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Investigating Design Opportunities for an Inclusive Adaptive Worker Assistance – A Case Study with Cognitively Disabled Workers

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Abstract. The integration of digital worker assistance systems (WAS) into occupational environments holds significant promise for enhancing the workplace inclusion of people with cognitive disabilities (PwCD). However, existing systems often fail to dynamically adapt to individual user needs, limiting their effectiveness. This study investigates design opportunities for adaptive WAS through a comprehensive case study conducted in a German integrative company. The research explores the challenges faced by PwCD when using non-adaptive systems and identifies key preferences for adaptive features that cater to their unique abilities. Findings reveal a strong preference among PwCD for systems that personalize both instructional content and interaction modes. This work offers critical insights into developing inclusive adaptive technologies that foster meaningful workforce participation for PwCD, aligning with global goals of decent work for all.

Keywords: Adaptive Technology, Worker Assistance Systems, Cognitive Disabilities, Workplace Inclusion

1 Introduction

Although international policy frameworks such as the United Nations Convention on the Rights of Persons with Disabilities (CRPD) [1] and the Sustainable Development Goals (SDGs) [2] affirm the obligation to ensure decent work for all, especially persons with cognitive disabilities (PwCD) continue to face systemic barriers to equitable labor market participation. In Germany, a majority of PwCD (232.000 in 2023) are employed in so-called sheltered workshop organizations, which provide vocational training and secure employment tailored to their individual abilities and needs [3,4].

Within these organizations, work is predominantly manual in nature, encompassing activities such as assembly, packaging, and order picking, and is generally characterized by low to medium levels of complexity. However, due to advancements in industrial automation, these tasks are increasingly taken over by automated systems, leaving behind more complex, variant-rich activities. This increased complexity poses significant cognitive challenges for many PwCD.

A common approach applied in sheltered workshops is to decompose complex processes into smaller sub-tasks, which are then allocated to multiple workers along an assembly line according to their individual abilities. While effective in terms of productivity, this approach can result in workers performing narrowly defined tasks with sometimes only single steps, potentially limiting job satisfaction and failing to align with the broader goal of decent work. An alternative approach lies in the use of work-oriented digital assistive technologies, commonly referred to as digital worker assistance systems (WAS). These systems provide interactive, step-by-step instructions with multimedia content to reduce cognitive load, enabling PwCD to undertake more complex and diverse tasks. Studies and practitioner feedback highlight their general potential to improve task efficiency and reduce error rates, thereby promoting occupational inclusion for PwCD (e.g. [5,6,7]).

However, current digital WAS often lack the capability to adapt the assistance to the individual abilities and needs of users [8,9]. This mismatch can diminish the effectiveness of these systems, particularly given the wide variability in cognitive abilities among PwCD. Here, individualized adaptations are essential to provide optimal support and ensure the systems meet the unique demands of different users [10,11].

This article investigates design opportunities for creating adaptive digital WAS to support PwCD in occupational settings. Through a comprehensive case study conducted in close collaboration with a German integrative company, we explore the challenges PwCD face when using non-adaptive WAS and their preferences for adaptive features in future systems. The paper offers two key contributions: (1) an insight into the problems and challenges of using non-adaptive WAS for the occupational support of PwCD and (2) an insight into the preferences of PwCD regarding the adaptive design of WAS. Our findings aim to advance the development of inclusive technologies that address the diverse and dynamic needs of PwCD, fostering their meaningful participation in the workforce.

2 Related Work

This section situates our case study within the existing body of research by reviewing prior work in three key areas: (1) the design of assistive technologies specifically tailored for PwCD, (2) the development and evaluation of WAS aimed at supporting

PwCD in professional settings, and (3) the potential applications and strategies for incorporating adaptive design into WAS.

2.1 Designing Assistive Technologies for People with Disabilities

Designing digital assistive technologies for PwCD presents significant challenges, largely due to the variability in the types and severity of cognitive abilities. Established design strategies often fall short in addressing the heterogeneity of abilities and needs, necessitating highly individualized adaptations [12,13]. Over time, various design frameworks have been developed to promote inclusivity in assistive technology. Common approaches like *Universal Design*, *Inclusive Design*, and *Design for All* focus on creating broad, one-size-fits-all solutions that accommodate a wide range of users. While these strategies are effective in promoting accessibility for diverse populations, they frequently fail to account for the unique abilities and preferences of individual users, limiting their applicability in specialized contexts [14,15]. In contrast, *Ability-based Design* emphasizes tailoring solutions to individual users or narrowly defined subgroups by adapting systems to their specific abilities and needs [16]. While this approach offers greater personalization and effectiveness, it demands detailed assessments of individual abilities and contexts, which can limit scalability and transferability [17]. A critical consideration in designing assistive technologies lies in the involvement of different stakeholders throughout the design process. Direct collaboration with PwCD, combined with insights from transdisciplinary experts, is essential to ensure that technologies address real-world needs effectively [18, 19]. Principles of co-creation and participatory design, as discussed in recent studies, highlight the importance of shared decision-making to bridge gaps between user expectations and technological abilities [20,21].

2.2 Digital Worker Assistance Systems for PwCD

The development of digital WAS for the support of workers in industrial manufacturing has been in the focus of research for many years. In this context, previous work has covered a whole range of stationary and mobile assistance systems based on different visualization and interaction technologies [22]. This previous work has focused in particular on use cases in the field of manual assembly and order picking as well as maintenance and servicing [23]. Besides the development of digital WAS for the support of non-disabled workers, a whole series of projects and publications also dealt specifically with the development and evaluation of systems designed to support PwCD [6, 24]. Beyond visualization and interaction technologies [7, 25, 26], prior research has also examined alternative forms of presenting instructions and user feedback [27, 28], as well as the use of gamification approaches [29, 30].

In this context, various studies indicate that using digital WAS can lead to decreasing processing times and a reduction in error rates [5,10,27]. In addition, studies indicate that PwCD are generally open towards using digital WAS and show a correspondingly high level of acceptance towards these systems [7,31]. However, several studies and feedback from practitioners also indicate that current digital WAS are generally too static and can only adapt to the individual abilities and experiences of the users to a very limited extent (e.g. [8,9,10]). This can result in an increasing gap between the level of assistance provided by the WAS and the level of assistance required by the user, which reduces the benefits of the system. For example, the study presented in [32] found that the use of a WAS only had positive effects on processing times and error rates for inexperienced workers for a limited time, while the performance of experienced workers actually deteriorated in some cases. Consequently, a key requirement for future WAS is the adoption of more flexible designs that can be tailored to the individual abilities and experiences of users.

2.3 Designing Adaptive Digital Worker Assistance Systems

In Human-Computer Interaction (HCI), adaptive interactive systems aim to tailor system behavior dynamically to user needs, preferences, or context. Common adaptation strategies include system-initiated, user-initiated, and mixed-initiative approaches, each with distinct benefits and challenges related to usability, control, and trust. *System-initiated Adaptation* involves the system autonomously adjusting its behavior based on user interaction patterns or environmental inputs. This approach can enhance efficiency and reduce user burden [33], but it may lead to reduced user agency or misaligned behavior if the system's reasoning is opaque or incorrect [34,35]. Concerns about privacy and transparency are common [36]. *User-initiated adaptation* gives users control over how the system behaves, fostering personalization and autonomy [37,38]. However, it assumes users are aware of and capable of configuring options, which can be problematic for individuals with limited cognitive or technical skills [39,40]. *Mixed-initiative adaptation* blends both approaches, allowing systems to suggest adaptations while enabling users to accept, modify, or reject them. This strategy supports collaboration and transparency [33,36], but can also increase interface complexity or cause decision fatigue if not carefully designed [41, 42]. While adaptation strategies have been extensively explored in domains such as e-learning [43] and intelligent tutoring systems [44], their application within digital WAS has received comparatively little attention. Most prior work in this context remains conceptual, offering models for adaptation logic, triggers, and control (e.g. [45]). Practical implementations are rare and often limited to system-initiated strategies. For instance, [8] and [46] describe systems that automatically vary instruction detail based on performance indicators like task completion times and error rates. Similarly, [47] presented an adaptive assembly line that redistributes tasks

Interaction Design and Architecture(s) Journal - IxD&A, N.65, 2025, pp. 144 - 169
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across workers with and without disabilities according to real-time performance—a fully system-driven adaptation. Other system-initiated approaches use cognitive state estimation [48], workload and visual attention monitoring [49], or machine learning–based cognitive modeling [50] to adapt the assistance without involving the user. In contrast, user-initiated strategies are rarely addressed in WAS research, possibly due to concerns about complexity or accessibility for target user groups.

Furthermore, [51] conducted a literature review examining key aspects of adaptive design in digital workplace assistance systems (WAS). The resulting design space for adaptive digital WAS is structured around six key dimensions: the goal of adaptation, the target of adaptation, the initiator, the level of control, the timing, and the criteria for evaluating success (see Fig. 1). This framework not only illustrates the breadth of potential adaptation strategies but also highlights the limited empirical evidence on their practical implementation, particularly in contexts involving cognitively diverse users.

	Dimensions					
	Goal (D1) *What is the purpose of the adaptation?*	**Target** (D2) *Which aspects of the WAS should be designed adaptively?*	**Initiator** (D3) *How should the adaptation be triggered?*	**Control** (D4) *What influence should the user have on the adaptation?*	**Moment** (D5) *When should the adaptation be initiated?*	**Evaluation** (D6) *How should the adaptation be evaluated?*
Options	*Learning* *Performance* *Motivation* *Ergonomy*	*Instruction Structure* *Instruction Content* *Interaction* *Presentation*	*Specific user behavior* *Analysis of last executions* *Analysis of recent interactions* *...*	*Fully manual* *Recommendation* *Objection* *Automated* *Fully system controlled*	*Immediatly* *Between steps* *Between executions* *Time-based*	*User feedback* *Data analysis*

Fig. 1. Adapted representation of the multidimensional design space from [50], illustrating six key dimensions and various implementation options for each dimension.

2.4 Summary

In summary, while inclusive and ability-based design principles have laid important foundations for supporting persons with cognitive disabilities (PwCD), practical implementations of adaptive workplace assistance systems (WAS) remain limited, particularly in real-world industrial settings. Prior research has largely emphasized conceptual frameworks or fully system-driven adaptations, with comparatively little attention to user preferences or mixed-initiative approaches. Our study addresses this gap by examining adaptation needs and design opportunities directly with PwCD in sheltered workshop environments. By grounding our investigation in lived experiences and participatory feedback, we provide empirical insights that advance the operationalization of an adaptive design of digital WAS for PwCD.

3 Context

Our study was conducted in collaboration with a German non-profit integrative organization for people with disabilities. The organization comprised of a certified sheltered workshop as well as an inclusive company with work areas in the fields of electronics and metal manufacturing, packaging and gardening and landscaping. This combination provided workers with disabilities with secure employment and a direct access to the inclusive labor market. The case study was primarily conducted in the vocational training area as part of the company's sheltered workshop. This area served as the first entry point for new disabled employees and offered various training and education opportunities to prepare them for a job in one of the company's work areas according to their individual abilities and interests. Unlike the integrative work areas, where people with and without disabilities collaborate closely, the vocational training area is reserved exclusively for individuals with disabilities, who are supported by a team of social, educational, and technical professionals. A majority of the employees were PwCD with various types and severities of cognitive disabilities. According to the experts, their disabilities primarily manifested themselves in reduced memory performance, shorter attention spans and longer reaction times, as well as partial difficulties with reading and writing. Furthermore, some individuals in this group were also affected by additional physical disabilities, which primarily affected aspects of their mobility, reach, precision or strength. In the vocational training area, activities from the various work areas were carried out. More complex and variant-rich tasks were broken down into a series of sub-processes, distributed across multiple workers based on their individual capabilities, and executed at several workstations. The activities primarily involved assembly and packaging tasks for external regional industrial clients. These included the assembly of circuit boards with through-hole technology (THT) components, cable assembly or the assembly and packaging of mechanical and electrical products. The activities were usually carried out at industrial workbenches equipped with multiple component boxes for the provision of components, work materials, tools (screwdrivers, cutting machines, etc.) and testing equipment (weight measurement, optical testing, functional testing, etc.) for the corresponding task. The vocational training area also possessed a non-adaptive projection-based WAS installed on an industrial work table. The system allowed to display texts, images and videos as well as graphical highlights and virtual buttons in the workspace. Via a hand-tracking feature, the system was also able to detect access to the component boxes and the virtual buttons to create interactive step-by-step instructions.

Interaction Design and Architecture(s) Journal - IxD&A, N.65, 2025, pp. 144 - 169
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4 Case Study

In this section, we present the methods and results of our investigations towards the adaptive design of digital WAS for PwCD. In accordance with the initially posed research objectives, the case study was divided into two parts (Fig. 2). In the first part, we conducted observations, an experiment and contextual interviews to investigate the challenges PwCD face during the use of non-adaptive WAS. In the second part, we conducted a survey and another experiment to assess the preferences of PwCD regarding the adaptive design of WAS.

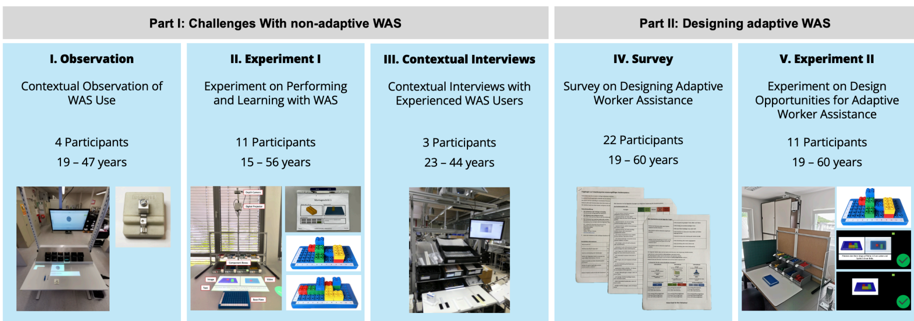

Fig. 2. Overview of the case study process and the research methods, systems and tasks used.

4.1 Phase I - Contextual Observation of WAS Use

The goal of the first phase was to observe how PwCD interact with a non-adaptive WAS in a real-world vocational training context. This helped identify usability challenges and inform later phases of system adaptation.

Participants and Setting. Four employees (1 female, 3 male), aged 19 to 47, from the vocational training department participated in the observations. According to the experts, two were classified as having mild cognitive disabilities and two as moderate disabilities. In addition, one participant was described as illiterate. The observations were conducted at the vocational training facility using a projection-based WAS integrated into a standard industrial assembly workstation.

WAS Setup and Task. The WAS setup included a projector, a depth camera, a computer unit, and a display mounted at head height (Fig. 3). The system allowed to present step-by-step instructions as projections on the table surface and on the display. The instructions included images and short textual descriptions for each of the 12 steps of the task (6 picking, 6 assembly). Additionally, white and green projected

Interaction Design and Architecture(s) Journal - IxD&A, N.65, 2025, pp. 144 - 169
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rectangles were used to highlight the component boxes. Step changes were triggered through hand tracking by activating a virtual button projected onto the table surface. As a task for the observations, we used a real work process where the participants had to assemble several metal parts using a fixture and an electric screwdriver.

Procedure. During the observation, a supervisor first demonstrated the assembly process using the WAS. The participants were then asked to repeat the task several times independently. Two researchers observed the sessions and took structured notes on task behavior, interface interaction, and usability issues. After the last repetition, the participants completed a short interview about their experience using the WAS.

Observational Findings. All participants successfully learned to operate the WAS independently after a brief familiarization phase. Task completion times and error rates improved between repetitions as participants showed progress in learning the task. The duration of this familiarization phase appeared to be related to the cognitive abilities of the participants. A recurring issue concerned difficulty with activating the virtual button used to progress through the steps. Initially, participants held their hand in the activation area longer than needed. But after a few runs, they began to remove it too early, leading to missed activations and repeated attempts. The illiterate participant was able to follow the task using image-based instructions but was unable to interpret text-based error messages. He could not resolve the picking errors until a supervisor explained that the system also highlighted the correct component box, allowing him to proceed without understanding the text.

Fig. 3. View of the projection-based WAS in the vocational training area of the sheltered workshop (left) and the component to be assembled during the observations (right).

User Feedback. In the interviews, all four participants reported overall positive impressions of the WAS and could imagine using similar systems in the future.

However, they expressed dissatisfaction with the timing of button activation and noted that some colleagues, such as illiterate users, would require additional adaptations. This feedback emphasized the importance of user-adjustable timing and multimodal support.

Summary. The observations revealed both the potential and the limitations of non-adaptive WAS for cognitively diverse users. While basic system operation was manageable after familiarization, interaction issues and accessibility barriers—especially related to timing and literacy—highlighted the need for more flexible, adaptive support. These findings informed the design activities and adaptation strategy selection in the following phases.

4.2 Phase 2 - Experiment on Performing and Learning with WAS

Building on the contextual observations from the first phase, this phase examined how PwCD perform and learn over repeated task executions using a digital WAS compared to paper-based instructions. The experiment focused on evaluating performance, workload, and usability challenges identified in the initial observations with more detail.

Participants. The experiment involved 11 employees (6 male, 5 female) from the vocational training department, aged 16 to 56 years (M = 33.54, SD = 15.51). The experts stated that all participants had mild to moderate cognitive disabilities. Nine participants reported being open towards using new technologies and two reported to have limited prior experience with digital WAS.

Setup and Task. The study was carried out using a portable projection-based WAS setup and the same software as in the first phase (Fig. 4). The setup consisted of a digital projector, a depth camera and eight component boxes. The task involved assembling Duplo bricks of two different sizes and four colors in a prescribed

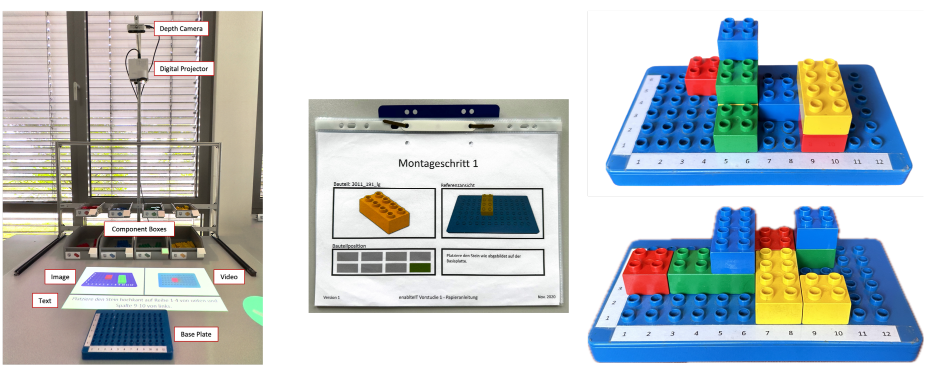

Fig. 4. View of the portable projection-based WAS used for the experiment (left), the paper-based instruction (center) and the end states of the Duplo tasks for the WAS (top-right) and the

sequence onto a baseplate. Each variant of instruction (WAS and paper) comprised 16 steps, alternating between picking and placing bricks. The WAS provided textual instructions, images and videos, and projected overlays, while the paper-based version included textual instructions and images. The instructional content differed slightly in order and layout to match the delivery medium.

Procedure. After informed consent and a demographic questionnaire, the participants completed seven repetitions of the Duplo task with both types of instruction. Before using the WAS, the participants completed a short demo task consisting of three picking steps and three placement steps. They were allowed to repeat the demo until they felt confident in using the system. Processing times and error rates were automatically recorded in the WAS condition and manually extracted from video recordings in the paper-based condition. After each type of instruction, the participants completed a simplified NASA Task Load Index (NASA-TLX). In a final interview, the participants reflected on their experiences and challenges using the WAS.

Quantitative Results. Both types of instruction showed a consistent reduction in completion time over repeated trials (Fig. 5). A significant difference in processing time between WAS and paper-based instructions was found only in run four (p = .042); all other runs showed no significant difference. For the runs with the WAS, pairwise t-tests revealed significant differences between the first and the second run (p < .001), the second and the third run (p = .002), the third and the fourth run (p = .021) and the fifth and the sixth run (p = .043). For the runs with the paper-based instructions, there were significant differences between the first and second run (p < .001), the second and third run (p = .035), the third and fourth run (p = .007) and the sixth and seventh run (p = .005). The rates of picking and placement errors varied between individuals (Fig. 6). On average, participants made 2.09 picking errors (SD = 2.43) and 2.45 placement errors (SD = 3.24) when using paper-based instructions.

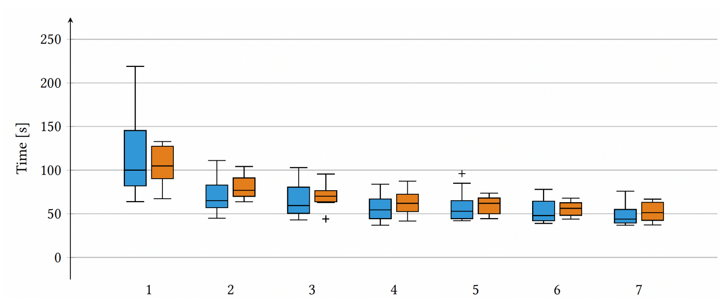

Fig. 5. Overview of the distribution of processing times for the seven repetitions with the paper-based instructions (blue) and the WAS (orange).

Interaction Design and Architecture(s) Journal - IxD&A, N.65, 2025, pp. 144 - 169
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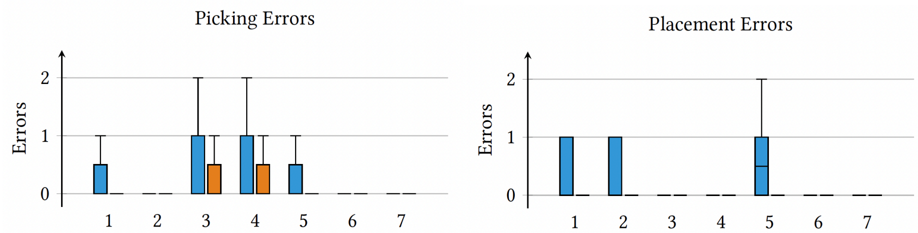

Fig. 6. Overview of the distributions of the picking errors (left) and the placement errors (right) for the seven repetitions with the paper-based instructions (blue) and the WAS (orange).

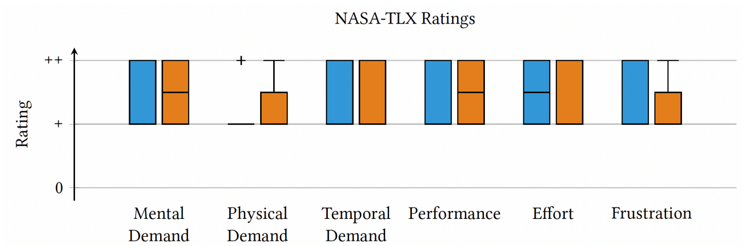

Fig. 7. Overview of the distribution of the simplified NASA-TLX ratings for the paper-based instructions (blue) and the WAS (orange).

Using the WAS, they made fewer errors on average: 1.27 picking errors (SD = 1.62) and 1.45 placement errors (SD = 2.07). However, statistical comparisons did not reveal significant differences between instruction types for either error category. The workload ratings showed similarly positive results for both instruction types (Fig. 7). The average NASA-TLX score was 1.38 (SD = 0.289) for paper-based instructions and 1.41 (SD = 0.368) for WAS. A Wilcoxon signed-rank test did not show a significant difference (p = .327).

Observational Insights. Observations confirmed our previous findings from the first phase. Participants quickly adapted to both types of instruction, but some struggled with the timing of the button activation while using the WAS. After several repetitions, multiple participants began to remove their hands too early from the activation area. Furthermore, with repeated executions, participants in both conditions relied progressively less on the instructions as their familiarity with the task increased, often consulting them only briefly or omitting them altogether in later repetitions.

Participant Feedback. The participants generally responded positively to using the WAS, but emphasized that it should not interrupt their workflow. Several noted that step-confirmation and activation delays became frustrating over time. One participant (P2) explained that "*you have to confirm steps too often and it takes too long to* *activate the buttons after a few passes*." Another (P7) remarked that "*the separation into picking steps and placement steps is too detailed over time*", suggesting that experienced users might benefit from more compact instructions. A third participant (P9) stated that "*confirming errors when accidentally reaching into the wrong box is too cumbersome*". Participants further expressed a desire for adaptive support that responds to individual needs and levels of experience. Some suggested adjusting the activation time of the buttons. Others proposed the option to hide or skip unnecessary instruction content, such as text, images, or videos, once the task became more familiar. One participant (P5) noted that "*the texts and videos became obsolete after a few runs*". Two others explicitly recommended merging the picking and placement steps for experienced users to reduce redundancy and speed up the workflow.

Summary. The experiment demonstrated that while both types of instruction enabled learning and task improvement over time, WAS users encountered specific interaction issues. Although objective performance measures showed little difference, qualitative insights pointed to a clear need for adaptive mechanisms in WAS. These should adjust pacing, content granularity, and interaction demands according to the users experience and abilities. The results directly informed the selection of adaptive strategies evaluated in Phase 4.

4.3 Phase 3 - Contextual Interviews with Experienced WAS Users

This phase aimed to explore challenges occurring during the long-term use of digital WAS by PwCD. By conducting contextual interviews with experienced users, we sought to understand recurring usability issues and gather insights into how adaptation might better support autonomy and workflow.

Participants and Setting. We interviewed three female employees, aged 23 to 44, from one of the integrative work areas who had been using a projection-based digital WAS daily for several weeks to support an order-picking and packaging task. All participants were classified by their supervisor as having mild cognitive disabilities.

Task and WAS Setup. The supported task involved folding a packaging box, retrieving components in a predefined sequence, and sealing the box with barcode labels. The WAS guided users with projected visual overlays and component images. Step confirmation occurred automatically via hand-tracking upon picking action. The WAS setup was similar to the system from the first and second phase, but included three component box levels and three barcode labeling areas on the table surface (Fig. 8).

Fig. 8. View of the projection-based WAS used by the experienced workers in the production environment of the sheltered workshop.

Procedure. Contextual interviews were conducted by a single researcher during the participants' regular work shifts. Interviews were informal and situated, allowing participants to demonstrate challenges directly on the system. Participants were asked to reflect on their experience and suggest improvements to the system design.

Key Findings. Participants reported that the WAS was particularly helpful during the early learning phase of new or rarely performed tasks. As one participant stated, "*The system helps to learn the correct sequence at the beginning*." However, as their familiarity increased, reliance on the system decreased, and the participants felt that the WAS increasingly hindered their workflow. Specifically, the participants noted that the need to confirm every step and handling errors became unnecessarily disruptive as their work speed improved. As one user put it, "*The system could not keep up with the increasing work rate*." Another participant reported using the WAS primarily in the morning or when switching between task variants to refresh her memory. Participants generally supported the idea of an adaptive WAS that would reduce required interactions as users became more confident. One participant stated, "*Adapting the instructions to my personal experience would be beneficial*." Additionally, two users mentioned ergonomic challenges due to their smaller body size, suggesting that adaptive support should also address physical setup. As one expressed, "*It would be beneficial if the height of the work surface could also be adapted*."

Summary. The interviews reinforced prior findings: WAS can effectively support initial learning but may impede the workflow as users gain experience. Participants expressed a strong desire for adaptive behavior that reduces interruptions and

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accommodates cognitive and physical diversity. These insights helped define user-driven adaptation scenarios explored in Phase 4.

4.4 Phase 4 - Survey on Designing Adaptive Worker Assistance

After examining the challenges and difficulties faced by PwCD in using non-adaptive digital WAS during the first three phases, the fourth phase focused on exploring their preferences regarding the adaptive design of digital WAS. To this end, we conducted a written survey with cognitively disabled employees at the sheltered workshop, aiming to evaluate attitudes toward different adaptation concepts and to gather feedback on content personalization, user control, and feedback representation.

Method. The survey was designed in close collaboration with social workers from the vocational training department to ensure clarity and accessibility. It consisted of four sections: (1) a participation statement and brief introduction to WAS, (2) demographic and attitudinal questions about WAS usage, (3) 13 statements on different adaptation aspects, rated on a 5-point Likert scale, and (4) three illustrated examples of adaptive feedback mechanisms (Fig. 9), with questions about information clarity and user influence. Statements in the third section covered four adaptation themes: general attitudes, specific adaptation strategies, progress feedback, and user control. The survey was distributed in paper form by social workers across departments. Participants could complete it during working hours or at home with optional assistance from staff or family, if required.

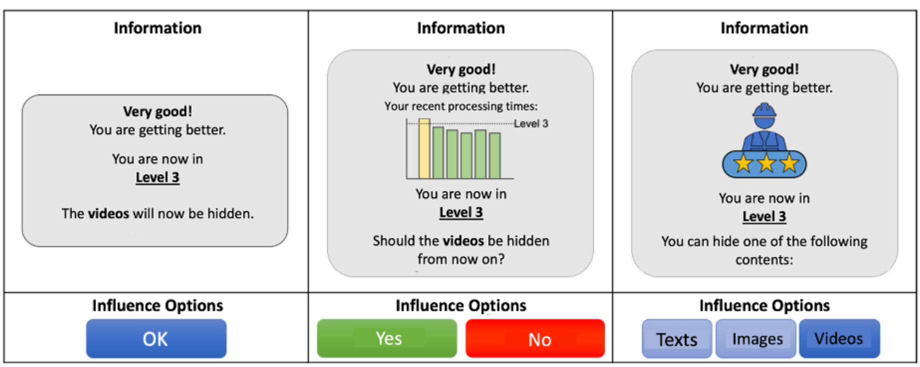

Fig. 9. Illustrations informing the user about a performance progress and the possibility of adapting the assistance visa three different information and influence options.

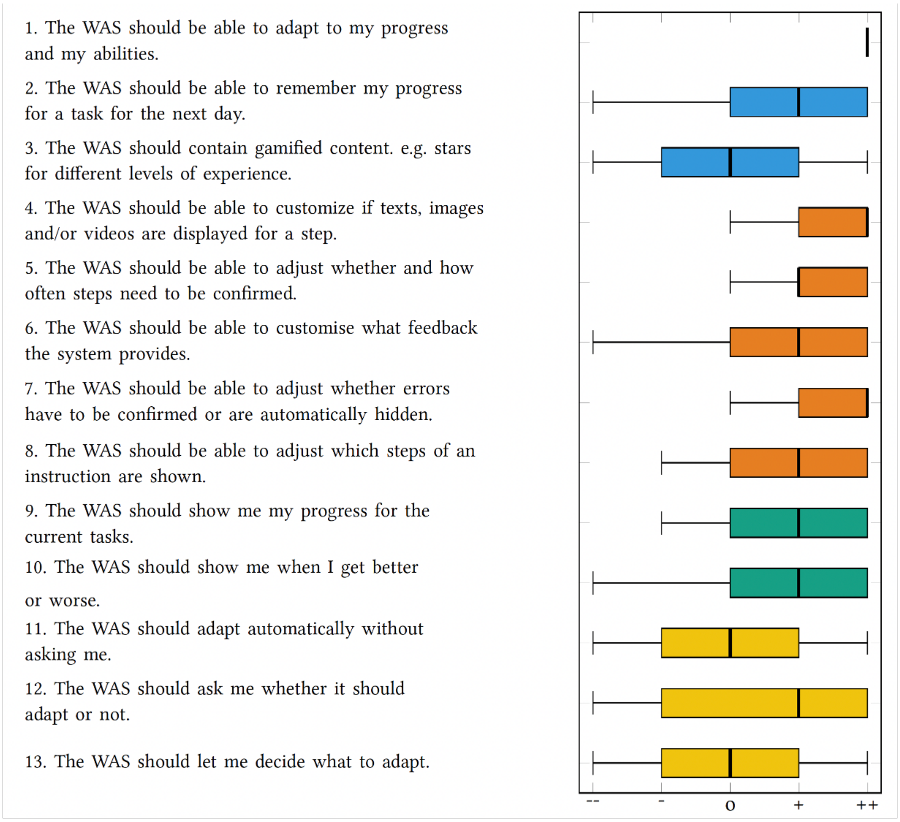

Fig. 10. Distributions of the feedback on the 13 statements towards general attitudes (blue), specific adaptation strategies (orange), progress feedback (green), and user control (yellow).

Participants. We received feedback from 24 participants. Two participants were excluded due to incomplete responses, resulting in 22 valid responses (10 female, 12 male), aged 19 to 60 years. Eighteen participants reported being generally open towards using new technologies, and nine stated having prior experience with WAS.

Results. The feedback on the 13 statements are shown in Figure 10. A majority of participants generally supported an adaptive design for WAS. Statements 1 and 2 on general adaptivity and memory features received high median scores, while statement 3 on gamification was rated neutral, indicating ambivalence. Statements 4 to 8, addressing specific adaptation strategies, received mostly positive ratings. Statements 4 and 7, in particular, showed strong support. Statements 5, 6, and 8 were rated positively but showed more variation in responses. Statements 9 and 10 on performance reflection were also received positively. The feedback on user control was more divided. Statements 11 on automatic adaptation and statement 13 on manual adaptation had neutral medians and wide interquartile ranges, suggesting mixed views. Statement 12 on recommendation-based adaptation was rated slightly more positively but also showed variability, indicating differing preferences for how much control users want over adaptation. For the illustrated examples of adaptive feedback, most participants rated the information density of all three versions as "enough". However, in terms of user influence, the first two examples were preferred, while the third—which gave users extensive control—was seen as "too much" by many participants.

Summary. The survey results affirmed general support for an adaptive design of WAS, particularly in terms of simplified instructions, memory features, and performance feedback. However, preferences regarding user control were less consistent, underscoring the need for flexible, optional involvement in adaptation. These findings supported the creation of adaptive interaction approaches explored in the next phase.

4.5 Phase 5 - Experiment on Design Opportunities for Adaptive Worker Assistance

While the survey conducted in Phase 4 showed general support for the adaptive design of WAS, it did not reveal clear preferences for specific adaptation approaches. Therefore, this final phase aimed to investigate user preferences for different adaptive features through a controlled, exploratory experiment using a Wizard-of-Oz simulation.

Participants. The study involved 11 participants (5 male, 6 female) aged 19 to 60 years ($M = 38.86$, $SD = 14.49$), all from the vocational training department of the sheltered workshop. Participation was voluntary and conducted during working hours. Eight participants had taken part in previous phases of the study, while three had no prior experience with WAS.

Experimental Setup. To simulate adaptive functionality without requiring a fully implemented system, we employed a Wizard-of-Oz design using a partially animated slide presentation controlled by the experimenter. The presentation was delivered through the portable WAS setup from the second phase and incorporated the same step-by-step Duplo assembly task (16 steps: 8 picking, 8 placing). Each picking step displayed a component image, a short textual instruction, and a visual highlighting of the corresponding component box, while each assembly step included an image, an instructional video, and accompanying textual guidance. Step transitions were triggered by a button located at the right side of the workspace.

Procedure. Participants first completed three repetitions of the assembly task using the non-adaptive WAS instructions to get familiar with the system. Following this, they were introduced to 9 different adaptive approaches, each modifying a different aspect of the WAS (Tab. 1). For each approach, participants could explore and test the different available options. After trying out an adaptation strategy, participants were asked to rate its desirability using a 5-point Likert scale ranging from very undesirable (--) to highly desirable (++). They were also asked to indicate their preferred option for each strategy. At the end of the session, we used a brief closing questionnaire to collect additional feedback on how users should be involved in controlling and evaluating the adaptation.

Tab. 1. Overview of the 9 approaches to adapt different aspects of the WAS.

#	Approach	Description	Options
1	Content selection	Adaptation of the instructional content shown by the WAS (text, image, video)	3 instruction types: (text, image, video), (image, video), (image)
2	Experience-related instruction sets	Adaptation of the instructional content and the interactions according to the experience level of the user	3 instruction types for beginners, advanced and experts
3	Content positioning	Adaptation of the position of the instructions on the table surface.	2 instruction steps for one picking step and one assembly step each with different instruction layouts
4	Content sizing	Adaptation of the size of the instructions on the table surface.	2 instruction steps for one picking step and one assembly step each with different instruction sizes
5	Button activation duration	Adaptation of the duration for activating the virtual buttons to switch between steps or confirm errors	4 activation buttons with different activation durations
6	Step change duration	Adaptation of the delay before switching to the next step	3 picking steps with different delays before moving to the next step
7	Error presentation	Adaptation of the way errors are presented by the WAS.	3 error presentations: (text), (complex image), (simple image)
8	Error handling	Adaptation of the interaction required in case of an error.	3 interactions: (manual confirmation), (automatic hiding 1s), (automatic hiding 2s)
9	Flexible instruction sequence	Adaptation of the flexibility of the sequence in which instruction steps have to be executed.	1 instruction variant with two steps: (build first layer), (build second layer)

Results. The key results of the experiment are summarized in Figures 11–13. As shown in Figure 11, all adaptive approaches were evaluated positively by participants, with eight of the nine approaches receiving a median rating of (++), indicating strong approval. Only content selection (Item 1) received a lower median rating of (+), reflecting slightly reduced support and greater variability in preferences. A Friedman test confirmed significant differences among the ratings ($\chi^2(8) = 15.98$, $p = 0.043$), with a Kendall's W of 0.182, suggesting low to moderate agreement across rankings. Despite the overall positive evaluations, some approaches elicited more mixed feedback. Specifically, content positioning (Item 3), content sizing (Item 4), step

Interaction Design and Architecture(s) Journal - IxD&A, N.65, 2025, pp. 144 - 169
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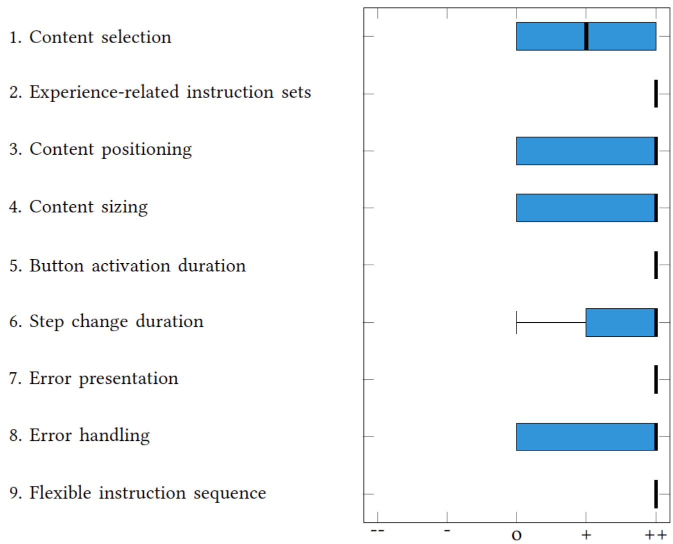

Fig. 11. Distributions of the desirability ratings for the nine adaptive WAS design approaches as described in Table 1.

change duration (Item 6), and error handling (Item 8) displayed lower quartile ratings of (o) or (+), indicating heterogeneous user preferences. Figure 12 provides further detail on individual configuration preferences. For content selection, most participants (n=7) preferred hiding videos first, while four preferred hiding text. In error handling, the majority (n=7) favored automatic hiding after one second, while four preferred a two-second delay; no participant opted for manual confirmation. Preferences for button activation duration varied: five participants indicated no preference, while other selected 250 ms (n=3), 375 ms (n=1), or 500 ms (n=2). None selected the maximum duration of 750 ms. Regarding step change duration, most participants (n=7) preferred immediate transitions (0 ms), while others selected 500 ms (n=3) or 750 ms (n=1). Feedback on user control and adaptation evaluation is summarized in Figure 13. For adaptation control, eight participants preferred a recommendation-based system that suggests changes, while three favored manual adjustments; none supported fully automated system-driven adaptations. Regarding evaluation of adaptation success, preferences were divided: five favored system-based data evaluation, while six preferred user feedback. Finally, the closing questionnaire revealed strong interest in adaptive WAS for daily work. Ten participants reported that such systems would help them complete more complex tasks.

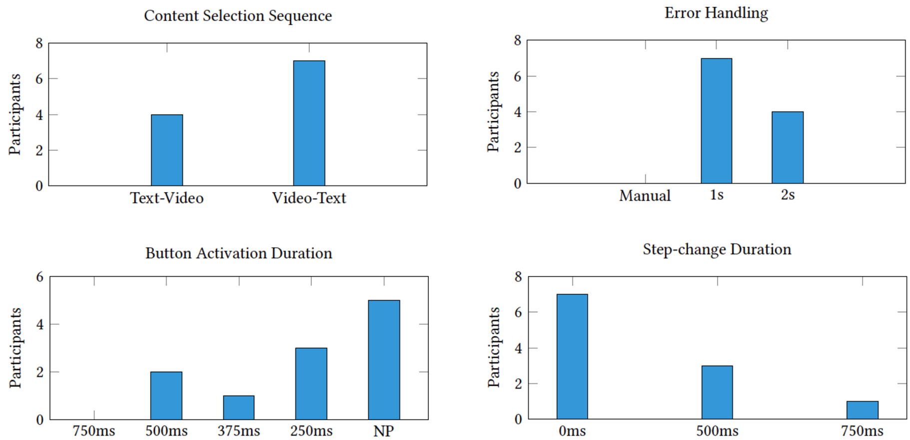

Fig. 12. Overview of the preferences of the participants for the options for configuring the various approaches for adapting the assistance.

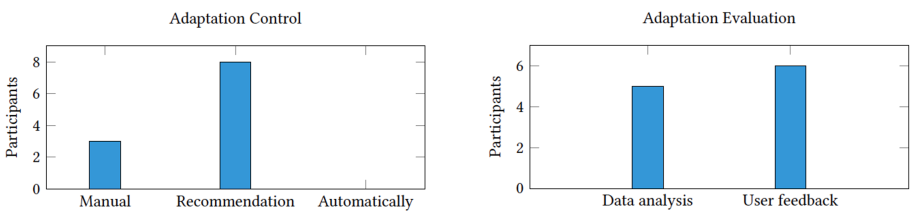

Fig. 13. Overview of participants' preferences for control over adaptation (left) and evaluation of performed adaptations (right).

Summary. The experiment confirmed the strong desire of PwCD towards adaptive features in digital WAS. However, it also revealed significant individual variability in preferences—especially in timing, content presentation, and error handling. The rejection of fully automated adaptation in favor of approaches that at least involve users emphasizes the need for mixed-initiative approaches. These insights support the case for configurable, user-sensitive adaptive WAS solutions that balance system guidance with user control.

5 Discussion

This section discusses the findings from our case study in relation to the research objectives posed in the first section, while situating them within prior research on assistive technologies, WAS, and adaptive interaction design. We begin by reflecting on the challenges PwCD face when using non-adaptive WAS, followed by a discussion of design opportunities for adaptive systems that align with users' preferences.

5.1 Challenges of PwCD with Non-Adaptive WAS

Our study aligns with and extends prior work showing that non-adaptive WAS can offer useful task support for PwCD, particularly during early task familiarization. However, as highlighted in previous literature [51], rigid instruction flows and static content presentation can result in a mismatch between system behavior and user needs as familiarity and competence increase [32]. Our observations in Phases 1-3 support this: participants experienced over-assistance, increased frustration, and workflow disruptions due to the inflexibility of the system. These findings echo critiques of traditional *Universal Design* and *Design for All principles*, which often assume a homogeneity of user needs and fall short in addressing the cognitive diversity within target populations [17]. While *Inclusive Design* and *Ability-Based Design* advocate tailoring support to user capabilities, our findings suggest that systems must go further —by not only adapting, but also doing so in ways that preserve user agency. Participants consistently emphasized the need for greater transparency and control over system behavior, challenging the notion that adaptation should be entirely system-driven [34]. Moreover, individual differences in preferences for interaction timing, error handling, and instructional pacing reflect the diversity of cognitive abilities among PwCD. These results align with earlier research on adaptive interfaces, which caution against one-size-fits-all timing or feedback mechanisms [35,36]. Non-adaptive WAS, by failing to accommodate such differences, risk alienating users or inhibiting skill development.

5.2 Designing Adaptive Worker Assistance Systems for PwCD

Our results provide actionable support for integrating adaptive mechanisms into WAS. In Phases 4 and 5, participants consistently favored features that allowed personalization of instructional content, pacing, and interaction flow. These preferences affirm the value of applying mixed-initiative adaptation strategies [33,36], where the system can recommend changes but the user retains decision-making authority. This is particularly relevant for PwCD, who may prefer gradual increases in autonomy over abrupt automation [39,42]. In contrast to system-initiated-only approaches, our participants expressed discomfort with adaptation that occurs without explanation or consent. This finding supports recent calls for incorporating user empowerment principles into adaptive system design [20], particularly for users with varying trust in automation. The design space introduced in [51] offers a useful conceptual framework for adaptive WAS, but our empirical results help refine how its dimensions—such as user control, trigger mechanism, and evaluation method—can be implemented in practice. For example, participants preferred adaptation success to be evaluated through a combination of user feedback and performance data, reflecting a need for participatory adaptation loops rather than purely algorithmic reasoning. Importantly, the strong desire towards adaptive WAS in our study aligns with the broader goals of inclusive HCI and sustainable workplace inclusion, as emphasized in previous WAS research targeting PwCD. Participants explicitly stated that adaptive assistance could help them perform more complex tasks and remain engaged—an outcome directly supporting the UN's Sustainable Development Goal 8 on decent work and inclusion.

5.3 Limitations

Despite the promising results, our study has several limitations. The sample size was small and drawn from a specific vocational training setting, limiting generalizability. As noted in other studies, preferences for adaptation may vary widely with task type, organizational context, and user demographics. Additionally, our tasks were relatively simple compared to real-world industrial scenarios. Future work should evaluate adaptive WAS across more complex environments and over longer periods to assess sustained impact and evolving user needs. Moreover, the use of Wizard-of-Oz methods applied in Phase 5, while effective for prototyping, limits insights into how users would respond to fully automated adaptation in real time. Future research should involve functional adaptive systems, as well as triangulate subjective preferences with long-term usage data to account for novelty effects and potential social desirability biases.

6 Conclusion

In this study, we investigated the challenges and preferences of people with cognitive disabilities (PwCD) in relation to the adaptive design of Worker Assistance Systems (WAS). Within a two-part case study spanning five phases, we investigated real-world usage scenarios, explored specific adaptation features, and evaluated user feedback through observational, experimental, and survey-based methods. Our findings confirm that static, non-adaptive WAS can provide useful support during initial task familiarization but often fail to accommodate the long-term and individualized needs of PwCD. As task familiarity increases, rigid systems become inefficient, highlighting the importance of a flexible and adaptive design. Across different phases, participants expressed clear preferences for adaptation strategies that allow user influence, particularly favoring recommendation-based systems over fully automated approaches. This underscores the need for mixed-initiative interaction models that balance system intelligence with user control. Furthermore, participants responded positively to various adaptation features, including adjustable timing, content simplification, and flexible error handling. However, the preferences were not uniform, revealing the diversity of needs even within our user group. This emphasizes the value of user-friendly and customizable design strategies in future WAS development. Despite these promising insights, limitations such as the small sample size, simplified task scenarios, and short study duration restrict the generalizability of the results. To address this, future research should involve more diverse user populations, evaluate adaptive systems in complex and realistic work settings, and include long-term usage studies. Furthermore, deploying fully functional adaptive systems, beyond Wizard-of-Oz prototypes, will be essential to validate these findings under real-world conditions. In conclusion, adaptive WAS have a strong potential to improve task performance, workplace inclusion, and autonomy for PwCD. By embracing adaptive, user-centered design approaches and grounding system behavior in both user feedback and performance data, systems can become more inclusive and effective to empower PwCD in meaningful employment.

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CRediT author statement.
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