# Providing Context-Sensitive Mobile Assistance for People with Disabilities in the Workplace

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**Abstract.** Recent research has shown that computer-based Assistive Technology (AT) has the potential to support individuals with disabilities in production environments. At the same time, step-by-step instructions enable workers to be successful in their performance of industrial tasks that were formerly difficult to accomplish. We merged these two types of intervention and developed an application running on a mobile device that can assist disabled workers working more independently. In an evaluation study, we investigated how our assistive system affects the task efficiency as well as participants' subjective evaluation. Results show advantages when using the assistive prototype with regard to users' task efficiency and subjective evaluations.

**Keywords:** Assistive Technology · People with Disabilities · Human Computer Interaction · Industry 4.0 · Inclusion · Context-Sensitive Assistance · Step-by-Step Instructions · Production · Mobile Assistance

## 1 Introduction

Recent studies show, that about 15% of the current world's population suffer from some form of disability and it is estimated that this number will increase in most countries [1]. Studies also show that the rate of unemployment for people with disabilities is significantly higher than for people without disabilities [2,3]. At the same time, a growing shortage of qualified personnel is observable in many companies [4,5]. In this context, new assistive devices and technologies are emerging, which bear great potential to enhance the quality and satisfaction of work life for individuals with disabilities by empowering their independence and inclusion in the workforce [6,7].

In this paper, we demonstrate how such technologies could be used to support the inclusion of individuals with disabilities in production processes. The focus of our work is on enabling users to accomplish repetitive tasks in a more refined manner, without the need for support from any workers. To achieve this, we applied a user-centered design approach to set up an assistive prototype system. It enables people with disabilities to complete industrial tasks, like for example changing a broken drill head on an industrial machine supported by guided instructions on a mobile device. It enables the workers to create easily comprehensible maintenance instructions with associated QR-codes, which can be printed and subsequently placed on the corresponding machine. If required, users can access the instructions by simply scanning the code with a mobile device.

This paper is structured as follows. In Section 2, we present relevant related approaches to our work. In Section 3, the implemented prototype system is described. An evaluation study with users of the target group including results is presented in Section 4. Finally, results are discussed in Section 5.

## 2 Related Work

The usage of assistive technology has the strong potential to enhance the level of autonomy of individuals with disabilities [8,9]. Studies have shown that employing assistive technology can be beneficial in physical [10,11,12] and mental rehabilitation [13], as well as in higher learning capabilities [14] and employment outcomes [15]. With the increasing dissemination of mobile technology, advantages of mobile phones and tablets such as ubiquitous access and portability [16] without any time, location and device restrictions [17], have been embedded into assistive technologies. Through the integrated features in mobile devices such as digital cameras, wireless internet access, location-detection, speech-to-text and user-centered applications, assistive systems extend their technical capabilities and cost-effective accessibility of information for people both with [18,19,20,21] and without [22,23,24] disabilities in all economic and social areas of life.

In particular, assistive systems with step-by-step instructions for disabled workers in industrial environments, including technologies such as Augmented (AR)/Virtual Reality (VR), have gained high attention in recent years. For instance, Korn et al. [25] investigated the potentials of using projection-based Augmented Reality for impaired people in production. They implemented an assistive system projecting assembly instructions immediately into the workplace (in-situ). Results showed that the impaired participants could reduce their assembly time and reduced error rates by using the prototype. However, some participants were overwhelmed by interacting with the new system and performed worse. Funk et al. [26] compared in-situ vs. pictorial instructions in a study with cognitively impaired workers. Results revealed that the workers are three times faster by using in-situ instructions and reduce their error rate with up to 50 percent. In a further study [27], they compared a contour-, a video- and a pictorial-visualization to a control group using no visual feedback. They found that disabled participants made fewer errors and were faster using the contour-visualization in an assembling task. In a comprehensive study, Büttner et al. [28] compared in-situ projection and hand-mounted display (HMD) to a paper baseline in a workplace scenario. Their results indicated that performing tasks with both ins-situ and paper instructions are significantly faster and more accurate than using HMD. Aksu et al. [29] investigated how step-by-step instructions affect users' task efficiency and subjective evaluation while performing an industrial task. They developed a prototype that is equipped with remote controlled LEDs in order to guide disabled workers through the cutting steps by presenting video instructions on a mobile device. Here, results showed a positive impact across experimental conditions time on task, task accuracy and user satisfaction.

In addition, Auto-ID technology such as RFID and QR codes seems to be a promising technology to support people with disabilities in their everyday live. Al-Khalifa [30] proposed a barcode-based mobile system to assist visually impaired and blind people to identify objects and products in their environment such as in museums or shopping malls. Utilizing a QR reader on the mobile phone, the user can scan objects and products tagged with QR-codes to get more information about them. Tatsumi et al. [31] investigated the use of barcodes and RFID tags in educational environments and showed that these technologies are effective in providing blind people with adequate information. They demonstrated their system in two examples. In the first scenario, they used bar codes on a bulletin board where blind students could scan them using a PDA ("Personal Digital Assistant") and get announcements from the server using a voice reader software. The second scenario was about building a messaging system connecting students and teachers by using a PDA with a RFID unit that read the messages from the RFID tag attached to a laboratory door. Similar assistive systems for mobile tagging can be found in healthcare [32] and location detection [33,34]. Uzun and Bilgin [32] implemented a QR code-based system that identifies and provides medical information about the patient to decrease medical errors. In [33,34], a wayfinding system using QR codes has been presented to provide current directions for people with special needs. Barcode-based technology is also applied to increase efficiency and flexibility in production environments [35,36]. However, mobile systems using barcodes and step-by-step instructions have not yet been applied in production environments although this is a promising direction especially for people with disabilities. In this paper, we explored how to build a user-centered solution that can also be transferred to similar production tasks in a modified form. We tested our concept in a comparative user study with disabled workers from sheltered work organizations.

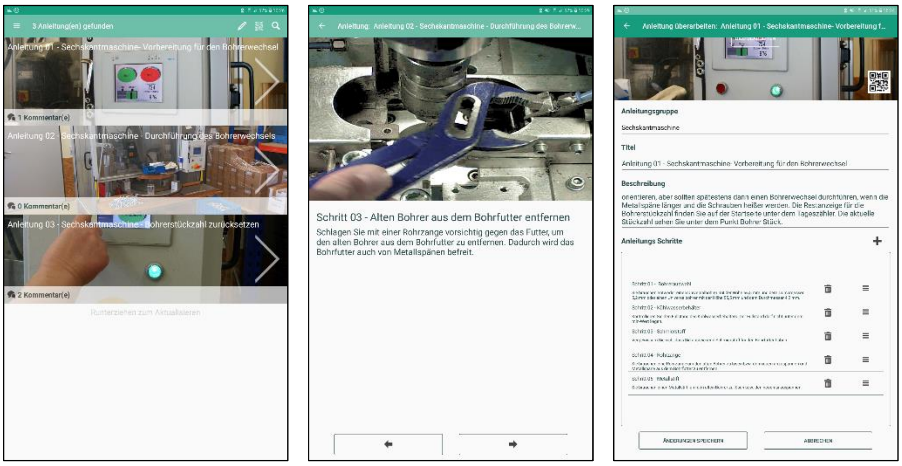
## 3 Materials and Methods

### 3.1 Prototype System

The prototype system was developed with user-centered design methodology. First, qualitative interviews were conducted with four disabled users and three attendants interacting with the industrial machine. On this basis, user requirements, needs and problems were analyzed as a starting point for the novel prototype. Based on this input, a simple interactive click-prototype was created using the tool Adobe Experience Design (XD). After evaluating the structure and usability of the design prototype with four disabled workers and three attendants, an application was developed using the IDE *Visual Studio* Professional 2017. The application consists of a front-end and a back-end (see Fig. 1). The front-end was realized with the framework Xamarin.Forms and provides a graphical user interface for guiding the workers through the instructions using QR codes to the retrieve the instruction for the machine to be maintained. The frontend also allows disabled users to add their open questions and notes by text or audio recordings. The back-end was implemented in C#. It provides attendants with comprehensive access to all application settings and is responsible for creating, editing and storing step-by-step maintenance instructions with associated QR-codes.

The application runs on a Tablet PC Samsung Galaxy Tab A with 16GB, WiFi and Android 6.0. The MVVM (Model-View-ViewModel) architecture was used to structure the code for the application. Data persistence is achieved using a single file SQLite database running inside the applications environment.

In the present study we focus on evaluating the impact of our mobile prototype on disabled workers performing a challenging and complex industrial task.


3 Anleitung(en) gefunden

Anleitung 01 - Sechskantmaschine- Vorbereitung für den Bohrerwechsel

1 Kommentar(e)

Anleitung 02 - Sechskantmaschine - Durchführung des Bohrerwechsels

0 Kommentar(e)

Anleitung 03 - Sechskantmaschine - Bohrerstückzahl zurücksetzen

2 Kommentar(e)

Runterziehen zum Aktualisieren

Anleitung: Anleitung 02 - Sechskantmaschine - Durchführung des Bohrerw...

Schritt 03 - Alten Bohrer aus dem Bohrfutter entfernen

Schlagen Sie mit einer Rohrzange vorsichtig gegen das Futter, um den alten Bohrer aus dem Bohrfutter zu entfernen. Dadurch wird das Bohrfutter auch von Metallspänen befreit.

Anleitung überarbeiten: Anleitung 01 - Sechskantmaschine- Vorbereitung f...

Anleitungsgruppe: Sechskantmaschine

Titel: Anleitung 01 - Sechskantmaschine- Vorbereitung für den Bohrerwechsel

Beschreibung: orientieren, aber sollten spätestens dann einen Bohrerwechsel durchführen, wenn die Metallspäne länger und die Schrauben heißer werden. Die Restanzeige für die Bohrerstückzahl finden Sie auf der Startseite unter dem Tageszähler. Die aktuelle Stückzahl sehen Sie unter dem Punkt Bohrer Stück.

Anleitungs Schritte

Schritt 01 - Bohrerauswahl

Schritt 02 - Kühlwasserbehälter

Schritt 03 - Schmierstoff

Schritt 04 - Rohrzange

Schritt 05 - Metallstift

**Fig. 1.** Application screenshots: Overview of existing instructions (*left*), an instruction step (*middle*), admin area (*right*).

### 3.2 Evaluation Study

The aim of our study was to compare the assistive prototype against what is otherwise often used to support disabled workers: paper-based instructions. To avoid a carry-over effect, the study applied a between-subject design with two experimental conditions: *paper-based interaction* and *tablet-based interaction*. As dependent variables we measured the following:

- *Mental Effort:* Participants' perceived mental effort in conducting the specific tasks, was assessed with the SEA scale ("Subjectively Perceived Effort") [37]. The one-dimensional scale ranges between 0 ("no cognitive effort") and 220 ("maximum cognitive effort").
- *Consequences of intuitive use:* To assess users' subjective satisfaction with intuitive use of the interface prototype, we employed the standardized QUESI questionnaire ("Questionnaire for the Subjective consequences of Intuitive use") [38]. It consists of 14 items grouped into five sub-scales: (1) subjective mental workload, (2) perceived achievement of goals, (3) perceived effort of learning, (4) familiarity, and (5) perceived error rate. The answer scale is a Likert agreement scale with five levels from 1 (fully disagree) to 5 (fully agree).

Finally, we also investigated participants' efficiency in performing tasks. To this end, we measured how long it took them to complete the tasks (*time on task*), whether they succeeded or failed at a task (*task success*) and whether they solved the task without help (*task accuracy*).

### 3.3 Procedure

The study was conducted as part of a workshop for handicapped people in a real production environment. First, participants were welcomed by the experimenter. Prior to participation, all participants were given a brief description about the aim and procedure of the study. The participants were divided into two groups. Disabled workers with no previous experience in using industrial machines were assigned to the paper-based experimental condition, in order to avoid overwhelming them with a use of mobile device. Workers who were already familiar with the machine because they used it multiple times before were assigned to the tablet-based condition (see Fig. 2).

Then, the experimenter explained the general task in a detailed manner, answered questions and clarified issues. Subsequently, participants were asked to conduct the task on the industrial machine either with the help of digital or paper instructions, depending on their assigned condition. The task consisted of three subtasks: 1) preparing the change of the drill head, 2) changing of the drill head, 3) resetting the settings after changing the drill head (see Tab. 1).

The first and third subtask included pictorial- and textural elements and were conducted in both condition. The second subtask consisted of video- and textural elements was just performed in the tablet-based condition because presenting video instructions was not comparable to the paper-based one. This is why the second subtask was examined individually for the tablet-based condition.

All step-by-step instructions were defined with the help of attendants to ensure being easily to understand for impaired workers. Therefore, pictorial, textural and video-based elements were used to create the instructions.

**Table 1.** Overview of the three subtasks for changing the drill head on the industrial machine.

| **Nr.** | **Subtask 1:** Preparation (textural+pictorial) | **Subtask 2:** Changing the drill head (texturial+audio) | **Subtask 3:** Resetting settings (textural+pictorial) |
|---|---|---|---|
| 01. | You need a universal bit with diameter of 5.2 mm. | *Open the machine door:* To change the bit, open the left door of the machine by pressing the START-button. | Press the key "Tipp" on the display to get the settings. |
| 02. | You need oil. | *Loosen the chuck:* Grasp the chuck with the pliers while you hold the handle of the chunk with the long screw. Twist the chuck counter- clockwise to loosen it. | Press the key "Amount of Pieces". |
| 03. | You need a pliers. | *Remove the bit:* Remove the bit by tapping gently on the chunk with the pliers. | Press the key "Reset". |

| | | | |
|---|---|---|---|
| 04. | You need a long screw. | Grease the chuck with the oil. | Press the key "Save". |
| 05. | | *Set the new bit:* Insert the bit into the chuck and tighten the chuck with your hands. | Press the key "Duration" to get back to the main page. |
| 06. | | *Control the bit:* The head of the bit should be 1 mm above the drill bush. Please check it. | |
| 07. | | *Tighten the chunk:* Tighten the chuck clockwise using the long screw and the pliers. | |

After finishing the task, participants provided a post-task rating of their perceived cognitive workload on the SEA scale. After finishing all three tasks, participants were requested to fill out the QUESI questionnaire. Finally, participants were debriefed and thanked for their time.

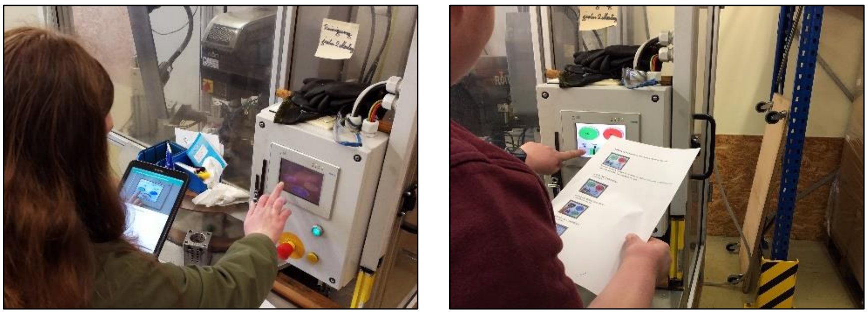


**Fig. 2.** Setting: Participants performing a task in tablet-based condition (*left*) and in paper-based condition (*right*).

### 3.4 Participants

Six German speaking participants (4 males, 2 females) with a minor impairment of intelligence took part in this study. They ranged in age from 20 to 35. The participants mean age was 27.2 years (*SD* = 10.34). Four of the participants had clinically diagnosed disruption of social behavior. One of the female participants had epilepsy. The study was conducted at the Werkstatt Begatal of Lebenshilfe Lemgo e.V., a German sheltered work organization supervising about 600 workers with cognitive and motoric limitations. Neither of the participants had previous experience with our assistive system.

## 4 Results

In the following we report results regarding the effect of experimental conditions on (1) measures of task efficiency, (2) subjective evaluations (measured with standardized inventories). Due to the small sample size, we report only use descriptive statistics to assess general trends in boths conditions. The reported results are not meant to be interpreted in the sense of inferential statistics.

### Task Efficiency

Here, we investigated participants' efficiency in performing the subtasks 1) and 3) with regard to *time on task*, *task accuracy*, and *task completeness*. All three variables were noted by the experimenter who observed the participants' activities on performing the task. Results are visualized in Figure 3.

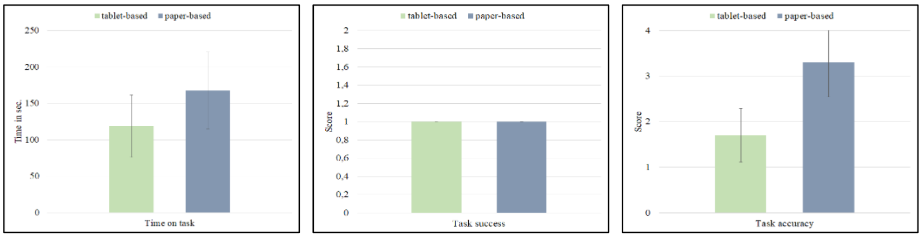


**Fig. 3.** Comparison of mean values and standard deviation for variables time on task (*left*), task success (*middle*) and task accuracy (*right*).

*Time on task:* We compared the sum of participants' completion time for finishing the task across experimental conditions. The mean task completion time in the tablet-based condition was 118 seconds while tasks performed in the paper-based condition took about 167 seconds on average.

*Task success:* Task success measures whether participants succeeded or failed at a task. A score of 1 was given for "full success" on a task, 2 for "partial success" and 3 for "no success" (see Fig. 2). In both experimental conditions, participants' success rate was maximal (*M*= 1, *SD*= .00).

*Task accuracy:* Participants' accuracy in task performance was measured as follows: 1 for "participant solved the task without help", 2 for "participant solved the task with trial & error", 3 for "participant solved the task with a single hint of the lab member" and 4 for "participant solved the task with constant support of the lab member". On average, participants' accuracy in the tablet-based condition (*M*= 1.7, *SD*= .58) was higher as in the paper-based condition (*M*= 3.4, *SD* = .76).

### Subjective Evaluation

Participants' subjective evaluation of the interaction was measured with standardized inventories in the dimensions of perceived mental effort and consequences of intuitive use.

*Mental effort*: We measured participants' perceived mental effort in task performance after performing the task with the SEA scale ranging from 0 ("no effort") to 220 ("extremely high effort"). On average, participants judged their cognitive effort in the tablet-based condition lower (*M*=13.3, *SD*= 23.09) than in the paper-based condition (*M*= 33.3, *SD* = 11.54).

*Consequences of intuitive use:* The intuitiveness of using the prototype was measured with the QUESI questionnaire on a 5-point Likert scale from 1 (fully disagree) to 5 (fully agree). Mean values and standard deviations are visualized in Figure 4. For the QUESI sub-scales, tablet-based interaction was rated as more intuitive as paper-based interaction for the following dimensions: *perceived achievement of goals* (*M*=5.0, *SD*= .00), *perceived effort of learning* (*M*=4.87, *SD*= .23) and *perceived error rate* (*M*=5.0, *SD*= .00). The dimensions *mental workload* (*M*=3.33, *SD*= 1.53) and *familiarity* (*M*=4.87, *SD*= .23) in the tablet-based interaction were rated lower than in the paper-based interaction.

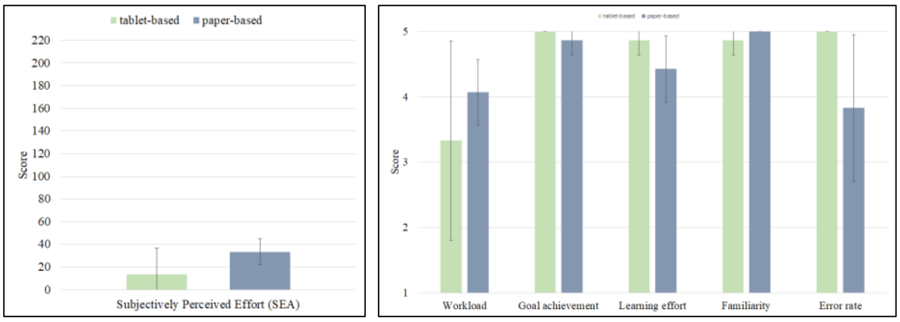


**Fig. 4.** Comparison of SEA (*left*) and dimensions of QUESI (*right*) in tablet-based and paper-based condition.

**Video-based instructions using a mobile device**

The experimenter conducted thinking-aloud tests with three disabled workers while performing the second subtask using step-by-step video instructions. It was observed that all participants could complete the task successfully and had no difficulties interacting with video instructions. They were satisfied using videos and could well manage to carry out the task without an attendant presence. For instance, autoplaying and looping videos show to be important for our participants as they need to see the instructions several times and otherwise would have to start the videos again and again. Crucially, a short pause should be integrated at the end of a loop to give participants enough time to conceptualize the work process before it is shown to them again.

## 5 Discussion

In this paper, we investigated the potential of step-by-step support for people with disabilities using a mobile assistive system in production. We applied a user-centered methodology and implemented a prototype application which enables disabled workers to perform industrial tasks with step-by-step support. In an evaluation study, we compared the tablet-based support against a paper-based one. Our results can be summarized in two major points.

First, participants' efficiency on using the mobile prototype was assessed with regard to *time on task, task accuracy* and *task completeness*. Along the dimension *time on task* and *time accuracy*, the tablet-based prototype turned out to be more efficient than than the paper-based condition. However, we did not observe any difference between both conditions across the *task completeness*.

Second, participants' subjective evaluation of the interaction was assessed with regard to *mental effort* and *consequences of intuitive use*. Again, our results showed a clear advantage for the tablet-based interaction. Participants' perceived cognitive effort using the assistive system with support was lower as compared to the paper-based condition. The advantage of the tablet-based interaction was also found in terms of intuitiveness of using the prototype: Here, the tablet-based condition was rated higher with respect to the dimensions perceived achievement of goals, perceived effort of learning and perceived error rate than the paper-based condition. Paper-based interaction, however, outperformed tablet-based interaction in terms of the dimensions mental workload and familiarity.

Overall, our assistive system *with* mobile step-by-step support showed to have several benefits over paper-based support. That is, the supportive technology we developed seems to be a helpful aid for disabled workers. Nevertheless, our pilot study has some limitations we plan to overcome in future work.

First, due to the small amount of five participants, only trends could be seen regarding differences in both conditions. Therefore, we conclude that the same study should be repeated with a larger amount of participants. Another major hurdle was the distribution of participants into the two conditions. Three participants had no prior experience using such an industrial machine. In order not to overwhelm the disabled workers with too many information, the participants with no experience were assigned to the paper-based condition. This design decision, however, might have affected our results as we cannot rule out that differences observed between the conditions might be due to participants' prior experience with the machine. In the next study, it should be taken care to conduct the study with experienced participants.

Second, participants didn´t have the full cognitive ability to read, completely understand and fill in the QUESI questionnaire. Therefore, the experimenter read out each question from the questionnaire and noted participants answers. In some cases, participants gave uninterpretable responses to the experimenter which may affect the results. The same applies to placing a check mark on the SEA scale to measure participants' mental effort. Future research includes a study with special questionnaires for people living with cognitive impairments.

Third, to enable for a comparison of paper- vs. tablet-based instructions, the tablet-based prototype was not used to its full extent. The most important task of changing the drill head with a video instruction was not included in the evaluation study. So, a crucial advantage of using a mobile device was lost in this study. Also, we eliminated QR-based support in the tablet-based instructions as there was no equivalent available in the paper-based condition.

Despite these obstacles that are still to overcome in a more compressive follow-up study, we could show in this paper that an assistance system can enhance the quality of work and thus improve job opportunities for people with disability to employment.

Also, we plan to extend our prototype with the integration of an augmented reality software that shows users the instructions as guided steps and the current status of the machine with graphical overlays. It has been proven that this technology reduces error-rates and time on task in manufacturing [39].

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