How to assemble an Automatic Water Dispenser System – Design of a Learning Station feat. Augmented Reality

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Abstract. In state-of-the-art research, the use of Augmented Reality (AR) technology for learning scenarios has been studied mainly in educational and laboratory environments like schools or universities, whereas learning processes in operating businesses received less attention. On top of that, industrial enterprises demand for practical cases to exploit AR for their operations. In response to both phenomena, this prototype paper presents the design of an AR-supported learning station which showcases the assembly of an industrial plant by the example of an automatic water dispenser system. The design was finally evaluated collecting qualitative test data and deriving initial insights. It was discovered that AR test users achieved positive learning outcomes in various dimensions, thereby surpassing those of test users with paper-based instruction booklets. In spite of limitations, the outcomes contribute to the scientific knowledge base regarding AR and learning processes in operating business in the industrial sector and offer perspectives for practitioners interested in exemplary use cases and future design opportunities.

Keywords: augmented reality, learning, industrial sector

1 Motivation

Research concerning the use of Augmented Reality (AR) has been strongly focused on technical dimensions in the past and has only started to thoroughly explore AR use in different application scenarios around 2016 [1]. Especially in the context of use in the industrial sector, a literature review identified "assembly", "maintenance", "product design" and "training/learning" as topics that were investigated more in detail [2]. The paper however also criticizes that many studies never implemented AR in a real context, thereby leading to a lack of real case implementations.

In October 2021, we conducted a literature analysis of 54 scientific papers regarding Learning and AR following the concept matrix approach of [3] (see section 3). Our results indicate that latest scientific work put an emphasis on school and higher education environments, confirming the findings of [2]. Furthermore, the most often represented aim was to increase students' "motivation to learn" or "improve learning performance". In contrast, learning scenarios in an industrial operations context were hardly considered. Only 8 papers concerned learning performance improvement in this area.

With the industrial environment demanding for real case AR solutions and the scientific knowledge base yielding a gap in the area of applied science in AR-supported learning for industrial enterprises, we derive the relevance and rigor for the design of a learning station (LS) for the evaluation of AR-supported learning in an industrial operations context. This prototype paper describes the artifact design and evaluation.

2 Design of an AR-supported industrial operations learning station

Previous studies of AR-based LS have primarily focused on technical details or cost-effectiveness, e.g. the "Seabery" welding station analyzed in [4]. The here-described LS should in an explorative way aim at industrial operations learning processes that could be supported by means of augmented reality glasses. The artifact was intended to focus on enabling users to learn something, thereby having low complexity and being transferable to real-world company cases.

Implicitly, an artifact design was proposed. The design was based on the structure of an industrial plant, more specifically an automatic water dispenser system, which was delivered in dismantled parts. With such a plant, the installer does not need to arrange all the cables, but only has to plug-in connectors and put the individual parts in the right place. Thus, the artifact is pre-assembled to a point where it only needs to be put together. The engineering/programming work had already been done. At the end of the assembly process, it should be possible to successfully put the plant into operation.

The plant was finally supplemented by two different support tools for new installers. The first option was a printed paper booklet with written instructions. The booklet contained instruction texts and photos of each of the technical components with descriptions. The second option was a HoloLens 2 device for AR projection and a "Microsoft Dynamics 365 Guides" application. The application would display the instructions: text, photos of the technical components, and navigation elements to go back and forward and view the photos. In summary, at the LS, users should be asked to build an automatic water dispensing system. To do so, they should assemble various electrical components guided by step-by-step instructions either on paper or displayed on AR glasses.

The present system comprises nine components: (1) a Raspberry Pi Zero computer, (2) a relay board, (3) an electric pump with a lustre clamp, (4) an ultrasonic sensor board with four clamping spots, (5) a plateau with a built-in button, (6) a control board, (7) a power supply unit, (8) an elastic tube and (9) a 3D-printed case. The technical setup will be described in the following.

A Python software runs on a Raspberry Pi Zero computer which receives the signals and controls the electronic components. The Raspberry Pi emits a control signal for a relay. This signal reaches the button on the bottom of the plateau where the user is supposed to place an empty glass. Once the button is pressed by placing the empty glass, the signal is transmitted to the relay, which is then activated. The activation triggers the pump that is placed in a jar filled with water. The pump starts to pump the water. Through an elastic tube that needs to be fixed through a hole in the 3D-printed case, water from the jar is directly transferred into the glass below. An ultrasonic distance measurement sensor is also located in the 3D-printed case above the glass. The sensor targets the glass and thus determines the filling level of water inside the glass. The measurement results are sent from the sensor directly to the Raspberry Pi, which processes them. When the threshold is reached, the pump stops. The filling process is now complete, and the user can remove the full water glass. The technical circuit and a photo of the LS components can be seen in Figure 1.

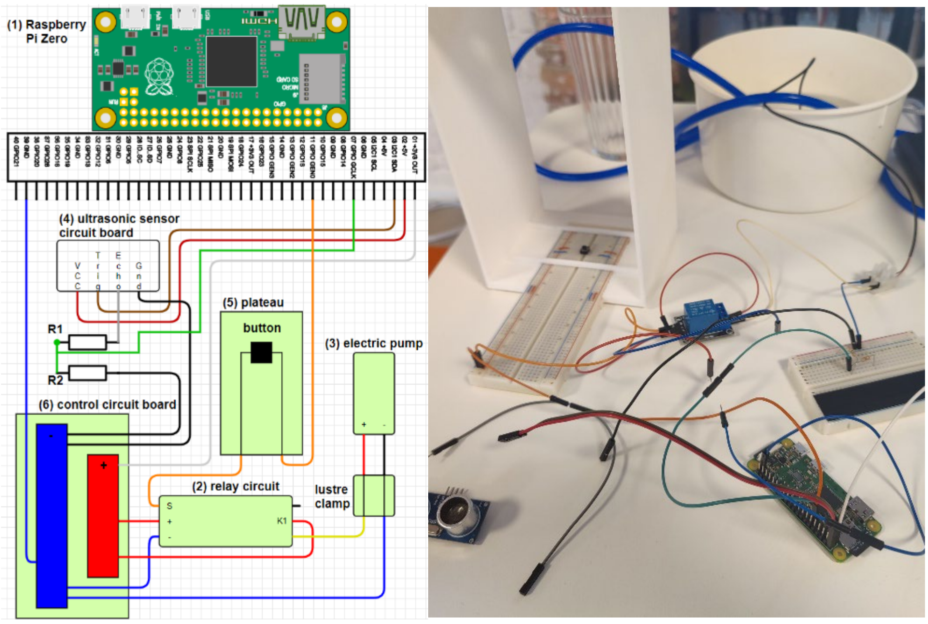

Fig. 1. Circuit diagram of the automatic dispenser system and a photo of the LS components

3 Significance to research

To analyze the existing knowledge base, a systematic literature analysis was conducted. Papers were searched in scientific databases and libraries such as IEEE Xplore, ACM Digital Library, AIS e-library, or Scopus using various search terms like “Augmented Reality”, “AR”, “Learning”, “Support”, “Teaching” and related terms. A filter on publication dates not older than 2020 was applied to examine only current work. However, papers differing from these criteria were included in forward and backward searches. The scientific papers found during the search were firstly checked for their fit to the topics of AR and learning based on titles and abstracts. At this stage, 158 papers were filed and numbered. They were then examined more closely based on full texts. Many papers mentioned learning only as a side aspect. In the end, 54 scientific papers were selected for the final analysis. For a transparent disclosure of our literature analysis results, which are not in the scope of this prototype paper, we provide a spreadsheet with all sources under the following link: *https://bit.ly/3tU6Hrx*

Five high-level concepts could finally be identified in current research on AR for learning: (1) “Acceptance of AR in learning”, (2) “Increase motivation to learn”, (3) “New way to display information to learners”, (4) “Improve learning performance” and (5) “Different use cases for learning with AR”. For each concept, the papers were labeled according to their target environments: schools, higher education, apprenticeships, and operating business. Given the detailed outcome, we found that research in the area of AR and learning is mostly concerned with teaching in schools and higher education. On the other hand, there seemed to be a gap in studying AR-supported learning for professional training and in enterprise environments. The little number of sources found in this direction were almost exclusively linked to the concept “improve learning performance” and barely touched other concepts. We thus derive the following research question (RQ) grounded on the before-analyzed knowledge base:

RQ: “How can learning in industrial operations be supported and improved by means of Augmented Reality?”

This RQ manifests the significance of our artifact design to the research community. By our design approach, the RQ shall be examined against the backdrop of the five identified concepts in literature through a qualitative evaluation of the artifact. Thereby, this prototype paper contributes to the scientific knowledge base by presenting new insights on potential usage value of AR in industrial operations contexts and extends the yet under-researched area of applied AR-supported learning in environments other than schools and universities.

4 Significance to practice

A core activity of our institutions is to co-operate closely with small and medium-sized companies (SMEs) in digital transformation projects, many of which are in industries such as manufacturing, construction, production, or agriculture within the regions of Berlin or Brandenburg in Germany. In communication with SME managers, an often-asked question regarding AR is: “Are there yet any meaningful use cases for this technology to really facilitate business processes?”. For a majority of these decision-makers, AR technology appears to be a non-useful tool in practice. This is also reflected by a survey paper claiming that “lack of budget”, “upper management’s lack of understanding of these technologies” and “design teams’ lack of knowledge” were among the top 3 limitations in adopting AR or Virtual Reality technologies [5].

In consequence, besides its contribution to the research landscape, the here described LS artifact should also serve as a showcase to all practitioners who are interested in opportunities to combine learning processes within operating businesses with AR. This showcase features an industrial scenario that provides a bigger closeness to practical business processes than e.g. studies about AR use in educational institutions. The findings of the artifact evaluation could also be used to design more LS in the future, targeting a variety of industrial operations learning situations. Finally, a use case may be found that could be implemented in real businesses.

5 Evaluation of the learning station

Currently, 14 tests were performed with 7 users using the paper-based instructions and 7 using the AR solution. The tests were embedded in a qualitative assessment of the designed LS. Comparison studies between a conventional version and AR use were found to be common in existing literature evaluating AR artifacts (e.g. [6], [7], [8], [9]). The tests were conducted at “Digitalwerk” (www.digital-werk.org), an innovation and co-working center for industrial SMEs. We applied the “thinking aloud” method (see e.g. [10]). During the test, video and audio were consensually recorded. The co-workers who served as test users had not been familiar with the dispenser system or the assembly tasks before. After the water dispenser had been set up and tested, which all users managed to accomplish successfully, a questionnaire asking for their user experience was handed out to the participants. These questions were aligned to the concepts identified before in the literature, thus targeting the effects on “AR acceptance in learning”, “motivation to learn”, “perception of the information display”, “learning performance” and “fit of the use case”. In the end, some open questions were asked regarding the learning outcome, whether the users could recall what they built and how they felt doing it.

On average, the test users with the AR instructions took four minutes longer than the group with the printed booklet. In comparison, [6] found that a test group using AR was consistently faster. In our case, however, the technology was completely new for all users. Moreover, according to the feedback of this small sample group, the AR instructions were better accepted, were perceived more helpful, motivated learning more, and extended the test users' knowledge better. The users had not only learned something but could also imagine repeating such a task in the future. AR users felt more confident in the setup and would also feel confident building more complex systems with such AR instructions. To AR users, the controls were unfamiliar at first but were quickly learned. Voice control was a popular mean for getting to the next step quickly. Users of AR glasses were more concentrated and less distracted during the test and were more motivated when using AR glasses. The fewer experience users had had before, the more they learned about electronics. With AR glasses, it was perceived as easier to navigate interactively between the assembly steps.

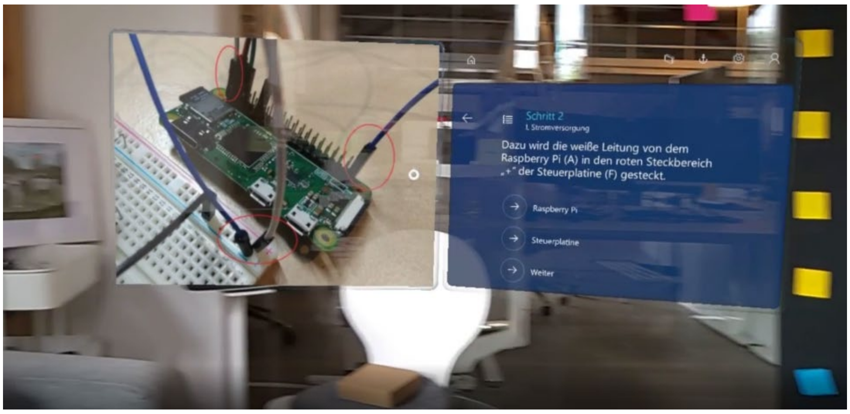

Fig. 2. Screenshot of the Microsoft 365 Guides application describing an assembly task

6 Conclusion

The here-presented prototype responds to a) a research gap discovered in the direction of AR and learning in operating business and b) a demand from industrial business and SMEs to develop meaningful use cases for AR use in-operation. Therefore, an LS was designed which lets users learn how to assemble an exemplary industrial plant with the support of either paper-based or AR-based instructions.

Even though the evaluation results indicated that the AR-based instructions of the LS created a positive learning outcome and topped the experience of using the paper booklet, there are of course limitations to our findings. Firstly, the sample size was still quite small. Secondly, the case was limited to the hardware selected and specific activities which may have been easier to accomplish with AR than in other future settings.

In conclusion, the RQ can be answered to a limited extent. We observe that AR seems to be just as helpful in the learning processes with industrial context as in schools and universities. First learning successes could seemingly be achieved with the LS. After its first iteration, the design provides orientation towards new future possibilities of AR use. Further research in this area is encouraged to enhance AR-supported learning processes and to close the research gap on AR for learning in operating businesses.

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