Technology, Knowledge and Learning
https://doi.org/10.1007/s10758-022-09630-w

ORIGINAL RESEARCH

Virtual Reality in Vocational Training: A Study Demonstrating the Potential of a VR-based Vehicle Painting Simulator for Skills Acquisition in Apprenticeship Training

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Accepted: 10 November 2022

Abstract

Previous studies on Virtual Reality (VR)-enriched learning pointed out the advantages of immersive learning for the development of competencies. In the context of vocational education in vehicle painting, training opportunities are severely limited for many reasons. VR can be utilized to develop a comprehensive learning environment with authentic training tasks. Besides the need to train psychomotor skills, vehicle painting procedures are complex tasks requiring incremental training to develop knowledge, skills, and attitudes.

This study aims to evaluate a VR training application for vehicle painting, focusing on the development of professional competencies regarding skills, knowledge, and attitudes.

47 apprentices participated in the evaluation study. A VR-simulated painting booth was developed based on the 4 C/ID model by van Merriënboer, where they dealt with typical painting jobs on 3D workpieces (e.g., car wings, engine hood).

Within the descriptive-inferential study, no significant differences between the types of competencies were revealed. The training application supports the acquisition of skills, knowledge, and attitudes equally. Further results regarding usability, cognitive load, etc., are promising.

The essential finding of this study is that the VR training application is generally suitable for supporting craftsmanship within the field of vehicle painting. Since training opportunities for apprentices in this context are often rare, VR offers a unique solution especially for skills training if it follows a proven instructional model for the development of competencies.

Keywords Virtual Reality · 4C/ID model · Competence development · Skills acquisition · Vocational education · Apprenticeship training

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Published online: 23 November 2022

1 Introduction

Virtual Reality (VR) has been widely adopted in various domains within vocational education (Allcoat & van Mühlenen, 2018; Hamilton et al., 2021; Merchant et al., 2014; Mikropoulos & Natsis, 2011), including surgery (McCloy & Stone, 2001), construction management (Sacks, Perlman, & Barak, 2013), weld training (Stone et al., 2013), and military training (Bhagat et al., 2016), as a way to engage and motivate learners, decrease time to achieve skill mastery, cut down on material usage, and improve performance outcomes. The technology has been applied for training a wide range of real-world tasks and procedures. It is of note that VR technologies seem to be particularly suited for training psychomotor skills and have limited benefits for the acquisition of declarative knowledge (e.g., Jensen & Konradsen, 2018; Makransky & Petersen, 2021; Xie, 2021). Traditional training methods are often not sufficient to support vocational skills acquisition adequately. In general, real-world vocational skills training has the following limitations: (1) it might be expensive due to the cost of preparing real-world training materials and hiring human coaches, (2) it might consume time and effort to set up the real-world training, (3) it might be counterintuitive and unappealing due to the lack of visual aids such as 3D animations, and (4) it might not be possible to train some skills in the real world (e.g., emergency procedures) that can only be safely trained in simulators. Depending on the domain, VR could reduce the costs of vocational skills training while increasing the number of learning opportunities and training cycles. Moreover, as VR learning scenarios mainly involve computer-generated 3D graphics, VR developers can easily create a variety of scenarios from existing 3D assets. These simulated scenarios can be applied for the training of learners with different prerequisites (at the beginning of the training vs. immediately before the final exam). Besides, VR applications allow learning in the comfort of a more personal spaces. This is especially important for cases where an apprentice might feel uncomfortable about their actions in a real-world training environment due to the presence of a trainer. Moreover, VR training provides a safe environment with minimal exposure to dangerous situations and no danger to damage expensive tools and machinery (Conges et al., 2020; Li et al., 2017). Altogether, VR technology has become popular in recent years and its effectiveness for vocational training has been demonstrated (e.g., Xie, 2021). Thus, VR offers a unique solution to address various shortcomings in the development of vocational skills. The technology seems to be predestined to support skills training, whereas the training of knowledge and attitudes may be further addressed by other instructional methods in the real world. However, the impact of VR on various dimensions of learning in the different fields of education needs further research and evaluation (Kim et al., 2020). Generally, apprentices in various vocational settings are often inexperienced, not able to carry out vocational tasks by themselves, and hence, less confident. Here, VR can provide many training opportunities with the possibility to repeat specific aspects several times. Thus, apprentices gain training experience and become more confident before applying skills in real-world scenarios. This means that VR learning environments are not perceived as a substitute for real-world training, but they can prepare apprentices adequately and can be added to real-world training to improve and accelerate mastery efficiently.

Xie (2021) comprehensively reviewed a set of VR skills trainings and distinguished between the following domains: first responder training, medical training, military training, transportation, workforce training, and interpersonal skills training.

Our following study is situated in the context of workforce training and there, in the field of vehicle painting. In this field of vocational education, authentic artifacts for training are often rare. Vehicle painters must operate effectively in a complex environment. Often, however, they have surprisingly limited opportunities to practice procedures before applying them on real workpieces from cars (e.g., Zender et al., 2019). In the field of vehicle painting, various methods and techniques of applying a coat to a workpiece under differing conditions must be trained thoroughly. For example, new part paintings as well as spot repair painting, which means painting over a small, damaged spot on the car, have to be done. However, frequent and repeated training of these skills is hampered by economic (e.g., material costs), physical (e.g., environmentally sensitive materials), and social factors (e.g., limited support capacity).

Skills training in vehicle painting typically relies heavily on memorization and routinization of procedural steps from criterion-based checklists. However, since apprentices often have limited opportunities to practice, they struggle to build routines for these procedures. VR can offer a unique and sophisticated solution to address this training problem.

In a VR simulator, learners are placed in a realistic 3-dimensional environment (here: a paint booth), where they can safely practice without causing any harm, such as producing workpieces, which are not suitable for customers due to mistakes in production, or wasting paint. Additionally, apprentices are highly motivated and engaged in environments that use novel and appealing technologies such as VR (e.g., Mulders 2020).

Vehicle painting seems to be a particularly interesting field for the application of VR. Psychomotor tasks are typically trained in repetition loops to strengthen the routine of skills. Moreover, haptic feedback from 3D workpieces is not required here, as these are not touched during the application. Instead of commercial controllers, a highly authentic spray gun (from 3D printing) can be provided, which facilitates transfer to practice. Additionally, feedback on the quality of the coating, for example, regarding layer thickness, can be provided immediately, whereas in the real world, it takes several hours until coatings are dried and results become visible and assessable.

In the next sections, we provide further details on the theoretical background of VR in vocational training and our methodological approach to analyzing the effects on the acquisition of competencies. Then, we present the results of our study. Finally, we discuss these results regarding the perspectives of VR in vocational education. The article closes with limitations, an outlook for future research, and a conclusion.

2 Background

VR is an emerging technology using computer-generated graphics to produce a realistic 3D environment for multiple sensory experiences (Burdea & Coiffet, 2006) including a tracking system (input) and a display system (output) (Kulpa et al., 2015). The user is fully immersed in a computer-generated world. Their viewpoint changes according to head movements (Slater et al., 2009; Slater & Sanchez-Vives, 2016). There are several elements of VR experiences, distinguished roughly by the degree to which the user's sensory perception is co-opted. HMDs with headphones, wearable haptic clothing, and other equipment that allows the user to walk freely exemplify the most common consumer-grade VR setups. VR is not limited to visual information, as the auditory, haptic, kinesthetic, and olfactory senses can also be technologically simulated.

While recent research has promoted technologically advanced VR learning environments, it has often been questioned if and how VR can be transferred from laboratory settings to everyday learning in schools and other educational environments (Dengel et al., 2021). There is a need to demonstrate and evaluate VR applications for training in real (accredited) curricula and formal education. In addition, many VR applications have been developed without substantial reference to instructional methods or research on learning with digital technology, seemingly reducing the acquisition of competence to a mode of "trial & error" (Mulders et al., 2020).

Therefore, we developed an approach that is situated in vocational education and a training environment based on the three-year apprenticeship curriculum for vehicle painting that is nationally accredited in Germany[1]. The learning application is based on the four-component instructional design (4 C/ID) model, which has been successfully applied and evaluated in various contexts and domains (e.g., Kester & van Merriënboer 2021; van Merriënboer, Jelsma, & Paas, 1992; van Merriënboer, Clark, & de Croock, 2002; van Merriënboer & Kirschner 2017). The 4C/ID model is a framework for developing instruction on complex tasks including skills development. To our knowledge, the 4C/ID model has not been applied to other VR trainings so far. Thus, we seek to develop a meaningful training application aligned to the principles of the 4 C/ID model. Here, competencies are defined as complex cognitive skills, consisting of integrated sets of constituent skills with their underlying knowledge structures and attitudes (van Merriënboer, 1997). A detailed description of how we applied the 4 C/ID models principles to VR and the vocational field of vehicle painting can be found in Mulders (2022) and Zender et al. (2019).

Previous studies on VR-enriched training pointed out its advantages for the acquisition of skills, but vehicle painting procedures are complex tasks requiring the training of whole tasks including all components of competencies (i.e., skills, knowledge, attitudes). Also, practitioners asked for the integration of the various relevant components in the VR application (e.g., knowing how to prepare workpieces, attitudes towards personal protective equipment) to fulfill a customer order successfully, and not only the training of motor skills to apply the coat.

Therefore, we have developed a comprehensive learning application with authentic training tasks for the field of vehicle painting using VR that addresses the integrated acquisition of all components of competencies: skills, knowledge, and attitudes. Still, the question remains if the virtual environment fosters competence acquisition sufficiently. For example, presenting textual information in VR is somehow challenging. In vehicle painting, work plans, technical datasheets, etc., are often text-based and wordy and might be difficult to grasp when presented in the VR environment. Our study aims to evaluate the VR training application with an instructional approach based on the 4C/ID model. We investigated if the VR training application is generally usable and suited to supporting competence acquisition for apprentices in the domain of vehicle painting.

[1] https://www.bibb.de/dienst/berufesuche/de/index_berufesuche.php/profile/apprenticeship/67867684.

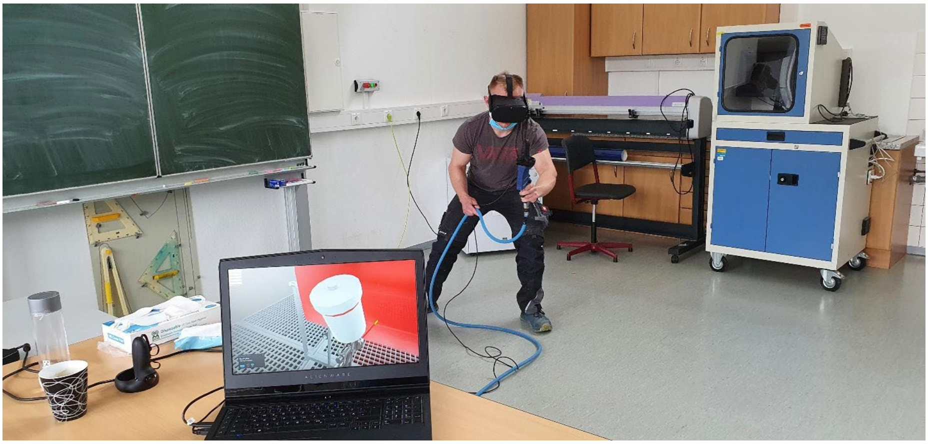

Fig. 1 Apprentice learning with the VR-based painting simulator

3 Methods

The VR system used in this study was developed during a 38-month research project.[2] The project was conducted by representatives from different disciplines, such as computer scientists and instructional designers. Within the project, all training elements were developed from scratch. The 3D environment and its components were programmed with *Unity*.[3] To develop an instructional design, several interviews with practical partners were conducted and curricula were studied. The result of the project is the VR painting simulator, which consists of several task classes (e.g., repair painting) and corresponding learning tasks. Prerequisites of use for the VR painting simulator are a gaming computer and a connected head-mounted display (HMD; here: *HTC Vive*), a pressure tube, as well as one commercial controller onto which a 3D-printed spray gun is mounted (see Fig. 1). Moreover, an additional authoring tool allows teachers to design their tasks and assign these to certain apprentices. At the end of the project, we tested the training tool with apprentices in vehicle painting who should use the tool prospectively to practice skills repeatedly with immediate and consistent feedback. The available VR training includes a suitable variation and progression of learning tasks, which can be adapted by a trainer based on a defined number of parameters (e.g., type of workpiece, number of coatings) and in terms of complexity. With this feature, variations of learning tasks can be designed similarly to different customer orders (e.g., Mulders, 2022).

In the VR training application, apprentices work on various learning tasks, which are all designed as typical customer orders. To do this, the training is situated in a simulated

[2] The *HandLeVR* research project (01.01.19–28.02.22; funding code: 01PV18002B) is funded by the German Federal Ministry of Education and Research with partners from the University of Potsdam (computer science), the University of Duisburg-Essen (instructional design), ZWH e.V. (chamber of industry), and Daimler AG Berlin-Ludwigsfelde (international car manufacturer). A total of 35.6 person-months was necessary for the technical development of the VR training application (tasks such as project coordination, transfer, evaluation, etc., excluded). The software and accompanying materials are available as open source at https://github.com/HandLeVR.

[3] https://unity.com/de.

paint booth that contains a workpiece to be painted as a 3D model (e.g., an engine hood). Before and after the painting process, apprentices are equipped with the requisite knowledge and attitudes. A virtual trainer, instructional videos, as well as multiple choice and sorting tasks provide relevant information. During the painting process, the apprentices' performance regarding several parameters (e.g., paint consumption, distance to the workpiece) is recorded and stored. After each task, the apprentice is informed about their results and achievements. They receive visual feedback, e.g., by illustrating layer thickness on a heatmap on the workpiece. Different colors indicate layer thickness (detailed description in Mulders (2022) and Zender et al., (2019)). The learning environment consists of a progression of learning tasks with different training instructions and supporting information following the principles of the 4C/ID model.

The presented research investigates the overall effectiveness of a VR learning application in the vocational field of vehicle painting. One concern relevant to learning in VR environments is the cognitive load experienced when using VR (Makransky & Petersen, 2021). Makransky, Terkildsen, and Mayer (2019) as well as Huang and colleagues (2020) showed that learning in VR may overload and distract learners, resulting in poorer learning outcomes. Usability was identified as another decisive factor towards learning in VR. Usability refers to the quality and accessibility of the technology in use and is assumed to impact learning processes in VR (Lee et al., 2010; Radianti et al., 2020). Another research interest focuses on learning in VR regarding the competence to be acquired. As Jensen and Konradsen (2018) as well as Makransky and Petersen (2021) mentioned, VR seems to be particularly suited for training psychomotor skills and has limited benefits for knowledge acquisition.

To investigate learning processes within the VR painting simulation in terms of competence acquisition, we conducted an evaluative single-group study with post-tests and behavioral assessments. In the following sections, we outline the methods of our descriptive-inferential study in detail.

3.1 Sample and Context

A total of 47 apprentices in vehicle painting (11 female) participated in the study: 16 from *Daimler AG*, an international car manufacturer, and 31 from other national training institutions. Their age varies between 17 and 37 ($M=20.91$, $SD=3.65$). The study took place as part of their 3-year apprenticeship.

3.2 VR Painting Simulator

Following the 4C/ID model, the VR painting simulator includes a set of learning tasks that differ regarding various parameters (e.g., type of workpiece) as well as in terms of complexity (van Merriénboer & Kirschner, 2017). It intends to help apprentices achieve the overarching goal of vocational action competence. In the VR application, apprentices work on learning tasks. Prototypical learning tasks were developed according to the 4C/ID model of competence development (van Merriënboer et al., 2002). This was done in cooperation with experienced corporate trainers and apprentices in the field of vehicle painting. The tasks have been evaluated and re-developed iteratively through several design cycles. For example, one learning task illustrates a single-layer refinishing on an engine hood. To work

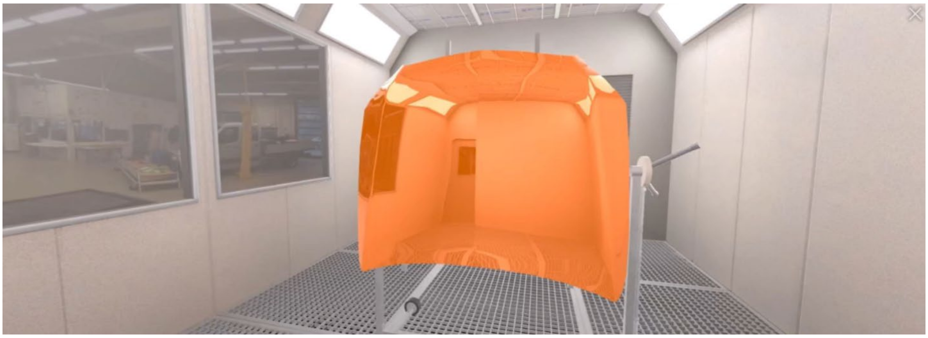

Fig. 2 The paint booth

Fig. 3 The virtual monitor

on a learning task, the apprentices immerse in a paint booth that has been recreated in detail and contains a 3D workpiece clamped on a painting stand (see Fig. 2). Moreover, there is a (virtual) monitor (see Fig. 3) in the 3D environment and a poster to test the spray pattern. In their dominant hand, the apprentice holds a spray gun produced from a 3D printer (see Fig. 3). In the 3D environment, a virtual trainer (presented as an avatar) is permanently present, guiding the apprentice through the task and providing feedback at certain steps (see Fig. 3). In addition to the painting process itself, the environment contains supportive information, mostly for preparatory and follow-up activities, and part-task training following the 4C/ID model (e.g., self-made videos by apprentices about using personal protective equipment). During the painting process, the apprentice is supported by a beam indicating the proper distance to a workpiece (see Fig. 5) and by supportive oral and written feedback from the virtual trainer. The feedback system is adaptive, depending on the learner's performance and level of expertise. For example, for beginners, elaborate explanations regarding

Fig. 4 The 3D printed spray gun

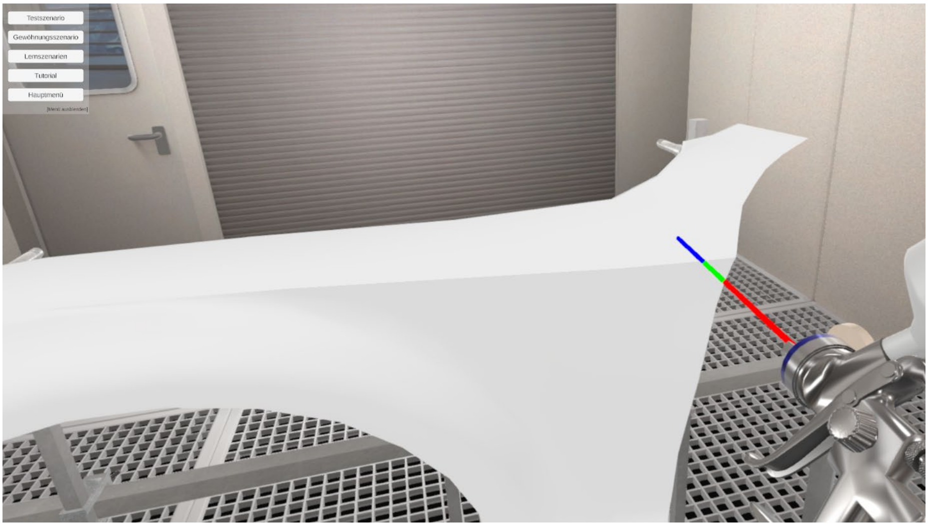

Fig. 5 The beam indicating the proper distance to the workpiece

the distance to the workpiece and its implication on the paint amount are given, whereas experienced learners are prompted with visual stimuli signaling that they are too close or

Table 1 NASA-TLX results

subscale	*M*	*SD*
mental demand	47.17	25.33
physical demand	46.05	28.09
temporal demand	17.50	18.85
effort	35.09	24.98
frustration	25.66	28.00

too far away from the workpiece. During coat application, the performance is recorded and stored along with a variety of parameters (e.g., layer thickness) and can be replayed for reflection and further discussions with a (real) instructor or supervisor. A learning task closes with feedback based on several parameters (e.g., wasted coat) and feedback on the quality of the application (i.e., heatmap).

3.3 Instruments

This descriptive-inferential evaluation study generates data from (1) questionnaires and (2) behavioral tracking. Demographic data, previous experiences with VR technology, and aversive impressions within VR were captured by several closed-ended single- and multiple-choice questions. Moreover, validated as well as self-created questionnaires were used during the evaluation study.

Validated questionnaires: The subjective cognitive load experienced within VR was tested by the NASA-TLX (Hart, 2006; $\alpha_{temporal\ demand}=0.68$ to $\alpha_{frustration}=0.74$). The questionnaire is based on six subscales (see Table 1, e.g., temporal demand) which are rated within a 100-points range (e.g., *How mentally demanding was the task?*). The overall usability of the VR painting application was measured by the User Experience Questionnaire (UEQ; Schrepp 2015; $\alpha_{attractiveness}=0.72$ to $\alpha_{\text{novelty}}=0.77$). Pairs of opposites (e.g., *attractive - unattractive*) were graded on a seven-point Likert scale resulting in six subscales (e.g., novelty).

Self-created questionnaires: Furthermore, apprentices were asked to what extent the learning tasks contributed to the acquisition of competencies, i.e., knowledge, skills, and attitudes, to test if there are differences between the types of competency gains (e.g., *The learning task has helped me know more about new part painting.*). The scale ranges from 1 (*absolutely disagree*) to 5 (*fully agree*). The internal consistency ranges from $\alpha_{knowledge}=0.70$ to $\alpha_{skills}=0.74$. Based on the identical scale, apprentices were asked if the application is satisfying ($\alpha=0.71$) and recommendable ($\alpha=0.77$).

Further data: In addition to data from questionnaires, the VR system itself provided data. Success criteria (e.g., layer thickness, angle) could, thus, flow into the evaluation.

3.4 Procedure

On completion of the second iteration of the system, we tested two prototypical learning tasks of the VR training application. The study took place in several training centers within Germany. For this, researchers and apprentices came together in several one-day workshops. First, apprentices watched a video tutorial explaining how to navigate, and select and apply paint within VR. After the HMD and the spray gun were adjusted, the apprentices spent some minutes without any action to become comfortable with the new situation. Then, they worked on two different tasks both illustrating single-layer coating. The apprentices

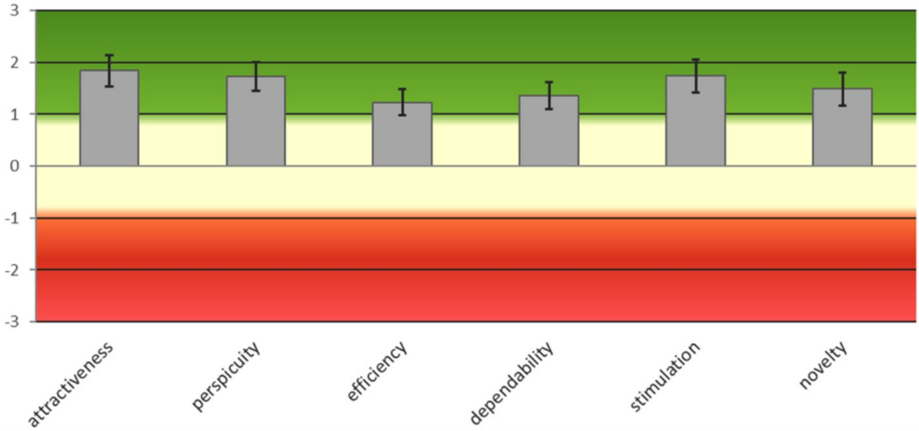

Fig. 6 The beam indicating the proper distance to the workpiece

performed alone and independently without external help (see Fig. 1). The test administrators followed a guideline to keep the test conditions as uniform as possible. They made sure that the maximum duration of headset use did not exceed 30 min (Smith & Burd, 2019). Subsequently, each apprentice filled in questionnaires (approximately 35 min) and took part in a discussion group (approximately 45 to 60 min).

3.5 Data Evaluation

We decided to provide means and standard deviations as well as t-tests to check if there are significant differences between the acquisition of skills, attitudes, and knowledge. We checked normality of the sample for the tested variables by Shapiro-Wilk-Tests ($p > .05$).

4 Results

In this section, we outline the results of our study. For 75% of the apprentices, the first language is German, others named Armenian or Turkish. Half of the participants (49%) reported having previous experience with VR, but in almost all cases extremely rarely. Participants were asked about unpleasant experiences. In a few cases, they reported difficulties with seeing sharply, disorientation, or general discomfort.

To answer our research question whether the VR training application is generally usable and suitable for supporting competence acquisition within the vocational training of vehicle painters, we gained several data.

First, the subjective cognitive load was surveyed by NASA-TLX (Hart, 2006). The apprentices reported an overall workload of $M = 31.09$ ($SD = 25.05$). Further data are provided in Table 1.

Second, apprentices rated the usability of the VR painting application based on the UEQ (Schrepp, 2015). The results are visualized in Fig. 6.

Table 2 Competencies results

subscale	*M*	*SD*
knowledge	3.17	0.79
skills	3.21	0.86
attitudes	3.45	0.86

Third, we gained data from behavioral tracking. These data revealed how difficult it was to maintain the correct distance as well as the correct angle to a workpiece. The correct distance was maintained 49,54%, and the correct angle 45,43% of the time.

Fourth, we questioned to what extent the learning tasks contributed to the acquisition of competencies. From these ratings, it can be concluded that the learning tasks support the acquisition of skills, knowledge, and attitudes satisfactorily (see Table 2). Paired t-tests revealed no significant differences between types of competencies, whether between knowledge and skills ($t(46)=-0.34$, $p=.74$, n.s.), knowledge and attitudes ($t(46)=2.45$, $p=.08$, n.s.), or skills and attitudes ($t(46)=2.20$, $p=.11$, n.s.).

Finally, apprentices were asked to give an overall rating of their experience. The contentment is $M=4.30$ ($SD=0.70$) and the recommendation is $M=4.46$ ($SD=0.75$). Within the discussion groups, training elements such as the beam and the heatmap were identified as major advantages, helping the acquisition of competencies. Moreover, the possibility to make mistakes without causing any damage, for example, producing workpieces, which are not suitable for customers, was rated as highly relieving. The wearing of an HMD sometimes felt uncomfortable, and the visual sharpness should be improved, so that even small mistakes (e.g., slight paint runs) become visible.

5 Discussion

This study aimed to investigate whether the VR painting shop, based on the 4C/ID model, can support vocational training in the field of vehicle painting. The results have implications for research and practice, which we discuss in more detail below. Furthermore, we will discuss study limitations.

5.1 Theoretical and Practical Contributions

The study demonstrates that the 4C/ID model is a suitable instructional model for designing a VR learning application within the vocational training of vehicle painters. This is an important finding, as there is a lack of instructional designs for VR in vocational training (e.g., Mulders et al., 2020).

Other studies (Huang et al., 2020) refer to the risk of overloading users when learning with VR. In our study, apprentices perceived the workload as on a manageable level. The calculated mean scores are comparable to or even lower than in similar application scenarios (Grier, 2015). We conclude that using the 4C/ID model is an effective way to overcome potential cognitive load issues, as revealed in other studies using VR in educational and training contexts (e.g., Makransky et al., 2019). In terms of duration, learning tasks could even last longer than the learning tasks tested in our study (see Table 1).

Also, the usability of the training application was rated highly positively. The behavioral data reveal that maintaining the right angle as well as the proper distance is a large challenge for the apprentices. It was striking that the participants maintained both the correct distance and angle less than 50% of the time. This indicates either that these skills are particularly challenging for apprentices or that the VR system may not be tracking them accurately or may contradict real-world skills. In any case, future studies should examine these low scales more closely. Unfortunately, we have no data from other measuring points to compare with to understand the level of difficulty the system implements. Nevertheless, these results confirm our prior hypothesis that apprentices need additional help to maintain the distance as well as access to a range of varying training tasks.

We hypothesized that VR would provide a way to practice skills and competence development. In the current study, we were not able to find differences regarding the components of competence development: VR seems to support the acquisition of skills, knowledge, and attitudes equally. Skills training, in our case vehicle painting, is often limited in vocational education. There are not enough training opportunities to prepare apprentices for exams or their future daily work. The study results indicate that the VR painting shop can address this educational issue in an appropriate way and could be established as part of the vocational training and, in the long term, also be embedded into the curricula. Therefore, it seems promising to explore the use of the VR painting shop in meaningful large-scale studies. Moreover, it is conceivable that technical solutions developed in this research project can be transferred to further domains of vocational education (e.g., welding).

5.2 Limitations and Future Directions

One study limitation is to that it was difficult to integrate the presentation of basic information and knowledge elements into the VR training application (following the 4C/ID model). Often, text-based information, documents, or time-consuming explanations of the virtual trainer are needed to explain an issue at hand. It might be more helpful to deposit these elements into a desktop application, a mobile app, or simply a paper sheet. Therefore, in further studies, we would recommend considering a design that combines the VR training application with learning materials provided by other means or technologies (e.g., on paper, on-screen). Moreover, with this study as a basis, future studies may investigate the effects of outsourcing some training elements from the 4C/ID model (e.g., explanations of the relationship between temperature and drying times) from the VR application and analyze the blending of these elements. Such an approach may reduce the cognitive load and effort of wearing an HMD and would provide a route for an elaboration of the 4 C/ID model regarding the integration of different types of media.

The apprentices' overall evaluation indicates that the VR painting simulator is experienced as highly supportive. Information obtained from this study will be incorporated into the final iteration of the VR training application in vocational education. The software for the system will be made available as open-source software.[4] It will be possible and it is planned - with our project partners - to build training facilities at various outlets of interplant training centers in several cities in Germany. With the feedback from this study, the next iteration should be tested with larger numbers, at multiple sites, and over an extended period to obtain a broader set of data that allows for more generalization. In this context, we have to admit that our sample is very small and does not allow generalized statements. Therefore, the results should be considered with caution. Next to larger samples, other research

[4] The software and accompanying materials are available as open source at https://github.com/HandLeVR.

objectives include monitoring the use of the system longitudinally to determine apprentices' ongoing willingness to practice in a VR environment or if the novelty of the system wears off. Moreover, future experimental studies should investigate the manipulation of instructional design parameters (e.g., guidance) as well as learning-related processes (e.g., flow, presence, cognitive load). Next to the beam indicating the proper distance between the spray gun and the workpiece, further support tools could be implemented and tested for their effectivity (e.g., arrows showing the right sequences of painting, acoustic signals showing if the angle is wrong). Another limitation should be mentioned: Most of the data rely on self-reports. Furthermore, results may represent apprentices who were excited and highly motivated to practice virtually in the first place. Future studies should investigate more behavioral data. Moreover, they could focus on the direct translation between painting performance in VR and the application in work tasks in real life. Achievements with the VR painting simulator will not guarantee the same results when painting real cars. Additionally, we used a self-created questionnaire consisting of only three items to measure the acquisition of competencies. In future studies, more validated measurements should be used.

In the design of our study, we deliberately considered the inclusion of a control group. However, it is not obvious what condition could or should be used to compare our VR-based training setup. Our implementation is a direct response to the lack of possibilities for practice often encountered in workplace learning environments. Therefore, we would not hesitate to acknowledge that the VR painting simulator will not substitute training in real life with real vehicle pieces. We do address the problem that these training conditions are incredibly scarce (e.g., rare training opportunities, limited support capacity), and even a three-year apprenticeship often does not offer enough training opportunities on the shop floor alone. Similarly, comparing the immersive VR condition with a desktop-based solution with a monitor and a mouse would not provide the necessary environment to develop professional skills: Our VR simulator has to be used standing up, requires the engagement of the full body, and provides an artificially crafted spray gun which is very similar to the real tool. The development of the aspired skill is based on the handling of this tool that needs to be moved in all directions when handling a 3D workpiece, which could not be presented appropriately on a flat screen. Consequently, the VR painting shop provides significantly more opportunities to train the skills needed to apply coating on workpieces. According to the positive evaluation and high scores for usability, apprentices appreciate the VR painting simulator as an otherwise missing possibility to gain these skills.

What would be interesting for further inquiry is a comparison of the instructional model of this environment (4C/ID model) with other instructional principles (like offloading instruction from the VR environment and segmenting the use of VR with other media).

6 Conclusion

The training of vehicle painting relates to a context that has intrinsic limitations: Training opportunities in vocational education are often too limited to support professional skills acquisition adequately. VR offers a unique solution to overcoming these limitations. In our study, all components of competencies (knowledge, skills, attitudes) were promoted equally in the VR environment. Yet it is noteworthy that, in contrast to skills, knowledge and attitudes could also be addressed by other instructional methods and media and, therefore, could be offloaded from the VR setup. Based on cost-benefit considerations, it must be decided which instructional methods and media seem favorable for addressing each of the components.

All in all, the VR training application evaluated in this study was well received by the apprentices and seems a suitable training environment for vocational education. Usability ratings demonstrate high motivation and, in most cases, eagerness to use this tool for vocational practice in the future. Although the current study has some limitations (e.g., small sample, unvalidated questionnaires), it became clear that VR is a promising educational technology in the field of vocational training for skills acquisition. It is important to emphasize that this study was not implemented in the laboratory but within the everyday practice of vehicle painters in a three-year dual education program at a global car manufacturer. The aim was to test the use of the application under typical training conditions with real apprentices. Hence, as long as real-world training scenarios are rare, VR can provide additional practical training scenarios to strengthen especially skill acquisition. The VR painting shop, which is published as open-source software, can be used (1) to conduct further studies contributing to the research field of VR and learning in terms of building VR-specific theories and establishing validated measurements and (2) to support competence acquisition within the educational practice.

Authors' Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Mulders. The first draft of the manuscript was written by Mulders and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL.

Declarations

Statements and Declarations The study is based on the research project *HandLeVR* (www.handlevr.de, see footnote 1). *HandLeVR* was funded by the German Federal Ministry of Education and Research (funding code: 01PV18002B) with partners from the University of Potsdam (computer science), the University of Duisburg-Essen (instructional design), ZWH e.V. (chamber of industry), and Daimler AG Berlin-Ludwigsfelde (international car manufacturer).

Conflicts of interest The authors have no relevant financial or non-financial interests to disclose.

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