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AR-Based Learning in Vocational Training — Evaluation of Learning Outcome Comparing Augmented Reality and Teacher-Instructed Learning Units

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AR-BASED LEARNING IN VOCATIONAL TRAINING – EVALUATION OF LEARNING OUTCOME COMPARING AUGMENTED REALITY AND TEACHER-INSTRUCTED LEARNING UNITS

Completed Research Paper

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Abstract

Augmented reality (AR) is gaining popularity as a tool for vocational training scenarios. However, quantitative research results regarding learning outcome of augmented reality applications in vocational training environments are scarce. In this paper, we present the results of an experiment conducted at a vocational school in Germany, where we compared the learning outcome of 52 students who used AR glasses to those who were instructed by a teacher. The selected learning unit is well-proven and part of the curriculum of the selected school. It includes the introduction and operation of a milling machine for woodworking. The paper describes difficulties encountered in the conducted empirical study when developing and using the AR- based learning unit. In an empirical evaluation the learners with AR glasses achieved the same learning outcome as learners in the conventional learning unit with the teacher.

Keywords: Augmented Reality, Vocational Training, Learning Outcome.

1 Introduction

Vocational education and training (VET) aim to equip students with skills and competences that can be used on the labor market (Tissot 2004). VET need to be continuously adapted towards new technological developments, as well as to the digitalization of production processes that are placing new demands on students and employees (Kazancoglu and Ozkan-Ozen 2018). Particularly in the manufacturing sector, employees need to continuously familiarize themselves with arising changes in various mechanical, electrical, IT, and networking processes (Kettunen et al. 2022). Innovative wearable assistance systems have the ability to support students and trainees in keeping up with the required level of professional competence and facilitate a new era of learning in workplace environment (Bower and Sturman 2015). One promising technology to provide learning units is Augmented Reality (AR). AR describes the real-time visual fade-in and fade-out of digital objects or digital content into the real environment (Vogel et al. 2020). Within the last few years, AR has gradually established itself as a medium for educational purpose, especially in the fields of technology and engineering (Sırakaya and Sırakaya 2020). Numerous studies in the educational context concluded that the use of AR can have a positive impact on learning

(Garzón et al. 2019; Ibáñez and Delgado-Kloos 2018), especially in domains requiring spatial comprehension (Radu 2014). By visualizing educational content in the real world, AR can improve students' understanding of abstract concepts (Akçayır and Akçayır 2017; Garzón et al. 2019). AR can also provide a valuable opportunity for differentiation, as it enables students to learn independently from teachers (Lester and Hofmann 2020) and therefore provides teachers with more time to support individual students. Nevertheless, it is crucial within the curriculum for teachers to develop a comprehensive concept that seamlessly incorporates AR-based applications, enhancing the overall educational experience. We dedicate our attention to VET because AR can support knowledge transfer especially in practice-oriented training (Garzón et al. 2019). In contrast to theoretical training, the educational content is made available on-site at physical work objects.

There are already empirical studies that focus particularly on the effect of AR on VET (Lester and Hofmann 2020; Sommerauer 2021). However, the positive effects of using AR on learners' practical skills have not yet been examined in detail (Mohammadhossein et al. 2022). Furthermore, to the best of the authors' knowledge, the learning outcome of an AR-based learning unit in VET compared to the learning outcome of the same learning unit instructed by a teacher has not been evaluated yet. Hence, our research question is: To what extent does the use of AR-based instructions in vocational education and training outperforms traditional teacher-led instructions in terms of students' learning outcomes?

Answering this research question is part of a three-year consortium research project, in which we strive to convert conventional VET learning units that take place in dedicated workshops into AR-based learning units. We conducted the empirical study in a vocational school for the field of woodworking in which the learning outcome of students that used the AR glasses was quantified and compared against a group who was instructed by a teacher in the traditional manner. The findings of the performance test show that in VET an AR-based learning unit can provide the same positive learning outcome as a conventional teacher-instructed learning in a workplace setting. The remainder of this paper is structured in the following way: the second section presents the related work, and the research approach is described in the third section. In section 4, the implementation of the AR-based learning unit for the operation of a milling machine is reported. The empirical study with control group is presented in section 5, followed by a discussion of the results in section 6 and the conclusion in the final section 7.

2 Related Work

Wong and Looi (2011) state that the concept of "learning anytime, anywhere" can be facilitated using mobile devices. Being timely and locally flexible as well as having a ubiquitous access to knowledge contributes to learning in general (Wong and Looi 2011). AR glasses are mobile devices and provide information to students and workers immediately during the task without the need of turning the pages or scrolling through the text document (Szajna et al. 2020). Such AR-based information can be three-dimensional, for instance pointers, arrows, text fields as well as images and construction data (Szajna et al. 2020). However, it is not the technology itself that determines the learning outcomes of students, but the implementation of the application (Webster and Hackley 1997).

The theory of situated learning is the most common pedagogical approach when implementing AR applications for educational settings (Garzón et al. 2020). The theory relates knowledge to the social situations and points out that learners gain knowledge by interacting with authentic environment (Brown et al. 1989). The gesture-based interaction with AR glasses supports situated learning through physical interaction, allowing learners to actively engage with educational content and enhance cognitive processes through embodied experiences (Kinshuk et al. 2016). Generally, AR adds three features to educational settings according to Santos et al. (2014): real world annotation, contextual visualization, and vision-haptic visualization. While real world annotations significantly reduce the cognitive load, contextual visualization refers to the connection of virtual information with familiar contexts in the real world. Vision-haptic visualization allows embodied interactions enabling more natural ways of acquiring information. The actual effect of these annotations and visualizations on the learning outcome depend on the respective learning situation, the pedagogical approach, the environment, and the intervention duration (Garzón et al. 2020). Neither the time required for task completion, nor the error count objectively reflects the degree to which learners have truly assimilated the learned material (Wuttke et al. 2022).

Several research studies indicate that AR can indeed enhance students' learning outcomes, especially by improving students' motivation (Akçayır and Akçayır 2017; Garzón et al. 2019). Studies within the school and academic context demonstrate that AR positively effects student's attitudes and motivations when used in science courses (Kalemkuş and Kalemkuş 2022) or in engineering courses (Elmunsyah et al. 2019; Urbina Coronado et al. 2022). AR applications in natural science helps to exemplify abstract concepts and can therefore increase the comprehension of learning material for students (Ozdemır et al. 2018). In the field of science, technology, engineering, and mathematics, AR applications can not only support the learning and teaching process and increase achievements of the learners but also provide a safe space for conducting potentially dangerous experiments or a reduction of costs in laboratory courses (Sırakaya and Sırakaya 2020). Most of the studies took place in classroom settings where AR was used to improve paper-based learning materials (e.g., Brilian et al. 2020; Fleck and Simon 2013; al Mehdawi et al. 2023; Shelton and Hedley 2002; Wang 2017; Yen et al. 2013; Zhang et al. 2014). The results of these studies in classroom settings support the assumption that AR helps to exemplify abstract concepts (Ozdemır et al. 2018) but do not cover teacher-instructed learning units in workplace environments as we do in this paper.

In VET, AR applications can convey domain-specific knowledge as well as experiential values interactively in contextual and dynamic annotations and visualizations (Zhou et al. 2019). Literature provides various prototypes of AR applications available for creating interactive scenarios for school lessons (Costa et al. 2020; Lytridis et al. 2018) as well as AR-based instructions, e.g., for technical processes (Webel et al. 2013, Dreesbach et al. 2023). While some studies in the context of VET use a tablet- or smartphone-based application (Dutta et al. 2023; Weinert et al. 2023) others use AR glasses (Lester and Hofmann 2020; Sommerauer 2021) to present the learning content. Sommerauer (2021) presents an AR application for workplace training in VET. The application for AR glasses provides instructions for connecting a truss. It includes the identification of the items and tools used in the activity and the preparation of the connection between the truss elements. Lester and Hofmann (2020) present an AR workplace training for a screw extruder in chemical operations training. The application for AR glasses instructs students setting up the screw extruder while the trainer intervenes only if necessary. The application includes a digital representation of the extruder as well as AR-based instructions how to set up the extruder in eight physical steps which are simple to follow but must be carried out correctly and in the right order.

However, AR is still in the early stages of adoption in VET, dominated by small-scale applications (Lester and Hofmann 2020). Therefore, teachers are often not familiar with AR (Durrani and Pita 2018) and the integration of AR into VET is associated with high effort (Garzón et al. 2019). Extendable AR systems are required to speed up the development of educational AR applications and fit all needs to develop AR-based learning units (Kaufmann 2003). To reduce the designing and implementation and standardize industrial training processes, one attempt is a step-by-step guide through the work task with multimedia support in the form of texts, images, videos, and 3D models (de Carvalho et al. 2021). A methodology that can be used by teachers to enhance their conventional learning units with annotations and visualizations in AR using the Business Process Model and Notation (BPMN) is provided by Dreesbach et al. (2021). BPMN was originally developed to record business processes according to fixed graphic design rules (Chinosi and Trombetta 2012). With the help of a formal syntax and easily understandable symbols, individual steps of a business process can be visualized and thus enable a comprehensible graphical description of the process. In certain use cases related to assembly and training processes, BPMN has been employed to document existing workflows and facilitate their accessibility on AR devices (e.g., Kammler et al. 2019; Sorko and Brunnhofer 2019).

3 Research Approach

Due to the research gap in empirical studies about the outcomes of AR-based learning units in VET settings, we started a quantitative research project that we report on in this paper. In Figure 1, we show the activities in our research.

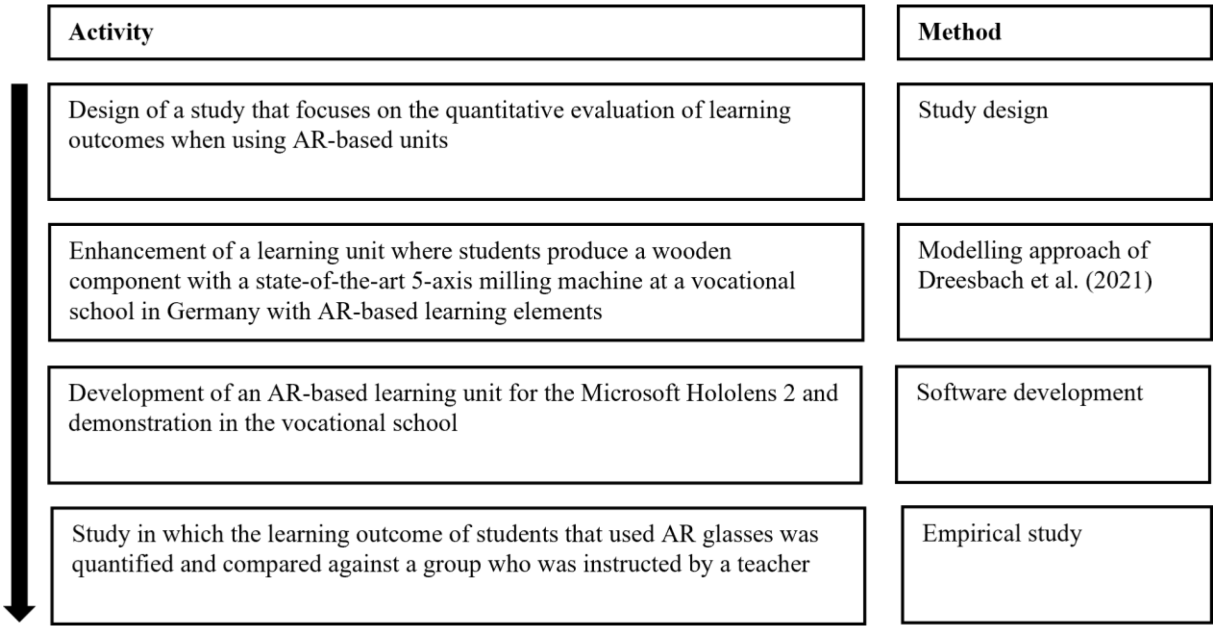

Figure 1. Activities in our research

We partnered with a German vocational school and examined an annually taught learning unit at that school where the students produce a wooden component with a state-of-the-art 5-axis milling machine and defined the educational scope of the unit (section 4.1). Before converting the examined learning unit using AR, three researchers in the field of AR and education documented the learning unit in BPMN together with the teacher. The researchers and the teacher used the approach of Dreesbach et al. (2021) and specified where AR elements should enhance the selected unit (section 4.2). The AR-based learning unit was developed with an AR-based learning platform that provides tools for teachers to build their own AR-based learning units (Berg et al. 2022). The AR application and its use for the transformation of the learning unit at that woodworking school is demonstrated in section 4.2, too.

To evaluate the learning outcome of the students, the researchers, and the teacher responsible for the learning unit conducted an empirical study with two groups. While the experimental group of students worked with the AR glasses, the teacher instructed the control group. Having developed the AR content in close cooperation with the teacher, we aim to evaluate the test results to determine if the AR-guided learning unit conveys knowledge as effectively as traditional instruction by the teacher. Consequently, we have put forward the following hypothesis: There will be a significant interaction effect between treatment type (AR vs. instruction by teacher) and time of measurement (before treatment vs. after treatment) on learning outcome, indicating that the change in learning outcome will vary depending on the type of treatment received.

As existing standardized scales do not cover the learning content of the training field under consideration, the teacher in charge of the milling machine and the conventional learning unit and an education researcher engaged in an iterative process to develop a performance test for the learning unit. The teacher is not only an expert in the field of training but has also been imparting knowledge in this area for many years. The performance test consisted of 29 knowledge questions about the learning unit to measure a student's learning outcome. The test was in the form of single choice questions with four to six possible answers. A second teacher familiar with the unit reviewed the test to assess whether the questions accurately reflect the knowledge to be taught in the class and to determine if there are any difficulties in understanding or ambiguities regarding the questions. The performance test was validated as a measurement tool by a group of 20 students who had performed the conventional learning unit on the milling machine with the teacher, one or two years before. The results of the questionnaire were compared with the expected basic knowledge that these students should possess. The result was a rate of 60 to 80 percent correct answers. A response accuracy of 60 to 80 percent indicates that a significant proportion of the questions accurately capture the intended learning outcomes, which underpins the content validity of the test. In the study conduct, the validated performance test was used with those students new to the milling machine before the treatment and after the treatment with both groups. The treatment consisted of either doing the learning unit with the help of AR glasses or being instructed by the teacher. The learning outcome represented the dependent variable in the empirical study.

4 Test Settings and Context of the Study

4.1 Content of the Examined Learning Unit

The study took place in the machine hall of the vocational school that participated in our research project. The school teaches apprentices in the field of wood technology. The examined learning unit has been taught for several years and is usually guided by a teacher in groups up to six students. To this small group, the teacher explains a milling machine and its components. The information given in this learning unit can be separated into six categories starting with an introduction. (1) During the introduction in a classroom, the teacher theoretically explains the function and terminology of the milling machine. The individual components of the machine are discussed, including the control panel, mounting unit, suction unit, main spindle, and tool changer. (2) After the introduction the teacher gives a safety instruction in front of the milling machine. It includes an explanation of the personal protective equipment. Only when the students know the safety precautions, they are allowed to operate the machine. (3) To explain the setup process for the milling operation, the teacher demonstrates how to place a wooden component on the mounting unit and fix it by activating the suction cups. The students must repeat the process. (4) When the machine is set up, the teacher quizzes the students about different milling tools and functions. (5) The next step is the start of the actual milling process. The students are introduced to the control panel and the remote control. The teacher releases all emergency stop buttons of the machine and starts the milling process. (6) At the end of the learning unit, the students learn how to shut down the machine. The examined learning unit was well-proven over the last years and lasts about 30 minutes.

The developed performance test consisted of knowledge questions covering all six categories. According to the teachers, the difficulty of the questions varied between easy (nine questions), moderately difficult (twelve questions), and difficult (eight questions). The test for the students was in German. An example of an moderately difficult question, translated into English, is: How can you check whether a component is fixed on the suction cups?: (A) By lightly hitting the component with a wooden block, (B) If the component is not correctly fixed on the suction cups, an error message is displayed on the control panel, (C) As soon as the milling process is started, the fixation can be checked visually and acoustically, (D) By a test shift which is carried out manually (correct answer), (E) With the pressure gauge.

4.2 Design of the AR-Based Learning Unit

The focus of the learning unit selected for the study is primarily on independent and problem-solving learning. The aim is to introduce the students to the milling machine, to make them aware of possible dangers, special handling steps, and to teach them how to carefully handle the milling machine. The process is thus based on a practice-oriented learning approach that is intended to promote the subsequent application and transfer of the knowledge. The original learning unit was transformed into an AR-based unit in five consecutive steps: (1) process analysis, (2) selection of AR elements, (3) development of new AR elements, (4) clarification of the process concept, and (5) effort and feasibility review (Dreesbach et al. 2021).

After the unit was documented in BPMN for step (1), the selection of AR elements followed in step (2). AR elements describe digital content that is displayed in the learner's field of view via the AR device and that can be placed in the environment of the milling machine. One teacher, one education researcher, and two researchers in the field of AR participated in a group discussion to find suitable AR elements visualizing the information comprised in each of the process steps of the BPMN documentation. The group discussed the potential of digital content for the respective process steps and identified possible connection points for the integration of AR elements. The teacher and the educational researcher argued to design AR elements that facilitate situated learning. The selection of AR elements for the learning unit considered that mainly cognitive skills should be taught (Limbu et al. 2018). While the teacher contributed to the content presented through the AR glasses, making the material from both traditional teacher-based instruction and the AR-guided learning unit essentially equivalent, the key distinction lies in the presentation and interaction with the information. Unlike the traditional method where the teacher delivers the content and demonstrates at the machine, the use of AR elements and the structure of the application allows students to set their own learning pace. The teacher only pauses the presentation upon request, but with the application, students can individually decide to revisit information. The four group members considered meta-reviews of AR in education to identify AR applications and find out which AR elements have been already used (Garzón et al. 2019; Radu 2014; Sırakaya and Sırakaya 2020). The initial search for possible AR elements to extend the individual process steps in the selected learning scenario identified seven elements which could be used to represent most of the learning content via AR glasses. These elements are a text panel for general information as well as situational hints, images, videos, three-dimensional markings (arrows, circles, etc.) to indicate selected points on the milling machine, checklists, and an avatar (de Carvalho et al. 2021; Keil et al. 2018; Sorko and Brunnhofer 2019).

The text panel for the general information welcomes students to the process and provides the background information of the learning unit. A progress indicator for the overall learning unit is integrated into the text panel in accordance with a framework of Bacca et al. (2019). The instruction in the milling machine is a situation-based scenario and need to be supported by situational hints, images, videos, and three-dimensional markings. To set up the milling machine, the students watch a demonstration video where the teacher demonstrates the individual steps and points out some special features. A checklist and pictures summarize the steps presented in the video. As described in the framework of Bacca et al. (2019), the educational researcher designed a virtual avatar that guides the students through the learning scenario (see Figure 2). The avatar appears in each process step and students can interact with it. It accompanies students through the learning unit with instructions, guiding questions, and answers to frequently asked questions, thus embedding the entire learning unit in a story or overall experience. As an example, the Avatar asks the students to release the emergency stop buttons and start the milling process or it refers to images where the students see how to influence the process speed of the main spindle during the milling process using the remote control. By following the instructions of the avatar, students learn the necessary skills and knowledge in a practical and context-related manner. When directly performing the given steps on the machine, they are engaged in the situation, which promotes the acquisition of skills and knowledge relevant to operating and understanding the machine.

In addition to the AR-elements already described, task formats were integrated into the documentation of the process to query the theoretical knowledge of the students. The integration of new elements was part of step (3). The researchers developed various learning success controls in the form of closed task formats and integrated them into the AR-based process. The newly acquired knowledge of the students is checked by multiple-choice questions, single-choice questions, cloze tests, and term sequence sorting before starting the actual milling process. A cloze test provides knowledge about the information displayed on the control panel. At the end of the process, a term sequencing task is provided to the students in which the students must determine the sequence of the steps before they shut down the machine the first time. Since direct feedback is beneficial for conducting an AR process (Bacca et al.

2019), the learning success controls were designed to evaluate the learner’s input and provide direct feedback.

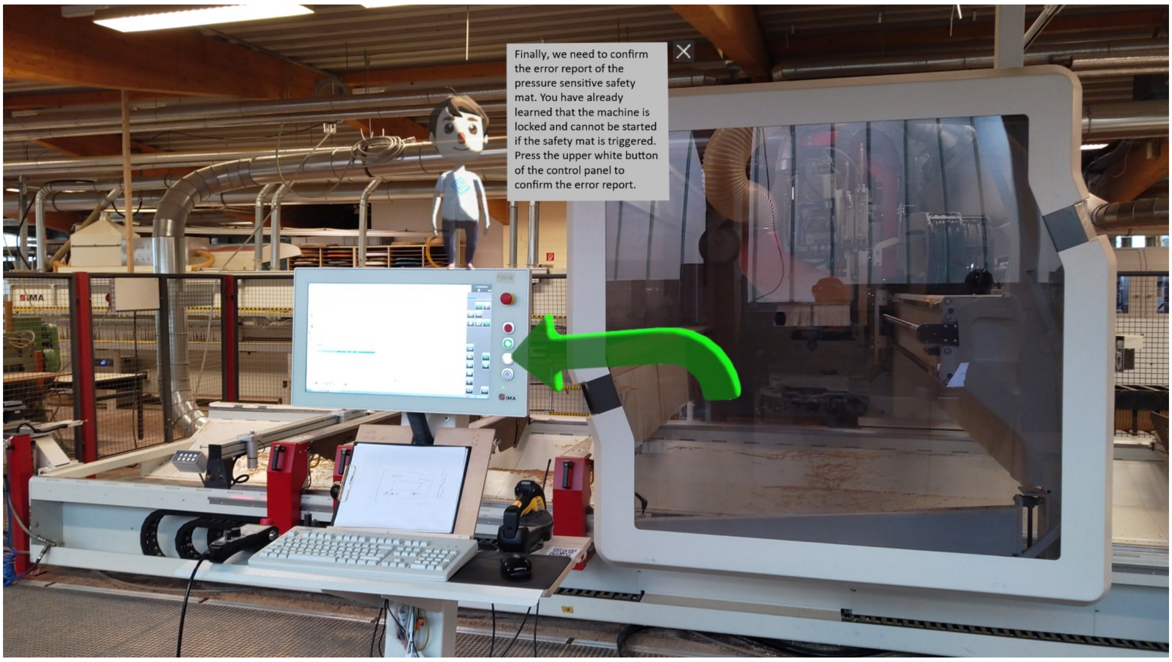

Figure 2. *3D marker and avatar explaining how to confirm the emergency stop (translated).*

Another approach of the researchers was to increase the didactic value of the learning unit by an AR element for an exploratory-based learning of the milling machine. Through which the students can explore and get to know the machine independently. The developed element for exploratory learning takes the motivation of the students into account and was designed in such a way that various relevant parts or components of the milling machine can be selected visually, and additional information becomes visible. Figure 3 presents the room exploration.

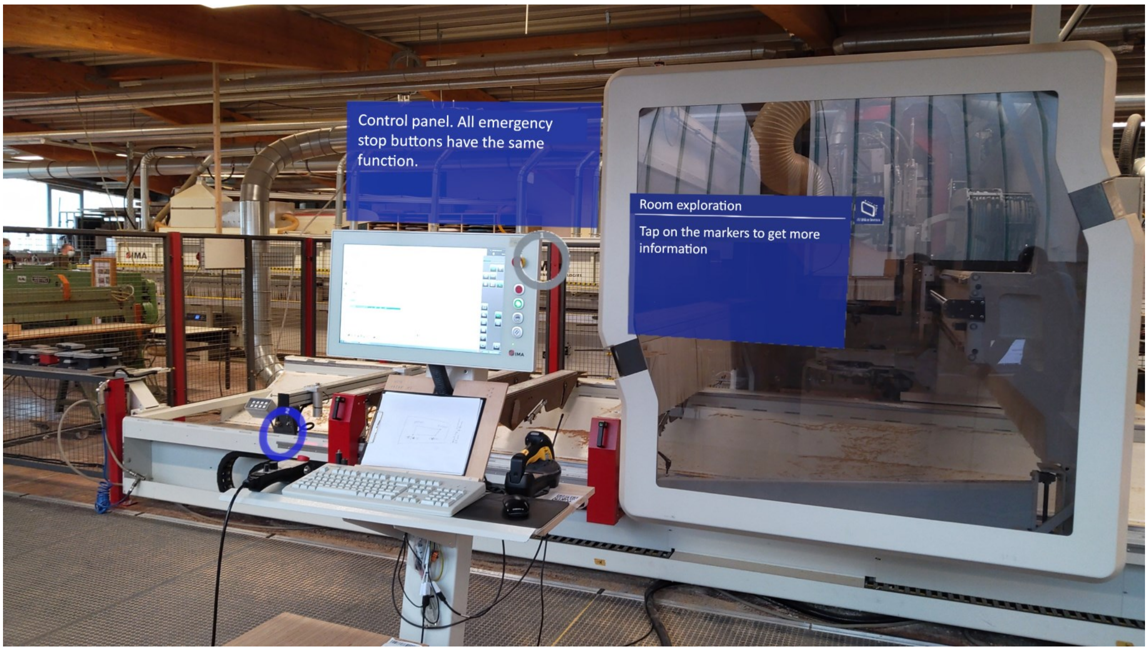

Figure 3. *3D Exploration to explain all emergency stop buttons (translated).*

The students can see 3D markers superimposed with each of the emergency stop buttons of the machine. When touching the markers, information panels with additional information to the emergency stop buttons appear. In step (4), the didactic researcher and the teachers checked in a final iteration whether the process concept met the didactic objectives and whether the AR elements were connected in a way that foster the learning process of the students. Table 2 shows a summary of the process concept. Each process step was compared with the planned learning objectives and adapted if required. Since the developed AR elements were found to be sufficient, no additional AR elements were added.

Steps	AR Elements	Content
1	Information board Spatial exploration	*Welcoming and introduction:* Welcoming explanation of the process navigation and introduction of the avatar that guides users through the learning unit. The information board displays relevant information about the process, for example a progress bar or the current learning step and is for all steps permanently present.
2-7	Avatar Video Single choice question Multiple choice question 3D-objects Spatial exploration	*Safety check and safety training:* To successfully complete these learning steps, students must be familiar with the various safety precautions. For this, users have to check their personal safety equipment using multiple and single choice questions. The positions of the emergency stop switches of the milling machine were visualized with 3D markers. Further information about the functionalities is provided by spatial exploration.
8-12	Avatar Video Image Textual note Term sequencing Checklist Spatial exploration Single choice question	*Setup process:* To set up the milling machine, the students watch a demonstration video. The teacher demonstrates the individual steps and points out special features. With the supporting AR elements, the students have to repeat the process on the machine so that it is ready for operation.
13, 14	Avatar Image Video	*Additional knowledge:* Explanation of the different milling heads and tools.
15-19	Avatar Cloze Image Text 3D-objects (arrows)	*Introduction operator panel & starting the machine:* The students are introduced to the operating panel and the control system. They unlock the machine and start the milling process. With the control system, they can influence the process and should thus recognize the different working processes of the machine.
20, 21	Avatar Term sequencing Single choice question	*Shutting down and cleaning:* When shutting down, the correct sequence must be observed. Therefore, students have to answer the task and bring the steps in the right order.

Table 1. Summary of the AR elements chosen for the learning unit.

Subsequently, in step (5), the AR developers reviewed the effort and feasibility of the implementation and estimated the required time for the implementation. During the implementation, the researchers paid attention to design the selected AR elements as generic as possible that the elements can be used in several successive process steps with different text content and different positioning in space. For almost all elements, the text content and positioning in space is adaptable. Other adaptable properties are explanations, question text, and answer options.

The application that was used to implement the AR elements for the learning unit under consideration, was developed with the Unity 3D runtime and development environment (Dreesbach et al. 2020). Deployed on the Microsoft HoloLens 2 AR glasses, the application incorporates user management features, enabling teachers to register trainees and manage access to the learning units. Furthermore, teachers can monitor the progress of all trainees assigned to the learning unit (Berg et al. 2022). The start screen of the application provides a menu to choose a user account. The students can navigate step by step through the unit without any time restrictions. Teachers can use the AR application in a different mode to adapt the position of the AR elements.

5 Evaluation of Learning Outcome

5.1 Test Setting

The target group of the learning unit consists of students who are in their first year of apprenticeship and who have not performed the learning unit in its conventional form yet. Of the 52 students in the concluded study, 85% were male and 15% were female. The average age of the students was 19.8 years. The youngest student was 15 years old; the oldest one was 34 years old. The students participating in the study worked in different kinds of apprenticeships but all of them in a technical branch. Most of them were carpenters (62%) followed by woodworking mechanics (31%). 36% of the students never heard of AR glasses before. 54 % heard of AR glasses before but did not have any prior experience with it. 10% of the students already used AR glasses before. The 52 students were randomly separated into two groups of each 26 students: an AR group and a control group. For the AR-group the students performed the process one by one. Before the process started, each student was requested to perform a standard tutorial that was given by the AR device so that they got to know the handling of the AR device. Additionally, they were requested to perform a second tutorial that explained the handling of the application implemented by the researchers. The total time of both tutorials was about 20 minutes. After both tutorials, the students could perform the actual AR-based learning unit by themselves. The time it took each student to perform the 21 activities of the unit lasted between 30 minutes to about one hour. For the control group, the process was shown in small groups between three and six students as it is prescribed in the curriculum and always by the same teacher. The preparation of the program data for the milling machine was independent from the study and was done in a different lesson performed before. Loading the finished program data into the machine was also not part of the study, it was previously done by the teacher. For safety reasons a trained person was always next to the milling machine observing the students.

5.2 Research Results

A mixed ANOVA was chosen to analyze the data to measure learning outcome over time and between the two groups of learning methods: the experimental group using AR glasses and the control group instructed by a teacher. The mixed ANOVA was used because there are two groups of learning methods and one dependent variable, which was measured at two different times. In a first step, it was checked whether all prerequisites for the application of a mixed ANOVA were fulfilled. For this purpose, the prerequisites of normal distribution (Shapiro-Wilk test), equality of the error variances (Levene test) and equality of the covariance matrices (Box test) were checked. Similarly, boxplots were used to examine the data for outliers. Normal distribution was tested, as the two groups do not meet the minimum requirement of 30 participants. The Shapiro-Wilk test is not significant for the control group measurement before the treatment ($p = .652$) but it is significant for the experimental group ($p = .01$). In the measurement after the treatment, both groups are not significant ($p_{Experiment} = .471$; $p_{Control} = .118$). Thus, only the experimental group is not normally distributed at the measurement before the treatment. Nevertheless, mixed ANOVA can be performed because it is a robust procedure towards violation of the normal distribution (Glass et al., 1972; Harwell et al., 1992). Levene's test for equality of error variances indicates that the error variances are equal, as Levene's test is not significant ($p_{Before} = .163$; $p_{After} = .117$). The Box test for equality of covariance matrices is not significant, indicating that the covariance matrices of the dependent variable are equal across groups (p = .262). The participants' scores do not contain any outliers. Thus, the requirements for the mixed ANOVA are met. With the conditions met for the use of a mixed ANOVA, an interaction effect between the groups of learning method and time was then tested based on the results from the performance tests before and after the treatment. Table 2 presents the mean values of the groups at the different time points.

Test	Experimental Group	Mean Scores	Standard Deviation
Before Treatment	AR-Glasses (N = 26)	11.08	6.22
	Instructed by teacher (N = 26)	10.38	4.89
After Treatment	AR-Glasses	20.19	4.73
	Instructed by teacher	19.69	3.72

Table 2. Means and standard deviations of the groups at the different time points.

Given the maximum achievable score in the performance test was 29 correct answers, the mean scores of both groups demonstrated an increase following their participation in one of the learning units, indicating the effectiveness of the treatment. The results of the effects can be seen in table 3.

Effect	Type III Square Sum	Df	F	p	η^2
Time	2206.163	1	135	<.001	.730
Group	9.240	1	0.280	.599	.006
Group*Time	0.240	1	0.015	.904	.000

Table 3. Results of the mixed ANOVA.

Due to the lack of statistical significance and the very small effect size ($F(1, 26) = 0.015$; $p = .904$; $\eta^2 = .000$), we found no interaction effect between the group and time. This shows that the learning outcomes of using AR glasses versus teacher instruction did not differ significantly over time. The research hypothesis is disproved, and the AR-guided learning unit conveys knowledge as effectively as traditional instruction by the teacher. Hence, we can answer the research question by stating that the AR-based learning unit under consideration neither outperforms nor underperforms the traditional teacher-led instruction in terms of students' learning outcomes.

Similarly, two main effects were tested by performing the mixed ANOVA. One is an effect of the groups of learning methods and the other is an effect of time. The F-statistics shows that the effect of time is present because it is significant and has a reasonable effect size ($F(1, 26) = 135$; $p= <.001$; $\eta^2 = .730$). Despite the AR group achieving slightly higher learning outcomes than the teacher-instructed group, the lack of statistical significance for the group effect reveals that both instructional methods resulted in comparable outcomes ($F(1, 26) = 0.280$; $p = .599$; $\eta^2 = .006$).

6 Discussion

Several studies indicate a positive impact of AR glasses on learning units (Garzón et al. 2019; Ibáñez and Delgado-Kloos 2018; Lester and Hofmann 2020). This study contributes to the body of knowledge as we examined the effect of AR on students' learning outcomes in a vocational workplace training in which students learned how to operate a milling machine in the field of woodworking. Our findings show that the AR-based learning unit is in terms of learning outcome as good as the conventional teacher-instructed learning unit which has been taught and optimized over years by vocational teachers. Considering the examined learning unit was well-proven over the last years and was instructed in a group of not more than six students, the results demonstrate the potential of AR-based learning units in vocational training. The results show that the AR-based application can complement regular instructions by potentially saving teachers time to focus on individual students. As part of the curriculum, it remains necessary for the teacher to develop a holistic concept in which the implementation of the AR-based learning units is embedded.

The practical implications of our findings especially relate to vocational teachers and students. Since AR-based learning units can provide equally high learning outcome as conventional teacher-instructed learning units, vocational teachers could increasingly complement their learning units with AR technology. In this way, it allows teachers for more flexibility in designing lessons. However, the actual adoption of the AR application by the teachers might depend on their time effort and other criteria (e.g., user aspects, perceived enjoyments, computer anxiety, etc.). A separate study is necessary to set the overall costs against the added values of AR-based learning units. Such a study in the educational context is done usually using variants of the technology acceptance model (Granić 2022). So far, we see the added value of the AR-based learning unit by allowing individual students to conduct the AR-based learning unit at their own pace at a machine which frees the teachers and give them ability to provide more focused and individual assistance to students. A few students did not feel confident while operating the milling machine and frequently asked the teacher about feedback. We did not adjust the AR-based learning unit during the experiment but identified possible improvements, such as a more detailed description of some of the tasks. Consequently, teachers should not consider the development of AR-based learning units as a one-time effort but continuously incorporate the student's feedback for further improvements. Furthermore, teachers should take upcoming practical experiences of the students as well as changes in the teaching material into account when updating the AR-based learning unit. Continuous improvements of the AR-based learning units come with additional time efforts for the teachers but could further improve the learning outcome and lead to a greater autonomy for struggling students. In accordance with earlier research by de Souza Cardoso et al. (2020), we recommend initial training in handling the AR device for the students. Even so, all students in our study were able to handle the AR glasses after two handling tutorials, sometimes questions about the handling appeared in complex situations.

Additionally, our findings lead to several implications for research and future research opportunities. We focused on teaching action skills and technical knowledge in our learning unit. We chose a predominantly linear process because besides learning how to operate a milling machine, the AR glasses as a learning medium were also new to the students. The study has shown that students gradually became accustomed to navigating through the steps of the learning unit. Therefore, we see potential to present students with non-linear process sequences in the future, allowing them more agency and requiring them to engage more deeply with the content in line with constructivist learning theory. The constructivist learning theory complements the situated learning theory by emphasizing the role of the learner's active participation in constructing their own understanding and knowledge. According to constructivist principles, effective learning does not simply occur through the assimilation of information, but through the active participation of the learner in constructing their own understanding through interaction with the environment and reflection rather than passively receiving information (Shuell 1986). While situated learning provide authentic and contextualized scenarios for the students (Young 1993), constructivist learning enables students to make profound and lasting connections in their knowledge framework, by using diverse kinds of information in their AR experience (Bower et al. 2014).

In the presented study, students were able to navigate through the learning unit at their own pace and independently verify their actions using checklists, which included tasks related to the milling machine. This self-verification through the checklists encourages self-management and self-reflection among the students. They had to move to different components of the milling machine to acquire the relevant knowledge with the help of provided AR elements. More complex AR elements, such as AR-based animations of safety mechanisms or machine operations, as well as AR-based visualizations of complex machine components, should be considered in the future to enhance student engagement. Furthermore, approaches that allow students to communicate with each other about the learning content or to seek further assistance when they are unable to solve tasks despite AR support are of interest. Gösling et al. (2020), for example, describe a peer-tutoring approach for AR applications through which students can help each other when questions arise.

Given that we cannot prove the reliability of our measurement due to the absence of consistent results over time, the limitation of our study becomes twofold: not only is its validity in our unique educational field constrained by the lack of an established scale for assessing learning outcome, but its reliability is also unverified, further complicating the evaluation of its effectiveness. Although we only examined students' learning outcome in one particular AR-based learning unit (i.e. learning the handling of a milling machine), our findings constitute one step to a better understanding of the implications of the AR technology on VET and education in general. In future research, we will evaluate more learning units in VET such as the handling of tools and the manual assembly of components. We encourage scholars to adapt our approach for other learning units in different educational areas to further increase the understanding of the effects of AR technology on learning outcome. The AR elements used in this contribution served to instruct the students, to explore the learning environment as well as to query the student's knowledge. We were able to cover the entire learning unit with these types of AR elements. Future research should examine, how the different types of AR elements differ in their effect on students' learning outcome in various contexts. Furthermore, we encourage scholars to evaluate the effect of different support functions during the AR-based learning unit on the learning outcome.

Moreover, we noticed during the study that some students overlooked some of the AR elements. These elements were not compulsory for handling the milling machine but provided additional information. We did not place the overlooked AR elements intrusive into the user's field of view and the students had to move around in the area of the milling machine to notice these elements. Therefore, the optimal positioning of AR elements in the learning environment should be considered in further research. Displaying the right information or tasks in a timely manner and at the right place could have a powerful impact on reducing the need for assistance in engaging with AR content independently (Kammler et al. 2019; Dreesbach et al. 2023).

7 Conclusion

In this paper we contribute to the current research and praxis on the integration of AR-based learning units in vocational training. For our research we documented a well-proven learning unit of a vocational school in Germany about the introduction and operation of a milling machine in the field of woodworking and converted it into an AR-based learning unit. In five consecutive steps, we developed thirteen AR elements to interactively guide the students through the learning unit, explain the learning situation and offer didactic learning tasks to query their knowledge. The elements, thus enabling a situated as well as practical competence development. To evaluate the learning outcome of the AR-based unit, we conducted the study with two experimental groups from which one was using AR glasses, and the other one was instructed by a teacher. The learning outcomes do not greatly differ between both groups. The study results demonstrate that the AR-guided learning unit conveys knowledge as effectively as traditional instruction by the teacher. Thus, it is feasible for students to become familiar with the handling of the milling machine without additional support of a teacher. Because of the low code design of the developed AR application, the presented AR elements can be adapted to further learning units in vocational training. Hence, teachers can design their own learning processes, can design the processes in different levels of difficulty, and use their time to focus on struggling students.

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