AR/VR-TRAININGS IN THE ARSUL-PROJECT: RESULTS FROM A PROTOTYPE EVALUATION

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Abstract

Augmented Reality (AR) and Virtual Reality (VR) can engage multiple senses more intensely than traditional trainings. Furthermore, physical laws can be suspended, extreme situations experienced in a risk-free manner, and learners can be provided contextual information as an overlay to reality. The ARSuL-Project ("Augmented Reality Based Support for Learning in the Heating, Ventilation and Air Conditioning Industry") aims to promote the development and evaluation of AR/VR-based support functions and learning offers for craft enterprises and their employees. First prototypes and demonstrators were evaluated in a comparative setup with apprentices and trained workers. In this paper, exemplary test results of the evaluation are presented, addressing knowledge gain, learning success, and the subjects' experience. In addition, problems, as reported by the participants and also improvement that they suggested will be outlined and cross-checked with conclusions from an analysis of the ARSuL AR/VR design elements with regards to their conformity with the principles of the Universal Design for Learning (UDL) framework.

Keywords: Augmented Reality, Virtual Reality, Training evaluation, Universal Design for Learning, Further Education, Apprenticeship, Learning Success.

1 INTRODUCTION

The ARSuL-Project ("Augmented Reality Based Support for Learning in the Heating, Ventilation and Air Conditioning Industry"), subsidized by the German Federal Ministry of Education and Research, aims to promote the development and evaluation of Augmented Reality (AR) and Virtual Reality (VR) based support functions and learning offers for craft enterprises and their employees. The heating, ventilation and air conditioning industry (HVAC) requires continuing education and flexibility of employees as product cycles are constantly becoming shorter.

The project consortium used findings from a user-centered requirements analysis to derive target group specific design elements for AR and VR trainings [6]. With the help of these design elements, first prototypes and demonstrators of AR and VR trainings were produced. Afterwards, they were tested with apprentices and trained workers, and evaluated in comparison to classical face-to-face trainings. During the evaluation phase, a holistic evaluation framework was used (see [9]). In the following paper, exemplary results from the evaluation of the demonstrators and prototypes from three test settings will be presented and discussed to answer the following research questions (RQ):

1 How did the participants experience and evaluate the VR, AR, and classical f2f training in comparison?

2 How did the participants perform in the pre- and post-tests?

3 What problems did they face when using the developed prototypes/demonstrators?

4 What suggestions for improvements can be derived from these findings?

Finally, the results for RQ 4 will be cross-checked with conclusions from an analysis of the ARSuL AR/VR design elements with regards to their conformity with the principles of the Universal Design for Learning (UDL) framework [7, 8]. UDL tries to overcome the "One-Size-Fits-All" approach by facilitating individualized learning. We consider this important for the ARSuL trainings, since the German HVAC industry lacks skilled workers and young talents, while a growing number of apprentices has only weak prior school education and in many cases weak German language skills.

The research questions will be answered chronologically in the following sections.

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2 LEARNING EXPERIENCE AND EVALUATION OF THE PROTOTYPES

For the test setting in the first evaluation phase in ARSuL, the replacement of a blower in a heating system was chosen as the learning content. This is a standard activity in the HVAC industry, which is usually not covered during vocational education so that most of the participants (mainly apprentices) were expected not to have any previous experience with the workflow. The evaluation took place in three different learning centers affiliated to the chamber of crafts, which ensures industry-wide trainings. Each testing involved one class of apprentices and their instructors at each location. The evaluation itself comprised 15 paper-based surveys that had to be completed by the subjects in a predetermined order. In addition, in a fourth run, representatives of craft businesses, that are supporting the research project as associated partners, participated in the test setting (nine craftsmen, one apprentice).

During each test run, the participants experienced identical learning content in a comparative setup. They were provided a VR training using HTC VIVE glasses, an AR training using Microsoft HoloLens glasses, and a classical face-to-face (f2f) training, conducted by a training engineer presenting slides and demonstrating the workflow on a heating system. In both, the AR and the VR scenario, a tutorial was provided to the individual users directly before the training, to show them how to interact with the system. Figure 1 summarizes the generic phases of each training, as described in detail in [6], and provides insights into the design of the three training types. In different steps, the training focused on the relevant components, their functions, and the actual process of replacement.

Figure 1. Learning Scenario of the ARSuL Test Setting: AR, VR, and f2f in comparison.

Before the participants went through the trainings, they were introduced to the ARSuL project, to main characteristics of AR and VR, and to the anonymous evaluation setup. All participants were randomly provided an envelope containing their individual agenda for the day and the questionnaires to be completed. While, e.g., questionnaires on the learning experience had to be filled out after each of the three scenarios (AR, VR, classical), the pre- and post-test, used to assess the learning success, had to be completed only before and after the first training of the day. At any time, project staff was available to support the participants in case of any difficulties. A detailed explanation of the evaluation setup is available in [9].

In total, 58 male test persons with an average age of 25.3 years (eight did not fill in their age) participated in the evaluation. 13 participants (22%) had used AR technology before, but only 4 of them (7%) actually used AR glasses. 23 participants (40%) had previous VR experience, with 8 (14%) of them having used VR glasses. After each training, the subjects were asked to rate the training using a 5-point Likert scale (“strongly disagree” to “strongly agree”) based on the statement “I liked the training”. With overall very positive results, the VR-training achieved the best results (compare Figure 2).

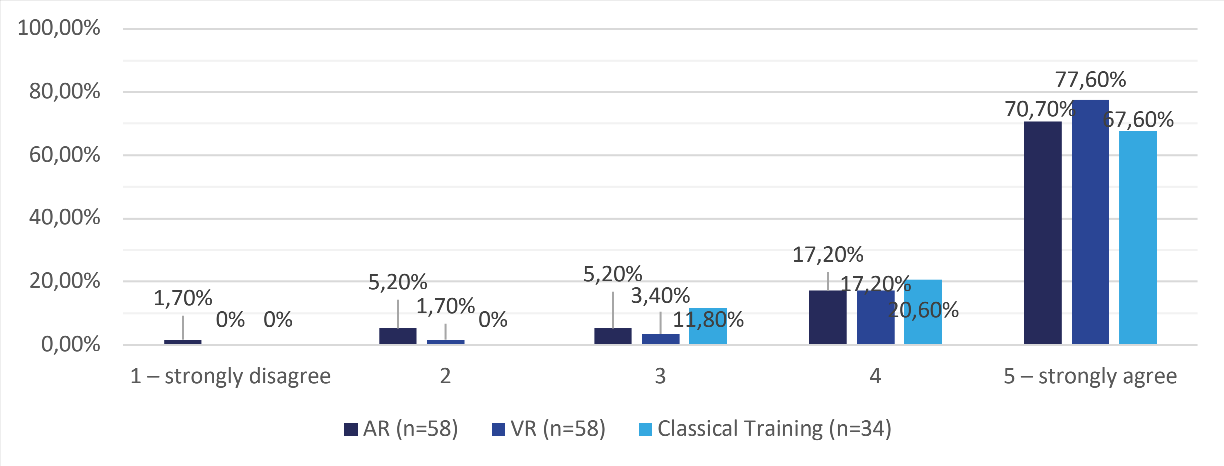

Figure 2. Results of the questions, whether participants liked the different trainings.

In addition, for each training, the participants rated the usefulness of the training for their job (5-point Likert scale) and answered several other questions on their personal learning experience. Questions, e.g., on the ease of use and the perceived complexity of the used technology, the flow experience and any fear of making mistakes were included. Figure 3 summarizes the ratings for the following three statements:

1 “I liked the training very much.” (Positive Experience).

2 “I consider the training useful for my work.” (Usefulness)

3 “I would like to use [VR/AR/Classical] trainings throughout my vocational training.” (Willingness to use).

Figure 3 shows that the ratings on the above statements for the three different trainings are very close to each other. Interestingly, the participants slightly prefer the classical training to AR and VR trainings, when considering a more intense use during their vocational education. A possible explanation for this result could be that 45 of the 58 participants (78%) had never used AR, and 35 (60%) participants had never used VR before the test setting, and that even those who had previous experience know AR and VR mainly from gaming (AR: 8 out of 13 (62%); VR: 19 out of 23 (83%)). The sample sizes between the VR and AR tests on the one hand and the classical F2F training on the other hand resulted from a spontaneously added second test group for AR and VR at one location. Furthermore, one of the test runs (with craft businesses as associated partners) was focused on AR and VR from the beginning.

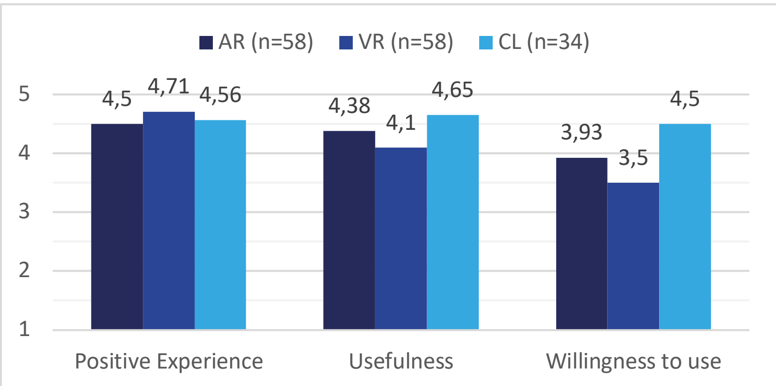

Figure 3. Positive Experience, Usefulness, and Willingness to use for the different Trainings.

In summary, with only very small differences, VR and AR created a more positive experience, while the classical training was considered the most promising for an intense use. The following section focuses on the learning success of each training, which was measured using a pre-/post-test approach.

3 LEARNING OUTCOMES

For organizational reasons, it was not possible to assess the subjects' learning success in a practical test on a real heating system based on the transfer of learning. Therefore, an objective paper-and-pencil knowledge test was used to assess the learning outcomes after the first training of each subject. To determine the knowledge gain of each subject the same test with a maximum score of 25 points was handed out before (pre-test) and after the training (post-test), with the difference between the two tests representing the knowledge gain.

In total, four evaluation runs at four different locations were accomplished. After analyzing the data from the first test run, the project team decided to revise the pre- and post-test, as all participants experienced problems answering important questions on the procedure of exchanging the blower. Consequently, for the following three test settings the according question types were changed into a cloze. The questions of the pre-/post-test addressed the following aspects:

- Assigning components to functions (1 question with 5 required answers)
- Labeling components (1 question with required 4 answers)
- Naming replacement parts needed (1 question)
- Naming three possible reasons for a speed deviation of the blower (1 question with 3 required answers)
- Naming the steps of the replacement workflow (cloze) (6 questions with 12 required answers)

The questions were created with the help of a training engineer of the heating manufacturer Vaillant, who also provided the sample solution. Besides the results from the testing at the first location (because of the changed questions), three incomplete datasets had to be excluded from the analysis, leading to a total of 31 pre- and post-tests that could be considered to compare the AR, VR, and the f2f trainings with regard to the learning outcomes of the subjects.

Table 1 and Figure 4 provide the overall results.

Table 1. Pre- and post-test results.

	N	Mean	Std. Deviation
AR-Pre	12	7.00	6.633
AR-Post	12	12.83	6.088
AR (Difference Pre-Post)		**5.833**	**3.689**
VR-Pre	11	4.91	5.049
VR-Post	11	7.36	5.427
VR (Difference Pre-Post)		**2.455**	**2.876**
f2f-Pre	8	4.00	2.673
f2f-Post	8	12.63	6.610
f2f (Difference Pre-Post)		**8.625**	**6.116**

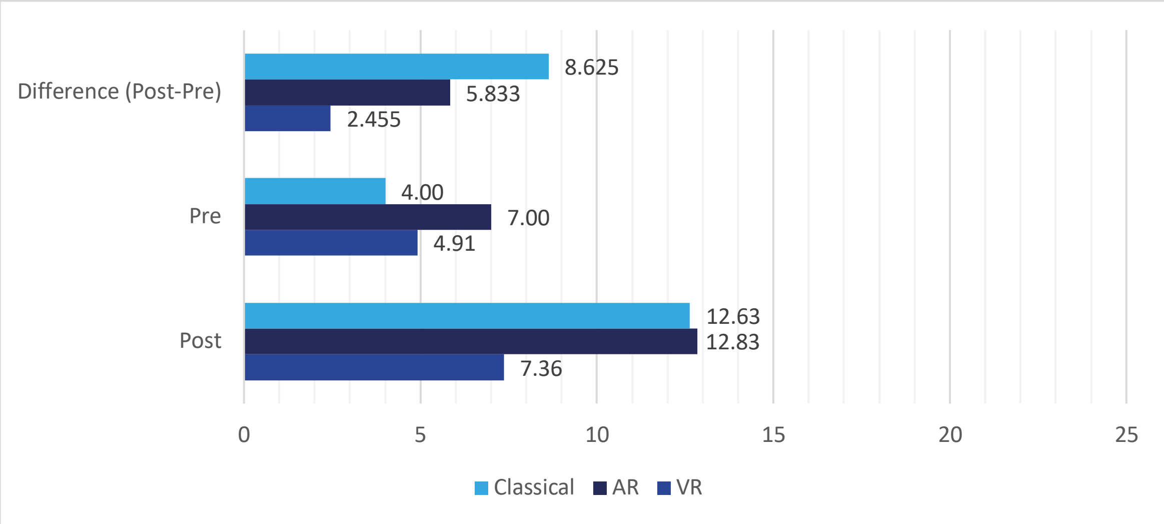

Figure 4. Means compared (in points; corresponding sample sizes are presented in Table 1).

3.1 Knowledge Gain

In this section the knowledge gain of the subjects is examined, this is defined by the difference if the knowledge post- and pre-test. Thus, it measures only the knowledge gains through the training.

With $p=.396$ for VR and $p=.350$ for AR, the data fulfills the precondition of a normal distribution according to the Shapiro-Wilk test. We assessed the significance of the differences in the knowledge gain of the VR ($M=2.455$, $SD=2.876$) and AR groups ($M=5.833$, $SD=3.689$) each in comparison to the classical group ($M=8.625, SD=6.116$) with a one-tailed one-sample t-test:

- H_0: The mean difference between pre- and post-tests of AR, respectively VR, is equal to or larger than that of the classical training (measured in points).
- H_1: The mean difference between pre- and post-tests of AR, respectively VR, is smaller than that of the classical training (measured in points).

As Table 2 shows, the null hypothesis is rejected for AR with $t(22)=-2.622$; $p<.05$ and a small effect size according to Cohen [10, 11] of $d=0.456$. Also for VR, the null hypothesis is rejected with $t(20)=-7.115$, $p<.001$, but with a large effect size $d=1.009$.

Table 2. T-Test (knowledge gain).

	Comparative value	t	df	Sig.
Test regarding AR	8.625	-2.622	22	.012
Test regarding VR	8.625	-7.115	20	.000

These results show, that the knowledge gain (measured as the difference between pre- and post-test in points) in both the AR and the VR training groups is significantly different than the knowledge gain in the f2f group. While there was a growth of knowledge in all three groups, the classical training created the highest knowledge gain.

Despite the limitation of the very low number of participants, several aspects of the above results are noteworthy. First, the average result for the pre-test in the classical setup was the lowest, while the std. Deviation for the knowledge gain in this group was the highest. This indicates that in this group some participants started with very low previous knowledge on the given task and notably improved during the training. This interpretation is supported by the individual results of the participants as depicted in Figure 5.

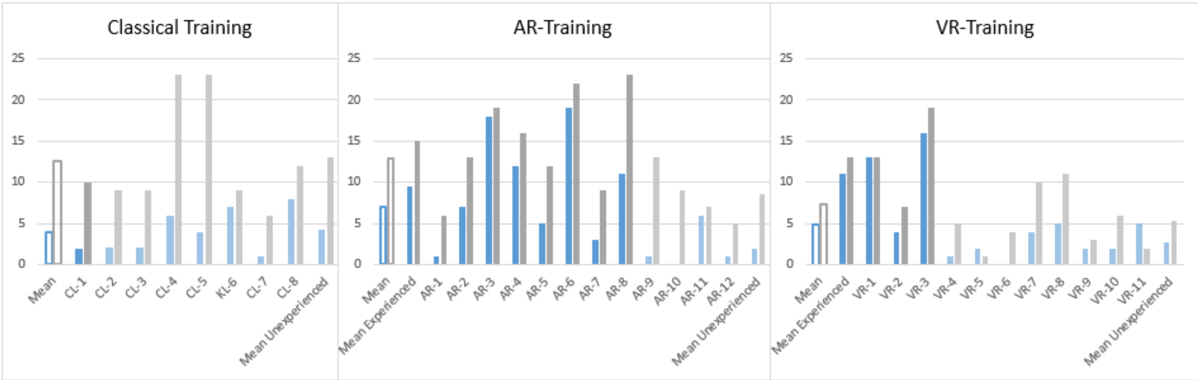

Figure 5. Test Results of Pre- and Post-Test in comparison (points achieved).
Pre: left/ blue; Post: right/ grey
Have already replaced a blower = "Experienced" (darker colors)
Have not already replaced a blower = "Unexperienced" (brighter colors)

As one can see, with only one exception, the classical training group contained only participants who had no experience with replacing blowers before the training. In general, previous experience lead to higher results on both the pre- and post-test, going along with a smaller knowledge gain (see Table 3). Some values of the f2f column are in brackets as they refer to only one participant (n=1).

Table 3. Experienced vs. Unexperienced.

		Total number (Exp.: n=12, UnExp.: n=19)	AR (Exp.: n=8, UnExp.: n=4)	VR (Exp.: n=3, UnExp.: n=8)	f2f (Exp.: n=1, UnExp.: n=7)
Experienced	Mean Pre-Test	9.25	9.50	11.00	(2.00)
	Mean Post-Test	14.08	15.00	13.00	(10.00)
	Mean Difference (Post-Pre)	4.83	5.50	2.00	(8.00)
Unexperienced	Mean Pre-Test	3.11	2.00	2.63	4.29
	Mean Post-Test	8.79	8.50	5.25	13.00
	Mean Difference (Post-Pre)	5.68	6.50	2.63	8.71

Second, VR created the smallest knowledge gain. Considering our observations during the test runs, this can be justified as follows: In all test-settings, the subjects took much less time for the VR training in comparison to the AR training and especially the classical training. While the classical training was instructor-paced, the AR and VR training could be conducted at the individual pace of the participants. A virtual avatar provided guidance to the students in both the AR and the VR training, but in contrast to the AR training, the VR training required no physical work on real heating systems, like, e.g., wrenching screws, taking off and carefully putting away parts, etc. Consequently, the participants were able to fulfill the workflow without tackling each necessary step in detail. In fact, they worked much faster, completing the steps with much less time for reflection. For example, the participants simply dragged and dropped components for the removal procedure, often completing the removal in seconds. It seemed as if the VR setting was perceived as a game, which the participants tried to solve as quickly as possible.

3.2 Learning Success

In the previous section, the knowledge gain was analyzed as an important learning outcome. Furthermore, as all trainings contained the same content, they should also lead to an equal mean of knowledge. To understand if this was the case, the post-test results of the participants will be assessed in the following. Significant deviations could indicate that e.g. in one of the trainings content was missing or was not retained by the subjects properly.

According to Table 1, the mean post-test result of the AR group is larger than that of the classical training. To test the significance of this observation, the t-test is repeated with the mean differences of the post-test results. The hypotheses for AR are:

- H_0: The mean of the post-tests of AR and the classical training (measured in points) is equal or smaller.
- H_1: The mean of the post-tests of AR and the classical training (measured in points) is larger.

The data are normally distributed as assessed by the Shapiro-Wilk test, as well (VR: $p=.392$; AR: $p=.412$). For the test, the mean of the post-test results from the classical training group is used as the comparative value ($M=12.63$, $SD=6.610$). For the AR training ($M=12.83$, $SD=6.088$), the null hypothesis cannot be rejected ($t(11)=0.116$, $p=ns$; see 4). According to Cohen, the effect size is small ($d=0.03$). Consequently, there is no significant difference between the outcomes of the AR and the classical training.

The hypotheses for VR are:

- H_0: The mean of the post-tests of VR and the classical training (measured in points) is equal or larger.
- H_1: The mean of the post-tests of VR and the classical training (measured in points) is smaller.

In the case of the VR training ($M=7.36$, $SD=5.427$), the null hypothesis is rejected ($t(10)=-3.218$, $p<.01$; see Table 4). In addition, the effect size is medium ($d=0.797$). This means that the results of the VR post-tests are significantly different from those of the classical training, they are smaller.

Table 4. Results of t-test (regarding post-test results).

	Comparative value	t	df	Sig.
Test regarding AR	12.63	0.116	11	.455
Test regarding VR	12.63	-3.218	10	.005

3.3 Summary

Despite the small sample size, which is a limitation of the significance, we could answer the second research question “How did the participants perform in pre- and post-tests?”. In average, there was a growth of knowledge in all the trainings, but this fact does not confirm that the AR and VR learning environments were better than the classical training regarding the knowledge gain. For both, AR and VR, the growth of knowledge is significantly smaller in comparison to the classical training. In addition, a distinction was made between those participants with and those without experience: The subjects who had already replaced a blower had higher results in pre- and post-tests, but a smaller knowledge gain. Further studies on additional causes would be interesting (e.g. regarding the impact of previous experience with VR and/or AR glasses on the learning outcome), but the sample size is too small.

The analysis of the post-test results showed, that there is no significant difference between the learning outcome from the AR and the classical training. This can be considered a success, as all trainings contained the same learning content. On the other hand, the results of the VR post-tests were significantly smaller than the results from the classical training group.

4 PROBLEMS AND SUGGESTIONS FOR IMPROVEMENT

During the test runs, the participants experienced the same learning content in AR, VR, and the f2f setup. After each training, they were asked what they liked, what they disliked, and what improvements they recommend. According to a qualitative content analysis following Mayring (2015)

[12], we derived six categories of problems and improvement suggestions for AR and VR from the participants' comments: 1) *Glasses*, 2) *Negative Side Effects*, 3) *Learning Content*, 4) *Navigation/Interaction*, 5) *Design of the Learning Environment*, and 6) *Technical Issues/Bugs*. In total, 56 comments on AR and 58 comments on VR were assessed.

As depicted in Figure 6, for AR, most comments referred to the categories *Navigation/Interaction* and *Glasses*. For VR, the categories *Design of the Learning Environment*, *Navigation/Interaction*, and *Learning Content* received most comments.

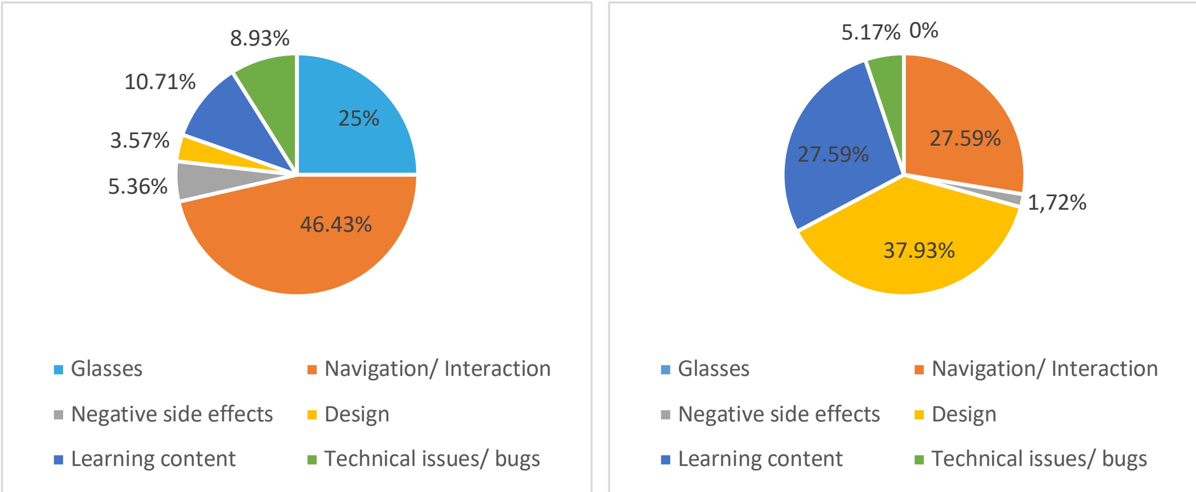

Figure 6. Distribution of Problems and Improvements mentioned (left: AR; right: VR).

Regarding the AR training, the category *Navigation/Interaction* received mostly comments on problems with the gesture and head movement control, needed for interacting with the virtual objects. Several subjects complained that especially small objects were difficult to select (mentioned seven times), and suggested the implementation of voice control. The *glasses* were criticized because of their dark lenses (three complaints), their weight (two complaints), and the limited field of view (one complain). One participant expressed worries that this could disturb them from their actual task. Further, they would appreciate smaller glasses in general and/or a possibility to lift up the glasses. Regarding *Learning Content*, they suggested to provide more information but also an option to skip explanations (six times mentioned). Unfortunately, also some *Technical Issues/Bugs* were reported, as for example the calibration needed to be repeated frequently, and in rare cases, animations were repeated randomly. As *Negative Side Effects*, two participants mentioned eyestrain and pressure pain on their nose. Regarding the *Design of the Learning Environment*, missing textures and blurred text were criticized (each mentioned once).

For the VR training, especially blurred text was criticized (mentioned eleven times). Furthermore, the participants complained about missing textures (mentioned once) and missing audio (mentioned eight times). As further development, the participants recommended context sensitive noises (matching the actual working steps) and audio announcements from the avatar. Regarding *Navigation/Interaction* problems with the controllers dominated the feedback (seven complaints). A more detailed tutorial at the beginning of the training was requested, to directly learn about the necessary interactions for the training (mentioned twice). Pointing in the same direction of better guidance of the users, the participants also recommended highlighting the button that needs to be used for the next interaction. The *Learning Content* was considered too superficial (mentioned eleven times). Moreover, different levels of difficulty and a more detailed representation of the heating system were recommended, including screws, gaskets, etc. To make the interaction with the virtual representation of the heating system more realistic, the participants also suggested to include consequences of mistakes in the simulation. Finally, like in AR, also in the VR training, the users experienced problems with the calibration process (*Technical Issues/Bugs*). Only one participant mentioned that he did not feel well during the training (*Negative Side Effects*).

Concluding from these comments, in the next development iteration, interaction, and navigation features should receive the highest priority. For AR, especially the gesture and head movement control need to be improved, while in VR more guidance on the usage of the controllers needs to be implemented. Further, the learning content should be enhanced with more details and explanations, with the latter being optional elements that users can turn on or off according to their individual preferences. Finally, technical issues and bugs need to be eliminated in order to avoid a negative influence on the user experience and the learning success. The complaints on the heavy and limited AR-glasses, at least the need for short sequences, need to be considered to keep the burden at a reasonable level. On the other hand, technical progress can be expected helping to overcome e.g. limitations like the currently still limited field of vision.

As mentioned at the beginning of the paper, the HVAC industry in Germany lacks skilled workers and young talents, why a growing number of starting apprentices has only weak prior school education, and also often weak German language skills, as well as a heterogeneous level of technical interest and skills. In conclusion, a more and more heterogeneous group of learners needs to be addressed with the trainings. This raises e.g. the need to incorporate different levels of difficulty for the different users, and to provide flexible support and guidance (e.g., step-by-step instructions vs. support on request).

Exactly pointing in this direction, the Universal Design for Learning framework (UDL) [7] aims to overcome a “One-Size-Fits-All” approach in education by facilitating individualized learning. Therefore, after finishing the requirements analysis which we used to derive 31 design elements for the development of the AR and the VR trainings (see [6]), we reflected these regarding their UDL compliance [8]. From this analysis, we derived the following improvement needs:

- “Craftsman” (Avatar) guides through the setting
- Simple navigation
- Voice control
- Introducing users to the system stepwise
- Plain interface
- Simple navigation/ interaction
- Multimedia presentation of content
- Alternative presentations for different types of learners

These findings match the results from the evaluation of the test settings, as the identified weaknesses and suggestions for improvements are very similar and refer to the same characteristics of the AR resp. the VR training. This is, for example, the need for simple and straightforward interaction and navigation e.g., with the help of voice control and guidance by an avatar, as well as the need for alternative levels and representations of content for different learners.

5 CONCLUSIONS

In conclusion, the AR and the VR trainings created a positive and valuable learning experience for the users. The knowledge gain was highest in the classical training. Both results need to be viewed with regard to the state of development of the prototypes, and also with regard to the novelty of the AR and the VR experience for most test persons. Furthermore, the low number of participants, which in parts resulted from the necessary adjustments to the pre-/post-knowledge tests and therefore the exclusion of the data collected in the first test run, limits the informative value of the comparative study on knowledge growth.

On the other hand, the many comments from the participants provided valuable insights into current weaknesses of the AR and VR demonstrators and show improvement options for the according trainings. Considering the evaluation results from the test runs and our findings from the crosscheck of the design elements with the UDL framework in [8], the following aspects will guide the upcoming development iteration in the ARSuL project:

- The gesture and head movement control in AR need to be analyzed in the context of the specific working steps that need to be fulfilled in the trainings. When possible, alternative options for navigation and interaction should be added. E.g., voice control is not yet implemented, although an according design element was already derived during requirements analysis. Also, the UDL analysis leads to the conclusion to provide for alternative control options (*UDL Guideline 4*).
- Besides providing textual information, the avatars in both AR and VR should be enabled to read out text (*UDL Guideline 1*) using a human voice (*UDL Guideline 2*), and they should get a

modifiable appearance (color, voice, etc.) to get the learners more involved (*UDL Guideline 7*). Furthermore, the avatars should be developed into flexible and context-sensitive contact points that offer support (*UDL Guideline 8*) according to the preferences of a user (e.g., regarding the level of difficulty), either automatically or on request.

- The trainings should be enhanced in the sense that they offer redundant multimedia representations of the same content and content on different difficulty levels, to provide the learners with flexible learning options (*UDL Guideline 1*).
- The representation of the heating system together with the necessary working steps needs to be reconsidered for the VR training. Either, more details and more realistic procedures (wrenching screws, etc.) should be provided, or the different user behavior in comparison to AR and f2f training (much faster and less reflected usage) should be utilized for specific didactical purposes, like e.g. a first quick introduction of students to a heating system, instead of teaching them a detailed maintenance procedure.
- Technical issues and bugs need to be eliminated.

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