was generally used self-organized and independently by the apprentices at work or at home over the three-month period and lasted an average of M=67.84 minutes, although the time values vary widely (SD= 42.26).

3.2 Empirical Methodology

The study comprised three data modules involving apprentices and trainers and combined qualitative (3.2.1) and quantitative (3.2.2) methods. The data were analyzed using mixed-method and a triangulation of two perspectives (3.2.3).

3.2.1 Qualitative Analysis: Data Collection and Analysis

Guided interviews were conducted with the apprentices (data module 1) and the trainers (data module 3).[2] The interviews with the apprentices were conducted on site with 16 apprentices at two project-related events in spring 2022. Only 16 of the 35 VR-project apprentices (46%) were interviewed because, for operational reasons, all of the apprentices involved in the project could not attend the interview sessions. The interviewees were between 18 and 21 years old. The guiding questions for the apprentices were primarily designed to get them to describe using the VR headset or experiencing the VR environment.[3] The apprentice interviews lasted an average of six minutes and 12 seconds, with the longest interview lasting eight minutes and the shortest four.

The guided interviews with trainers were conducted online in a Zoom or MS Teams environment. Three of the fourteen trainers involved in the project (21%) were unable to take part in the interviews for personal reasons. Interviews were conducted with 11 experienced trainers (average professional experience, 11 years) aged 29 to 55. The trainer interviews were focused on how they incorporated the VR headset into their work with the apprentices. The interviews lasted an average of 28 minutes and 12 seconds, with the shortest interview taking 20 minutes and the longest 35.

A structured content analysis of the interviews was conducted (Kuckartz & Rädiker, 2023). The interviews were transcribed using a transcription guide. A coding scheme was developed using an inductive approach based on the research question framework. We used MAXQDA 2022 (VERBI Software, 2021) for data analysis. Table 1 gives a summary of the codings (see Table 1).

2 Gender biases in career selection in Switzerland meant all participants were male.

3 The interview guides for the interviews in modules 1 and 3 could be requested from the authors.

Table 1: Codings in the Qualitative Content Analysis

Main Category	Total Codings	Trainers	Apprentices
Using the VR environment	58	36	22
Learning in the VR environment	115	77	38
Being in the VR environment	17	10	7
Limitations of the VR environment	53	47	6
Change through the use of VR	7	7	0
Further development of the VR environment	11	11	0
Learning in the real world	8	2	6

3.2.2 Quantitative Analysis: Data Collection and Analysis

The apprentices were asked to complete a questionnaire with 17 close-ended questions about aspects of the VR environment[4] (data module 2). The questionnaire was designed to evaluate the user experience, users' perceptions of and reactions to the VR learning environment and was based on existing questionnaires for evaluating user experiences in general and in games and virtual environments in particular (Carbonell-Carrera et al., 2021; Ijaz et al., 2020; IJsselsteijn et al., 2013; Inchamnan, 2016; Janßen et al., 2016; Tcha-Tokey et al., 2016). The items covered the aspects of the user experience as defined in section 2.1: Immersion, flow, emotional impact, usability, judgement, and side-effects.

The apprentices were asked to answer questions using a four-point Likert scale: 1 - Strongly disagree; 2 - disagree; 3 - agree; 4 - strongly agree. They could choose to complete the questionnaire by clicking on a link sent to them after their final exam in June 2022. Data were analyzed using descriptive statistics (see table 2). There were 35 apprentices in the subsample, 16 of whom completed the questionnaire (response rate of 45%).

Table 2: Results of the Questionnaire for Apprentices

	User experience dimension	*N*	*Min.*	*Max.*	*M*	*SD*
I enjoyed practicing with the VR headset.	Emotions	16	2	4	3.13	.806
I enjoyed practicing with the VR headset.	Emotions	16	1	3	2.13	.806
I was tense when practicing with the VR headset.						
It was important for me to be good at practicing with the VR headset and I made an effort.	Emotions	16	2	4	3.13	.500
I recommend practicing with VR headsets to other apprentices.	Judgement	16	1	4	3.06	.772

4 For example: 'Using the measuring device and the tools in the virtual garage felt natural', 'I felt like I was in a real garage when practicing with the VR headset', and 'I had little difficulty making my way around the virtual garage'. Further information can be requested from the authors.

I would also like to practice other content with a VR headset.	Judgement	16	2	4	3.13	.885
Practicing with the VR headset will help me do better in the exam (LAP).	Judgement	16	2	4	3.06	.574
Practicing with the VR headset had a place in my everyday life at work.	Judgement	16	1	4	2.88	.719
I think practicing with VR headsets is useful for electricians.	Judgement	16	2	4	2.75	.683
I always forgot about the real world when I was using the VR glasses	Presence	16	1	4	2.50	.915
I felt like I was in a real garage when practicing with the VR headset	Presence	16	1	4	2.81	.750
I lost track of time when wearing the headset.	Immersion	16	1	4	2.50	.894
I forgot about time when practicing with the VR headset.	Flow	16	2	4	2.69	.602
It was easy to navigate my way around the virtual garage.	Usability	16	1	4	3.19	.750
I had little difficulty making my way around the virtual garage.	Usability	16	2	4	3.00	.632
The VR headset and hand controls were easy to use.	Usability	16	2	4	3.19	.544
Using the measuring device and the tools in the virtual garage felt realistic.	Presence	16	1	4	2.31	.946
I was able to focus on the measurements while practicing with the VR headset and knew what to do next each time.	Flow	16	2	4	2.87	.500
I felt unwell when practicing with the VR headset (headache. nausea, dizziness)	Experience	16	1	3	2.13	.885
Valid values (Total)		16				

Note. Response scale: 1 – strongly disagree, 2 – disagree, 3 – agree, 4 – strongly agree; Average duration: 3 minutes, 10 seconds.

3.2.3 Triangulation of Data

The three sources of data were triangulated in two steps (see fig. 2). The first step involved integrating the qualitative and quantitative data for apprentices by topic. The topics were inductively derived from the qualitative content analysis data and matched with corresponding statements from the questionnaire. We linked the qualitative descriptions by the apprentices of their experience of the virtual space with items in the questionnaire rather than with the latent constructs to which they belong because the items were detailed enough to corroborate the qualitative statements while the UX dimensions were too broad to capture the specific semantic contexts and detailed nuances in individual user perceptions and interactions. In the second step, the mixed-methods results from the apprentices were compared with the results of the interviews with the trainers as a triangulation of two perspective of one phenomenon (see fig. 2).

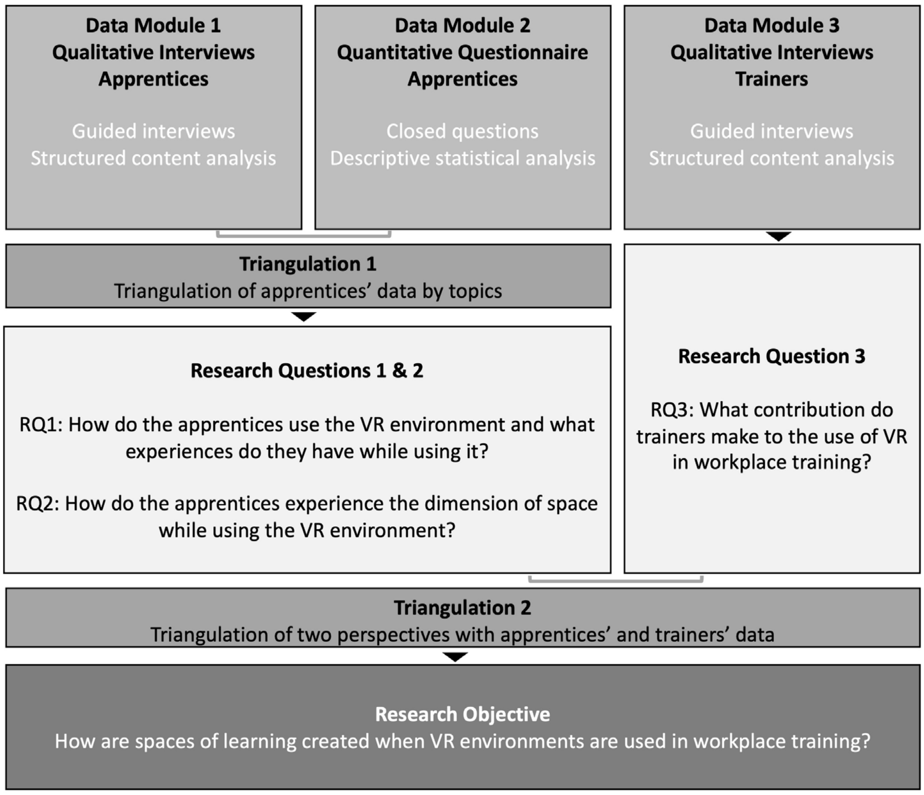

Figure 2: Empirical Structure of Study: Three Data Modules and Two-Step Triangulation

4 Results

The results are presented in the following, firstly combining the research questions RQ1 and RQ2 (results from the apprentices' data) and secondly giving the results from the trainer's perspective.

4.1 Results From the Apprentices' Data (RQ1 and RQ2)

The apprentices were allowed to use the VR headset self-organized and spoke in the interviews about *the external conditions when using it*. They made sure that they were alone when they used it and retreated to their room at home or in a separate room at work:

At work I was able to (.)just (.) set up in the shop myself, really use the space. (I3, pos. 10-12)

Apprentices were aware that they were still present in the physical world and tried to find or create a suitable environment for the exercise. This is corroborated by responses to the flow items "I always forgot the real world" and "I lost track of time" having low agreement ratings (M=2.50 , SD=0.915 and M=2.69, SD=0.894). The presence item "I felt like I was really in the garage" also did not have a high agreement score (M=2.81, SD=0.750).

The apprentices were also asked about *their time in the virtual world*, which they found straightforward after the initial orientation:

First had to get used to how it was, but - once you got it, you made good progress and // INT: Mhm // you could also (.) learn, yes. (I4, pos. 8)

This assessment is supported by agreement responses to the usability items on the questionnaire: Apprentices had little difficulty making their way around the digital world (M=3.19, SD=0.632) and were able to navigate it easily (M=3.00, SD=0.750). Few reported headaches, nausea, or other negative experiences (M=2.13, SD=0.885). The feeling of presence in the real world therefore does not appear to be weakened much, if at all, by being in the virtual world at the same time.

Apprentices felt that *the pedagogical elements of the VR environment* facilitated their learning. They specifically highlighted being able to consult the instructions at any time to check that they were executing the activity correctly. Apprentices who had not yet completed the sequence through to a final acceptance report were often not sure about which step came next and appreciated the fact that they could always get information or help from the VR program. This allowed them to build their competence incrementally:

The (bot) or robot thing, it talks and gives you help to the next step // INT: Mhm // step and I also find that quite good and it explains (.) ä::h relatively well what you have to do. (M8, pos 10)

Overall, the *emotional response to time spent in the VR environment* was favorable. They were comfortable in the virtual space. They enjoyed it (M=3.13, SD=0.806) and were not tense (M=2.13, SD=0.750). Independent learning in the VR environment also resulted in increased self-sufficiency, with apprentices appreciating the ability to manage their time without having to consult a trainer:

It's quite practical (.), if you have to learn in the company, you always have to make arrangements with someone, that can go on for 10 years, //. (M8, pos. 20-22)

It also eliminated stress due to issues such as constraints on practice time. They could learn at their own pace in the VR environment:

> *It makes for a more relaxed atmosphere, so to speak. // INT: Mhm. Mhm // I think that's very good. (I5, pos. 26)*

The fact that mistakes in a VR environment do not have real life consequences was also a viewed positively.

> *Nothing can happen, even if I measure it with a thousand volts, nobody dies, it doesn't break anything. (I5_Transcript, pos. 26)*

The apprentices commented on their *learning experience when using the VR environment*. They highlighted being able to learn sequences for routine activities:

> *The thing I have learned the most (.) is actually the sequence, the correct one. (I4, pos. 24)*

Being able to use the VR environment to review and practice what they had learned was also appreciated. The VR environment enabled them to consolidate skills and become more confident:

> *But it's always good to repeat again, afterwards you can be one hundred percent sure. (M3, pos. 24)*

The apprentices described *differences between the digital environment and a real garage*. They compared the VR environment and their actions in it to their mental representation of a garage from their experience in the real world. They were aware that although the VR garage was realistic, the experience of working in it was not identical to the real world:

> *You actually do it just like on the building site, actually. (I5, pos. 8)*

The "actuallies" here are telling. They were aware of the differences. They highlighted the lack of haptic sensation in when working in VR:

> *Now about measuring, it's just different whether you really have the actual measuring device in your fingers or use the VR tools, // INT: Mhm // because (.) if you have the measuring device, you also have to make the settings yourself /. (I4, pos 20-22)*

This was corroborated by the low (M=2.31, SD=0.946) agreement score for the presence statement, "using the tools felt realistic" in the questionnaire. In the interviews, the apprentices also commented on the difference between having something demonstrated in the workplace and having it explained in the VR environment (M4, pos 14) and noted the lack of constructive feedback in VR (I5_Transcript, pos. 8-10). Finally, they commented that the lack of variety in the activities available in the VR was a problem for competence development:

> *So I noticed with the VR headset, it's just always the same, // INT: Mhm // um: so these tasks don't change // INT: Yes // and in the company it's like this, when I check something on systems or*

something, // INT: Mhm // it always looks different, you always have to look at (.) uh new things, // INT: Mhm // um: you have to pay attention to different each time, uh yes I noticed that, // INT: Yes // that's different. (M2, pos 20)

4.2 Trainers' Perspective of the VR Environment (RQ3)

The interviews revealed that trainers saw moderating *apprentice access* to the VR headsets as their primary function:

Depending on the situation, if they had time, (.) I called them here and then they could (.) practice for an hour (B10, pos 18-20) and similar. (B8, pos 10)

They also decided how much autonomy an apprentice had over how they used the VR; 'good apprentices' were given greater freedom to decide when to use the headsets (B6, pos 12). Usually, they let the apprentices choose whether they used the headset at the construction site, in the workplace, or at home (B4). Sometimes, however, they intervened to regulate this (B5, pos. 22-26) or determined in which room in the company it was best to put the headset so that the apprentices could use them (B8, pos. 16).

The VR program *reduced pressure on the trainers*. The trainers noted the importance of the apprentice having "personal responsibility" (B2, pos. 18-20) and the fact that the program guided the learning process (B1, pos 18). Some were explicit on this point:

They can do it on their own, of course, it trains the apprentices to be independent. (B7, pos. 76-78)

This brought "some relief" (B9, pos 78), as the sessions for learning or practicing skills did not have to be repeatedly set up by the trainers and "no one had to stand around" (B7, pos. 70). This relief was offset by the fact that the trainers could not directly oversee the VR training and therefore *experienced a reduction in their relationship to the learning process* (B10, pos. 84).

The trainers emphasized the *value of the VR environment* as a "support tool" (B2, pos. 36) for workplace training. The VR environment is good for practicing smaller components that can then be used in more complex work processes:

Because then they could practice it themselves // I: Mhm // or in advance, so that they are prepared. (B7, pos. 96)

Or they can learn skills that the training company cannot give them access to (B7, pos. 74). Using the system to learn basic skills and routines was seen as the primary value of VR (B10, pos. 74). VR also gives apprentices the opportunity to "keep practicing important skills in the VR environment so that they don't forget them" (B2, pos. 48). From the trainer perspective, the VR setting allows apprentices to "get experience" (B1, pos. 44) in a setting with tolerance for errors (B4, pos. 10, B3, pos. 34). The trainers also felt that the VR system could be used more to teach declarative knowledge (rather than just routines):

> *Some sort of memory game, about standards or something like that. (B9, pos. 42)*

> *Planning (.) topics could be taught. (B2, pos. 50; also B10, pos 66)*

The trainers noted some *limitations of the VR environment* for the development of vocational competence. For example, knowing how much a screw needs to be tightened is a skill that can only be acquired "by hand" (B7, pos. 70), i.e., through practical, physical activity in a concrete, haptic, interaction with the material and tools. "Yes, every measuring device has its (...) (quirks)" (B1, pos. 70) and you can only learn how to work with them if you hold them in your hands. They also brought up the limited ability of VR to reflect the variability encountered in professional practice. For example, "interpersonal communication skills" (B2, item 48) can only be developed by having contact with customers and professionals must be able to modify learned routines to suit "different situations" (B4, pos. 52).

5 Discussion

This section discusses the findings, focusing on spaces of learning created using VR environments in workplace training (5.1) and on social spaces of learning for vocational competence (5.2).

5.1 Vocational Learning in Spaces of Learning Created Using VR Environments in Workplace Training

The study showed that spaces of learning created through the use of VR technology enable the acquisition of vocational competence despite a low sense of immersion. This supports the principle of "learning first, immersion second" (Mulders et al., 2020, p. 214) and the view that the implementation of VR should be based on an appropriate pedagogical framework, taking into account other important pedagogical factors such as opportunities for interaction, streamlining, and good support. Selecting which work settings are best suited for VR learning, from both a pedagogical and a technological perspective, should also be part of the framework (Zinn et al., 2020). For situated vocational learning supplemented by digital technology, this would be at least as important a consideration as the degree of immersion.

In their mapping review of current research literature Dobricki et al. (2020) stated that, depending on how the learning tasks are constructed, "situated digital VET" has the potential to develop vocational competence (Dobricki et al., 2020, p. 344). Here, our social space approach adds the dimension of social relations to the analysis. The reduced social situatedness of the VR learning process is an advantage because it increases the learners' autonomy and reduces stress for everyone involved (see also Pennazio & Genta, 2020). It is also a disadvantage because although it allows for the practice of standardized protocols, the variability of the real-world social work situation is missing. The digital replica of the workplace can automate an action sequence but it cannot reproduce the social dynamics of learning situated in the workplace (Illeris, 2011; Lave & Wenger, 1991).

In spaces of learning created through the use of VR technology, apprentices can build routines, acquire skills and knowledge, and automatize processes. This finding confirms results in the literature (Kim et al., 2020; Radhakrishnan et al., 2021; Xie et al., 2021). However, when standardized procedures are carried out in the real-world there is always variation because equipment may need to be manipulated in different ways, customers might interfere, or processes may fail to work as intended. In particular, the interactive and haptic aspects of work cannot be reproduced in the VR environment (Böhle, 2013).

These results can be summarized as follows:

- In spaces of learning created through the use of VR technology there is less pressure on the social teaching-learning relationship because the apprentices can act independently in the VR environment.

- Haptics are of great importance for vocational education: Routines can be learned in the VR environment, but this will only translate to limited habitualization of actual work processes.

- The VR environment enables personalized learning because the system enables unlimited repetition and allows apprentices to practice at their own pace.

- The VR application scenario lacks variability, which is good for perfecting procedures or routines but does not accurately reflect the complex interactions apprentices may encounter in future.

5.2 Spaces of Learning for Vocational Competence

Using a social space approach leads to additional insights that expand previous discussions about VR environments in workplace training. Our findings reveal how spaces of learning arise from the many relationships between the VR environment and the haptic-physical world of work and how they are created through a co-constructive interaction between different human and non-human actors. Four socio-spatial dimensions were found by empirically reconstructing the processes of how spaces of learning are created through the use of a VR learning environment in workplace training:

1. *Regulation and practices of use of the VR environment*. This arises from the relationship between the trainers' moderation of when, where, and how the VR environment is used and the autonomy and personal responsibility of apprentices to use the VR independently or with support from the trainers.

2. *Locality*. The external environment at the location where the VR headsets are used.

3. *Educational potential*. The way in which the virtual learning environment can be used and how it encourages and supports users to learn.

4. *Experience-based mental representation*. The image of the real garage, which the apprentices bring with them based on their experience in this workplace.

These spatial dimensions are situationally and co-constitutively produced by the human and non-human actors involved in the creation of a space of vocational learning, with apprentices and their active engagement occupying a key position. Spaces of learning are created through the interrelationship of these spatial dimensions during the learning process.

The VR headset acts as a *boundary object*. Apprentices enter the virtual world by putting on VR headsets in an environment free of distractions. Their time in the virtual world seems unproblematic for them, and they use it independently to explore the educational possibilities of the VR environment "embedded in social relationships" (Felstead & Jewson, 2012, p. 154), especially with their trainers. Trainers control access to the environment by managing the availability of the VR headsets and guiding their use. They tailor access to fit pedagogical goals and regulate the degree of autonomy apprentices have, depending on their ability to self-regulate. They act as "gatekeepers" (Baustien Siuty, 2019, p. 1032) to this virtually extended pedagogical setting. Within the framework of their educational responsibilities, they alternate between reminding apprentices of their personal responsibility and exerting influence to ensure that the learning opportunity is used. The VR headset acts as a boundary object in this interaction (Star, 2010), negotiating responsibility and autonomy. On the surface, the practical possibilities of learning in the VR environment are negotiated between trainers and apprentices using the VR headset as a "boundary object ". But this negotiation also reflects a reconciliation of the relationship between autonomy, personal responsibility and guidance during training.

6 Limitations

There are limitations arising from the study design. The participants, both apprentices and trainers, were all male. This is the result of a gender disparity in the electrical professions. A follow-up study should investigate other occupations and include female apprentices. The data for this study were collected via questionnaires and interviews but it would be important to supplement them with observations from both the location where the VR headsets are used and within the VR environment. The VR learning environment for this project was developed in just seven months, which meant that some of the technical possibilities of VR, such as having a multi-user system, could not be incorporated. Studies should look at how spaces for competence development are created in multi-user VR environments. This VR learning environment was to include scaffolding and gamification, but other pedagogical methods, such as intelligent tutoring, could be added. How much the creation of the spaces of learning contributes to the effectiveness of this VR environment, despite low immersion values, cannot be clarified within the scope of this study and would have to be explored in another study.

7 Conclusions

The results show that spaces of learning created while using a VR environment have advantages and disadvantages for the development of vocational competence. They facilitate the repeated practice and acquisition of declarative knowledge aspects of vocational competence but cannot convey the variability and haptic sensation that are also necessary for the development of vocational competence. The apprentices benefit from a space with increased autonomy and reduced emotional pressure when they use VR headsets, but they are also disadvantaged by having fewer personal interactions that could support their learning. While the trainers are relieved of some pressure when the apprentices are learning in their own space of learning created with VR technology, they also feel excluded from this space. It is therefore not surprising that the VR headset acts as a boundary object in the relationship between the trainer and the apprentices. Negotiating access to this space becomes part of "educational practice" (Gómez-Gonzalvo et al., 2022, p. 1) in workplace training when VR learning environments are used there.

Spaces of learning are created from the multifaceted relationships between the VR environment and the haptic-physical world in concert with the spatial dimensions of regulation and practices of use of the VR environment, locality of use, learning opportunities, and mental representations of the depicted workplace. These spatial dimensions are processed situationally and co-constitutively by all human and non-human actors involved in the creation of a space of education. They reveal the ways in which the "doing space" (Jucker et al., 2018, p. 86) is processed during competence development in workplace training.

Future research on the use of VR in vocational education would benefit from exploring additional topics:

- The results available suggest that it would be worthwhile to further investigate the role of the haptic dimension in the development of vocational competence and the materiality of vocational learning, both in general and specifically as it relates to the use of VR in vocational education.

- The relationship between the different locations involved in a learning process needs to be clarified. How is a virtual learning environment, which is designed according to pedagogical principles but recreates a workplace setting, related to the real workplace? How exactly can it contribute to situated learning, which is crucial for the development of vocational competence? And how is learning in the VR environment related to the location of its use?

- Another area of interest is the autonomy experienced in the VR location as compared to the social control and regulation of learning resources exercised in the workplace. Related to this, it would be interesting to examine the impact of VR multi-user systems that enable social learning.

- It would also be worth further exploring the role VR headsets as boundary objects in workplace training in terms of access regulation and autonomy of use. The power dynamics of interactions between learners and trainers could also be investigated.

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Ethics Statement

This study adhered to all of the research ethics regulations of the three participating universities. The procedures fulfill the requirements of the IJRVET's ethical statement. The requirement for informed consent was also carefully considered and fulfilled.

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