Promptly Authored Augmented Reality Instructions Can Be Sufficient to Enable Cognitively Impaired Workers

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Abstract: The benefits of contextualising information through Augmented Reality (AR) instructions to assist cognitively impaired workers are well known, but most findings are based on AR instructions carefully designed for predefined standard tasks. Previous findings indicate that the modality and quality of provided AR instructions have a significant impact on the provided benefits. The emergence of commercial products providing tools for instructors to promptly author their own AR instructions elicits the question, whether instructions created through those are sufficient to support cognitively impaired workers. This paper explores this question through a qualitative study using an AR authoring tool to create AR instructions for a task that none out of 10 participants was able to complete previously. Using promptly authored instructions, however, most were able to complete the task. Additionally, they reported good usability and gave qualitative feedback indicating they would like to use comparable AR instructions more often.

Keywords: Augmented Reality, Authoring, Assistance, Training, Cognitive Impairments

1 Introduction

Augmented Reality (AR) offers the opportunity to give contextualized instructions and feedback. Especially in assistance scenarios, this reduces the cognitive transfer required to bring the provided information into the physical context (e.g. mental rotations) compared to conventional instructions, such as paper instructions with text and figures. In AR, instructions are displayed directly into the context (in-situ) where the information is needed. That this can generally lead to faster task completion times [FKS16] and less errors made [FKS16, BSR+17] with only a minor cost of added cognitive load [BSR+17], was already shown in previous studies.

While those advantages are generally true for everyone using AR instructions, there are groups that especially benefit from the direct contextualization of the information. One of those are people with cognitive impairments. For them, the process of understanding, disassembling, and contextualizing provided information into the physical environment is often a challenge. Additionally, many not only have problems dividing their attention between separate tasks, but also struggle to stay focused in general [GAPB08]. Furthermore, many cognitively impaired people are also illiterate or have severe reading deficits [HHF00] and

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completing tasks on their own is a challenge for them. Conventional instructions do not fit their specific needs holistically, which results in the need for more assistance and support by either instructors or new approaches.

On the one hand, as those insights are generally agreed on in the community, AR is increasingly explored in the literature as a potential tool for instructors to utilize in assistance and training scenarios for people with cognitive impairments [BRP19a]. On the other hand, most studies focus on evaluating AR instructions which have been carefully designed by the researchers for pre-selected tasks and not instructions that can realistically be created/authored by instructors themselves [BRP19a]. Therefore, necessary requirements, needs and challenges are derived from the task the AR instructions would later be used in, an AR application with those specific task-dependent insights is developed and the AR instructions are then used in comparative experiments. AR instructions that could realistically be created by instructors themselves on the other hand, would be created through applications providing a modular set of AR elements and tools without knowing the tasks AR instructions could be created for at the time of developing the application (Described in [BRP19a], Figure 1). Naturally, this creates potentially limiting factors for the appearance and quality of produced AR instructions and results might not be directly comparable.

As the modality and quality of AR instructions can have significant impact on their provided benefits [BRSP18] and a number of research prototypes and commercial products are introduced (e.g. Microsoft Dynamics 365 Guides or Vuforia Expert Capture) that provide the tools for instructors to author their own AR instructions, the question arises: Are promptly authored AR instructions, while likely not being as precise as pre-defined AR instructions, sufficient to enable cognitively impaired workers?

2 Related Work

While there is research on utilizing Augmented Reality to assist people with cognitive impairments dating back to to over 15 years ago, this specific sub-field only gained increasing attention in recent years, as can be observed through the raising number of articles published in that time frame [BRP19a]. Therefore, naturally research on this topic is mainly exploratory, mostly focused on specific use cases and especially utilizes pre-defined AR Instructions to answer specific questions in a controlled setting. While this is by design and providing important insights, with current technical advancements that allow for an on-site promptly authoring, there is an apparent research gap.

A previously conducted systematic literature review reveals that between 2006 and 2018, 52 scholarly articles were published on utilizing Augmented Reality to either assist or train people with cognitive impairments [BRP19a]. Here only 1 out of the 52 articles, the *cARe* system proposed by Wolf et al. [WBS+18], incorporated a holistic approach with authoring abilities that enable caregivers of dementia patients to author AR instructions. However, it lacked a formal evaluation. A followup publication by Wolf et al. [WBS+19] evaluating the proposed application indicates that people with cognitive impairments, in this case evaluated again with dementia patients, could potentially benefit from this kind of AR instructions. They report high curiosity, comfort using the AR instructions and improved independence. An authoring tool proposed by the authors of this paper in previous work [BRP19b] also incorporated the training and assistance of people with cognitive impairments as one of the potential target groups, especially incorporating instructors and the trainees in the development process and evaluating both the authoring and the usage of the authored AR instructions. One of their key findings in the context of people with cognitive impairments was that especially the availability of different modalities of instructions (e.g. text, picture, video and 3D models) was identified as a crucial success factor based on the hugely differing levels of knowledge between the workers. Finally, for a projection-based augmented reality system that was also used to assist cognitively impaired workers at the workplace, Funk [Fun16] compared several authoring techniques in a comparative experiment. He showed that foreman were faster creating new AR instructions using intuitive *authoring by demonstration* or video recording approaches compared to programming values through a GUI on a laptop. The evaluation of the authored projection-based AR instructions with cognitively impaired workers indicated reduced error rates and lower task completion times. Those benefits do scale with the expenditure of the authored task [FMS15].

This paper revisits an experiment which has already been published [BRP19b] and frames the qualitative results in a more elaborate approach under this new, previously not discussed research question.

3 Methodology

To answer the research question, a primarily qualitative experiment in a sheltered vocational training facility for people with cognitive impairments was conducted. In this, the AR authoring tool proposed in [BRP19b] was used to author AR instructions for a real task identified as a challenge existing prior to the experiment. Workers with cognitive impairments used those AR instructions on a head-mounted AR device, namely the Microsoft HoloLens 1 (see Figure 1). Hereby, the focus was on observing if the authored AR instruction could enable the cognitively impaired workers, if it induced additional perceived cognitive load, was usable by the workers and most importantly, whether the workers would like to use such technology more frequently.

3.1 The Task

Prior to beginning the experiment itself, potential tasks were identified by interviewing 4 instructors in a non-representative preliminary study and by an observational visit to the facility. Several interesting potential tasks emerged including, for example, cleaning tasks, wood-working, as well as bicycle or motorcycle repair. The three most fitting tasks identified that were diverse compared to each other were:

Figure 1: The AR instructions displayed on the MS HoloLens. Multiple types of instructions were combined for each step: (1) text instructions, (2) photos (e.g. taken from the the target state) and (3) in-situ arrows indicating the physical position.

1. Picking a specific number of sorted items in a specific order and wrapping them up in a sealed plastic container (*Picking task*)
2. Measuring, sawing and glueing/screwing parts of a wooden chest (*Assembly task*)
3. Disassembling and cleaning a modern coffee machine (*Maintenance task*)

While all the tasks were fitting the scope, the maintenance task of disassembling and cleaning the modern coffee machine was selected. This task has to be completed at least daily as one of the duties of workers that are currently training to run a kiosk in the facility. Furthermore, the instructors reported that out of all the workers currently in the facility, only one worker was able to complete this task independently. The task thus fitted the scope of the research question precisely. While conventional instructions for the task existed (see Figure 2), the instructors reported that the workers were not able to use them independently.

3.2 The AR Instructions

After the task of disassembling and cleaning the modern coffee machine was identified and selected, one of the instructors authored the AR instructions for the task with the help of the experimenter. The procedure of the task is as follows: placing a collection container under the coffee machine, withdrawing it later, placing a milk tube first in a container with cleaner and afterwards a container with water, interacting with the touch menu and buttons on the machine, emptying the drip tray into a sink, injecting a cleaning tablet on top of the machine and ultimately cleaning the containers used. The instructions were authored

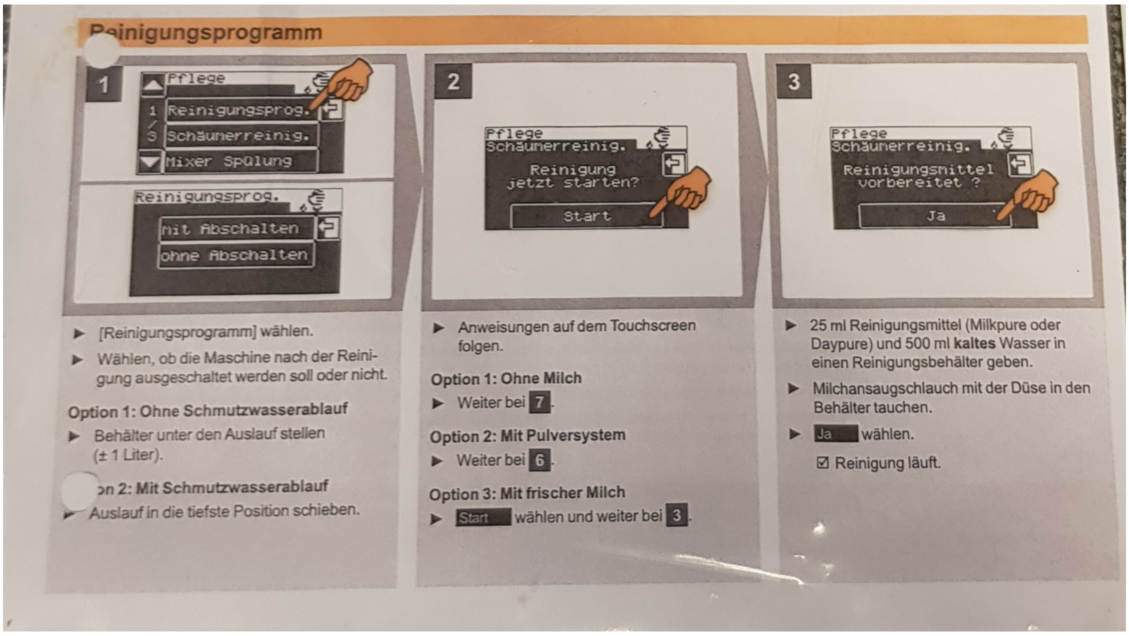

Figure 2: A part of the original instructions delivered with the coffee machine.

using the tool proposed by in [BRP19b]. They hereby consisted of a linear sequence of steps, each of them allowing several AR elements to be displayed simultaneously (see Figure 1). A sphere-based attention guiding technique was used to guide the user towards instructions that were not immediately visible, e.g. because of the small Field of View (FoV) [RP17].

While the AR instructions were promptly authored *on the fly*, some important insight were provided for the instructor, like using *in-situ* arrows to show physical positions, combining multiple modalities and placing instructions where the users would expect them. Those authored AR instructions were then saved and the same instructions were used in the experiment to display them on the Microsoft HoloLens for the participants to try to complete the displayed actions.

3.3 Procedure

Participants were first explained what the HoloLens is and what task they were going to carry out with the help of the AR instructions displayed on the head-mounted display. They were explained that they should verbally articulate their thoughts, can always ask for help or if they have questions and can exit the experiment at any given time. Afterwards the HoloLens was put on and the experiment started.

No task-completion times were recorded and thus no onboarding scenario was displayed to speed up learning. The participants started with the first step of the AR instructions for the coffee machine. If they completed one of the steps, the next step of the AR instructions was displayed through the *Wizard of Oz* technique by the experimenter. Simultaneously the experimenter marked errors, problems or questions asked on a experimenter sheet.

After all steps of the AR instructions had been completed, the participants were instructed to remove the HoloLens and asked to fill out three questionnaires. One NASA TLX questionnaire to record their perceived cognitive load, a System Usability Scale (SUS) questionnaire for the usability of the displayed instructions and a qualitative questionnaire asking what they particularly liked, did not like, if they would like to use such AR glasses more often and finally, if they have additional suggestions or comments. Hereby, the questions were deliberately phrased as *the AR glasses* instead of AR instructions as it was anticipated that they would struggle to differentiate those entities. Participants were offered that they could fill out the questionnaires themselves and ask if there was something they did not understand or wanted to be read or read and explained the questions in succession.

3.4 Participants

Participants were recruited by walking through the facility and asking workers if they would like to try out an *AR headset that would help them complete a work task*. Participants were rewarded with chocolate for their participation. Ten participants with cognitive impairments took part in the experiment. They were aged between 18 and 27 (average = 21.2, sd = 3.16) and 5 of them were female. None completed the cleaning of the coffee machine previously. Due to the small sample size, exploratory nature of this work and diversity of cognitive impairments participating, no quantitative descriptions of the impairments are included.

4 Results

4.1 Task Completion & Errors

All 10 of the participants were able to complete the task without major problems but 4 of the participants asked for additional help for the step of inserting a cleaning tablet on top of the machine, which was hard to see and reach from the front of the machine. For some participants this required to use a small stool to stand on. Additionally, 1 participant accidentally pressed a wrong button on the touchscreen of the machine.

4.2 Usability

The participants reported an average System Usability Scale (SUS) score of 74.25 (sd = 15.19, see Figure 3). A SUS score of 74.25 out of possible 100 translates to a *good* usability according to Bangoret al. [BKM09]. According to Tollis et al. [TS04] SUS scores yield reliable results with sample size of around 8 to 12 participants.

4.3 Perceived Cognitive Load

The perceived cognitive loads reported through rTLX questionnaires resulted in an average score of 20.4 (sd = 11.66, see Figure 4). While perceived cognitive loads through rTLX scores are task dependent and therefore are not directly comparable, an average score of 20.4 would

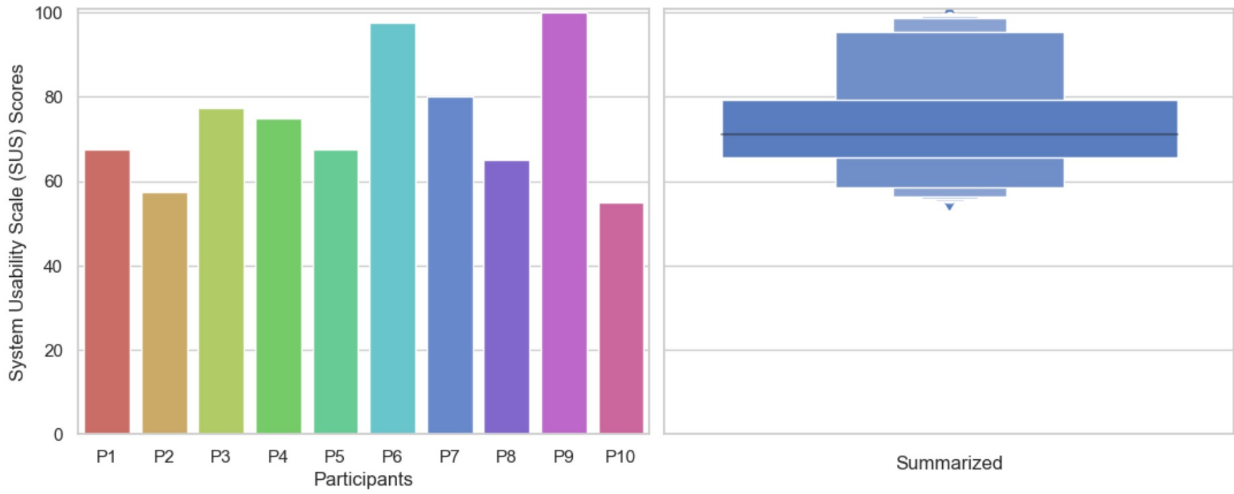

Figure 3: The reported System Usability scores per participant and summarized.

be categorized in the first quartile for *Mechanical Tasks* (20.10) and below the median for *Daily Activities* (18.30) identified in a meta analysis comparing rTLX studies [Gri15].

4.4 Qualitative Feedback

When asked what they particularly liked about the AR glasses and what helped them the most completing the task, they stated that they found the fact that instructions are displayed once at a time helpful to not get confused (P1, P2, P3, P6), that they generally found the instructions well described (P6, P7, P9), that they liked that multiple types of instructions were available at the same time (P2, P3, P4), that the visual approach with showing actual pictures helped them to understand the instructions (P1, P7) and that they liked that the arrows actually show the physical position in the room (P3, P5). One participant stated that they would prefer the instructions to normal instructions (P9). Furthermore, multiple participants mentioned a gamification aspect, e.g. stating that it felt like a puzzle (P4), that they liked that they had fun (P8) and that it was something new/different (P9, P10). Notably, one participants explicitly stated that they liked the availability of the textual instructions (P5), while others liked that it was not necessary to read the displayed textual instructions to understand the instructions (P6, P7).

Afterwards, they were asked what they did not like or what was hard to understand for them. Here, multiple participants noted that the AR glasses were too heavy (P1, P3, P8, P9) and that a lot of head movement had been necessary to actually see the instructions as, because of the small FoV, the instructions had been sometimes not visible immediately (P1, P2, P9). Furthermore, some participants stated that the photos appeared blurred to them (P3, P5, P7). They also stated that it felt like they would have to get used to wearing a headset like this and that it potentially could induce a headache (P4, P7, P9).

When asked if they would like to use AR glasses more often to get assistance completing work tasks, 6 answered *yes* and 4 answered *no*. The participants answering *yes*, stated they

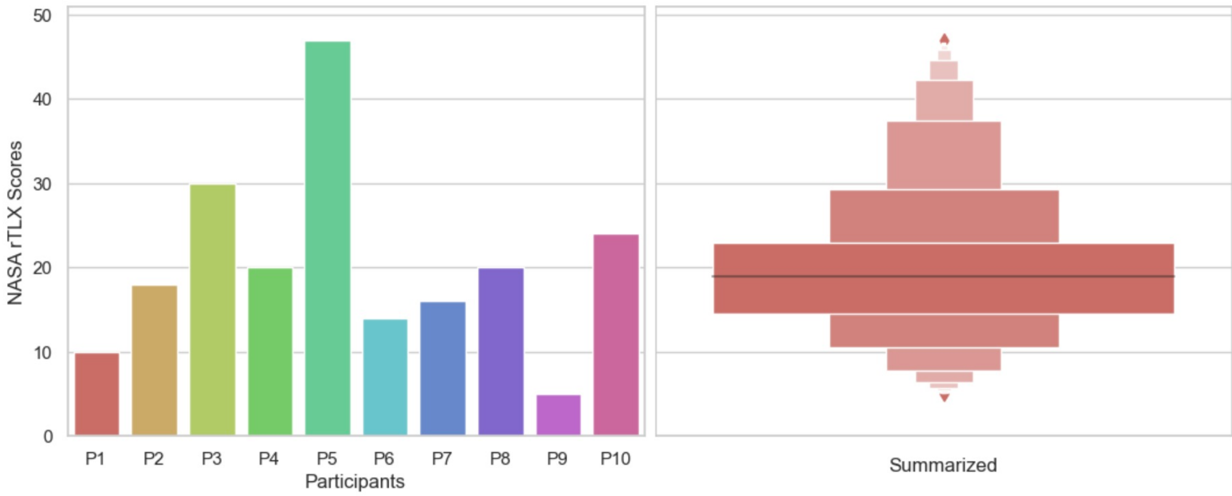

Figure 4: The reported NASA rTLX scores per participant and summarized.

believe that this could help them complete tasks more easily (P1, P2, P4, P9), that it helps to be faster without inducing additional stress (P5), is less exhausting than being helped by an instructor (P9) and that it especially helps people who cannot read very well (P6). One participant noted that the tasks have to be difficult enough for the glasses to be worth it (P1). The ones answering *no* stated as their reasons that the glasses are too heavy (P3), that pictures appeared blurry (P3), that it was too exhausting (P7) and that they simply do not like technical things in general (P8, P10)

In terms of additional feedback or suggestions to improve the AR glasses and instructions shown, one participant wanted to progress to the next instruction step on his own (P2). Several participants were enthusiastic about the AR glasses after trying them out and several already suggested other tasks that could be assisted. One participant mentioned that he would like the AR glasses to be used for navigation or to clear out the dishwasher as it is hard to remember where everything belongs (P2). Other participants suggested to use the glasses for other kitchen appliances (P5) or for wiping counters and the floor to not forget any spots (P4).

5 Discussion

The results of this study suggest that promptly authored Augmented Reality instructions, which can realistically be created by instructors themselves, can indeed be sufficient to enable cognitively impaired workers. The workers participating in the study were not only able to complete a work task they had not been able to complete previously, even more so, they also reported good system usability scores and qualitative feedback indicating that they would like to use comparable instructions more often. Generally, the AR instructions were received positively, for some participants even enthusiastically. The more critical qualitative feedback was mainly directed towards the hardware limitations of the Microsoft HoloLens

1 rather than towards AR instructions or the concept of AR in general. This feedback was mainly concerning problems that are not only already acknowledged but partially improved in the current HoloLens 2: namely the display resolution, weight, weight distribution and field of view. Additionally, the participants reported perceived cognitive load scores through the NASA TLX questionnaire that, while not directly comparable, at least indicate that no unnecessary cognitive load has been induced. Almost all verbal help requests and problems by the participants were caused by the same instruction step of the sequence: The insertion of a cleaning tablet on top of the coffee machine. Here not only an implicit additional step to use a small stool to stand on was necessary for some of the smaller participants but the insertion point was not easily visible for the participant as well. Even though an AR attention guiding technique has been used, the AR instructions might not have been authored sufficiently clear to guide the users towards the location.

Putting these results into perspective of the three metrics of measuring and quantifying usability: effectiveness, efficiency and satisfaction, the criteria for effectiveness and satisfaction were clearly met. Additionally, while measuring efficiency was not explicitly part of the scope of this work, it can be argued that the enabling factor itself is an efficiency improvement on a broader level compared to not being able to complete a specific work task at all. Notably some previous findings by Wolf et al. [WBS+19] not only show that authored AR instructions can even outperform conventional instructions in the context of cognitively impaired people, indicating improved efficiency, but also report qualitative feedback indicating high curiosity, positive reception and good usability that could all be reproduced in this experiment in the vocational setting. Especially interesting is their result that despite the improved efficiency, high curiosity and positive perception, half of the participants explicitly stated that they would not have needed the authored AR instructions to complete the task. As in our experiment, none of the participants would have been able to complete the assisted task without the AR instructions, the results of both studies complement the broader picture nicely and provide first indicators that provoke discussing cognitively impaired workers as a special case when analysing the cost-benefit trade-off of utilizing authorable AR instructions.

5.1 Cost-benefit Trade-off of Authorable AR Instructions

Like any assistive system, utilizing authored AR instructions naturally comes with a cost-benefit trade-off. While it is generally understood that AR did not reach consumer level yet and just now starts more widespread adoption in industrial assistance contexts because of the hardware infancy, sparsity of suitable software and ultimately monetary costs, the usage of AR for people with cognitive impairments is somewhat different: due to the shortage of trained personnel that can assist people with cognitive impairments, assistive technology is generally welcome and monetary investments are not the main hurdle. Therefore it can be argued that the relevant costs are mainly the necessary media competence of the instructors, acceptance to wear and use AR glasses on a daily basis and acceptance of some technical limitations. Both, this study, and the study by Wolf et al. [WBS+19] indicate, that those costs generally seem to be acknowledged but accepted because of and ultimately out-weight by the benefit of enabling the cognitively impaired people. Beyond question, for them the help provided by the AR instructions is more impactful compared to people without cognitive impairments so even now with those technical limitations, the benefits already out-weight the costs and even the simple AR instructions, that are promptly authored by real instructors on AR hardware of the last generation, clearly enable cognitively impaired workers. In the future, this will only improve with new hardware and wider availability of suitable software.

5.2 Relevance of Improved Conventional Instructions

Arguably, the conventional instructions that were delivered with the coffee machine are particularly questionable in their design and improved conventional instructions, e.g. using more figures/photos and plain language, could potentially also already enable the cognitively impaired workers in this specific case. Firstly, the scope of this work was not to show that AR instructions outperform conventional instructions but rather that AR instructions can enable cognitively impaired workers independent to other approaches that might also be enabling for them. Secondly, the goal was for the experiment to be conducted in a realistic use case in a real facility and here those improved conventional instructions simply did not exist and the reported result was that only one person in the facility was able to carry out the cleaning of that coffee machine. Finally, as the authoring process of the AR instructions only took roughly 45 minutes it would arguably be challenging to be faster while creating conventional instructions with comparable added value.

5.3 Authoring Good AR Instructions

As indicated by the results, even simple, promptly authored AR instructions that are authored by instructors and not carefully designed for a pre-defined task can enable cognitively impaired workers and provide added value for them. While this is promising, it has to be noted that in this study the instructors were helped with insights of how to author effective AR instructions during the process that stemmed from years of experience working with AR. Even then, as demonstrated by the step of inserting a cleaning tablet into the top of the machine, arguably one instructional step was not authored ideally. For a realistic, self-sufficient utilization of authorable AR instructions in this context, more research is necessary on how to formalize and communicate what good authored AR instructions consist of, what considerations have to be taken into account when authoring them (e.g. for this study the incorporation of in-situ instructions and usage of multiple types of instructions like photos, text and 3D models was emphasized) and what level of media competency is required.

5.4 Limitations & Future Work

The AR instructions used in this qualitative study elicited good usability, reasonably perceived cognitive load and qualitative results indicating that users would like to use comparable instructions more often. While the results are in itself consistent and give some insights into the applicability of authored AR instructions for cognitively impaired workers, additional research is necessary to quantify these observations. Additionally, the question arises of how reliable self-reported measures are in the context of studies with people that have cognitive impairments. Finally, it underlines that more research is needed on what constitutes *good* authored AR instructions, in particular for this audience, and on how the required media competency is taught to instructors to ensure sufficient quality.

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