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Engineering workshop education and supervision: AR for machine operation guidance and safety instructions

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Abstract

This research explores the implementation of Augmented Reality (AR) in the mechanical workshop of an engineering education program. The objective is to provide engineering students with an immersive and interactive learning experience, improving their understanding of machine operation while emphasizing safety protocols. This research introduces an AR approach designed to overcome challenges when comprehending the intricate workings of machines and adhering to safety guidelines. By overlaying digital information onto the physical workspace, AR assists students in visualizing machine components, operational procedures, and safety measures, promoting a more effective learning process. In the AR experience, we incorporate sensor data from the workshop environment. This integration enables real-time monitoring of machine performance, environmental conditions, and student activities. Furthermore, the study investigates the potential of AR for workshop supervision. Workshop operators can monitor students' activities in real-time, ensuring compliance with safety protocols and providing personalised assistance when needed.

Keywords: Augmented reality; Information-driven decision-making; Design education

1. Introduction

In engineering education, proficiency in machine operation in mechanical workshops serves as a foundational skill for prospective engineers. Annually, a heterogeneous cohort of students embark on this pedagogical pursuit, where all students have specific expectations, experiences, learning speeds and backgrounds. Among the crucial constituents of the educational efforts, prioritizing safety training is imperative in securing that students can safely use and navigate the workshop environment. In this, workshop staff are challenged to oversee and assist large numbers of students involved in machine operation. With ever increasing complexity of the machines involved, advancing learning strategies, and involved use of data in workshop environment, the use of technology to enhance and streamline the learning process creates new prospects. Augmented Reality (AR) is gaining traction as a key tool in this setting, offering an interactive and immersive learning experience – with a consistent link to reality. Presently, AR technology has matured to a level that allows for feasible incorporation into educational syllabi. AR can guide students while operating machines, but can also facilitate the collection and analysis of valuable data. Such data, if utilised effectively, offers insights into the learning process and aids in improving workshop safety. This paper explores the possibility of incorporating AR-guided operations with data utilisation to extend the benefits of technology in the engineering workshop, thus creating a more informed and safer learning environment.

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1.1. Potential in engineering education

An engineering workshop for education is a dynamic and intricate environment, where students embark on a journey that begins with a fundamental understanding of machines and processes and gradually progresses towards the ability to autonomously manufacture products [1, 2]. This process commences with comprehensive safety training for every student that will interact with equipment. Workshop staff play a vital role in striking a balance between allowing students to explore machine capabilities through trial-and-error and fostering a sense of experiential learning, while simultaneously maintaining a safe environment and safeguarding the machines from improper use and potential damage. Educational programs want to incorporate theoretical knowledge with practical application to enable students to be innovative, create, and adapt to challenges in the evolving engineering field.

The value of technology integration in this educational landscape has become increasingly evident with the availability of experienced staff under treat. AR is already a prominent tool in providing guidance for machine operations is various fields [3]. Next steps in AR applications address the seamless integration of AR with sensors or simulations that provide live, historical or predicted asset/machine data, thus unlocking the full potential of data utilisation. This research explores how this integrated approach can offer not only enhanced safety and supervision but also personalised support for students and staff, bridging the gap between theoretical knowledge and practical application.

By overlaying digital information onto the physical workspace, AR can assist students in comprehending the intricate workings of machines and processes, leading to a deeper understanding of machine operation beyond mere safety instructions. The value of the data generated in this process, and its implications for future visions and potentials is a central focus of this research, embedding engineering education in a more informed, efficient, and secure learning environment, while efficiently deploying the limited capacity of supervising staff.

2. AR in training

Currently, AR in machine operation training is available as an approach to education and skill development, particularly within engineering, manufacturing, and maintenance [4-7]. AR has demonstrated to be a powerful tool, effectively bridging the gap between theoretical knowledge and hands-on experience [8]. AR hardware is becoming more accessible and cost-effective, while showing a continuous improvement of user interfaces for enhanced usability [9].

The primary advantage lies in its ability to seamlessly merge digital information with the physical world, creating an interactive and immersive learning environment, where learning and doing are intertwined. In machine operation training, AR has proven itself valuable in providing students with safe yet practical experiences [10]. By superimposing step-by-step instructions, 3D models, and real-time feedback onto physical workspaces, AR enables students to better understand complex machine components and processes [11]. It promotes active engagement, allowing learners to experiment with different scenarios and learn from their actions without the risks associated with unsupported real-world environments.

However, the current application of AR in machine operation training does face challenges. The implementation costs, including expenses related to AR devices and software development, can be a barrier for some educational institutions and industries. Integration with existing machine control systems or PLM systems and ensuring interoperability with various AR platforms can pose technical challenges. Furthermore, instructors and operators require appropriate training and experience to effectively utilise AR systems. Addressing concerns related to data security and privacy in AR applications is also of paramount importance.

2.1. Operator safety

Among the aspects being explored in this research is the prospect of enhancing safety protocols through the provision of real-time safety alerts, with the aim of ensuring vigilant adherence to safety measures by students. This research acknowledges the critical nature of such enhancements, particularly in environments where the improper use of machinery may pose inherent risks, potentially leading to accidents and equipment damage. The potential of AR technology to facilitate personalised learning experiences can positively impact knowledge transfer efficiency, accommodating the diverse backgrounds, experiences, and learning speeds of individual students[12, 13]. Moreover, the incorporation of AR has the potential to streamline the learning process, potentially reducing the time and costs traditionally associated with training programs. This efficiency aspect is particularly relevant in the context of minimizing machine downtime and the need for operational support, potentially allowing students to acquire practical skills more consistently.

2.2. Visualising real-time and simulated data

Integrating machine data of real-life environments in an AR space allows for precise alignment of instructions with pragmatic indications and assessment of proposed actions [14]. This integration enables guidelines to be customised and meticulously designed for the particular tasks performed, thus enhancing the relevance and usefulness of the advice given. Examples of specific actions such as using the rotation speed of a spindle to validate if a student set the right parameters, or measuring the power consumption of the machine to relate this comparable activities from other students, enrich the learning experience and refine the precision of instructions.

3. AR-based data collection

One advantage of using AR headsets is the ability to capture real-time user activity while they interact with machinery. This includes information on the user movements, actions, engagement levels and decision-making processes. The recorded activity data can be evaluated against machine parameters and recognised standards. This then serves as an instrument for identifying discrepancies between the actions of the students and the expected operation of the machinery. Such discrepancies might indicate possible safety concerns or other anomalies. If a student operates a machine in such a way that approximates safety limits or exhibits behaviour that strays from standard operational procedures, the system can provide real-time alerts or corrective guidance – both to the students and to staff. This twofold data capture and analysis functionality not only advances learning, but also reinforces safety mechanisms.

Students in need of additional support or those displaying hazardous actions can promptly obtain relevant, context specific, feedback, improving their comprehension and guaranteeing their safety. Meanwhile, those who exhibit proficiency may progress with reduced numbers of different prompts, encouraging autonomy and confidence. Consequently, a sliding scale of guidance and education can be applied to enabled tailored and personalised learning.

3.1. Continuous improvement

The data collected through AR headsets serves as a resource for the establishment of a continuous-learning environment within the context of machine operation training. The AR tool facilitates an adaptable learning environment, enabling instructors to assess the progress of their students. Beyond its immediate applications in real-time guidance and safety monitoring, this data provides insights that can be harnessed to refine learning programs by tailoring the level of information and guidance for individual requirements, without the direct presence of a staff member. By aggregating and analyzing the data over time, educators can identify trends and patterns in student behaviour. This analysis can inform the development of instructional content that aligns with the evolving needs and skill levels of the students. Moreover, it enables instructors to identify specific areas where students commonly encounter difficulties or require additional support, enabling the creation supplementary learning materials.

4. Engineering education workshop supervision

In an educational workshop environment such as a mechanical workshop at either vocational or university level, a multitude of responsibilities converge. The educational programme is responsible for ensuring that students attain the desired learning outcomes by imparting the knowledge and skills required for their future careers. Workshop supervisors hold the responsibility of maintaining a secure learning environment and facilitating the transfer of essential knowledge on machinery operations. In turn, students also have responsibilities, observing safety guidelines and engaging in the learning process to master the intricacies of the machinery they work with. The aim is not solely to operate machinery, but to utilise its potential to produce something tangible and gain experience and expertise in the process. This perspective highlights the significance of practicality and ingenuity, which are fundamental to both vocational and higher education in mechanical engineering.

However, uncertainties do exist in the workshop environment. Numerous factors, including environmental conditions, equipment malfunctions, material defects, and the actions of other individuals using the shared workspace, remain outside of complete control. Despite this, the desired learning outcomes remain consistent, while the methods employed to achieve these outcomes can be adaptable to the unpredictable nature of the workshop environment. Such uncertainties can have a beneficial impact on the learning experience by promoting adaptability, problem-solving abilities, and the capacity to navigate unforeseen challenges - all indispensable qualities for future engineers. A balance must be struck in order to create a workshop environment that is uncertain yet manageable and safe to operate in. Embracing a manageable level of unpredictability can encourage students to cultivate resilience, critical thinking, and the capacity to apply knowledge in practical situations. Moreover, it equips them with the ability to confront the complexities and uncertainties they will encounter in their careers.

To review the implications of using AR in an educational workshop, and to understand the impact on student and staff, two qualitative case studies were conducted. The first case study focuses on the student-perspective, the second case study on the staff perspective. As a basis for both studies, a prototype of an AR support tool was created for providing safety instructions on the PICOMAX, a three-axis milling and drilling machine (see figure 1). The selection of this machine was based on its intricate design and the various functions essential to its operation. Additionally, mandatory safety training is required for all first-year students enrolled in Mechanical Engineering (ME) and Industrial Design Engineering (IDE), totaling approximately 450 students each year at the University of Twente. The first case study focuses on implementing an AR application to aid student learning. students, and the second case study concentrates on workshop personnel as well as an employee of health safety environment (HSE).

4.1. Approach

The Microsoft HoloLens 2 was selected as the AR device due to its mobility and hands-free capabilities. Additionally, the HoloLens permits users to wear regular and safety glasses with the device. Microsoft Dynamics 365 Guides was utilised for the

Fig. 1. Mechanical workshop environment, with the PICOMAX machine, at the University of Twente

development and testing of the software for the prototype, as its interoperability with Microsoft Office allows for future integration possibilities with existing university systems, while also having a low learning curve for workshop employees. A printed QR code was placed on the side of the PICOMAX to anchor the AR visuals, such as holograms, at the correct position in the environment. This will have minimal impact on the physical environment and is reliable when implemented in a well-lit setting. To create the holograms for the case study, a Solidworks model provided by the manufacturer of the PICOMAX is used. A section of the machine was extracted from this model and implemented as holograms in the prototype e (figure 2). Certain parts of the machine were intentionally not visualised with an AR hologram containing the geometry of that part; instead, a different indicator like an arrow (A/B) was employed to simplify the instructions arrow (C). Transparent blue AR lines were used to indicate part-specific areas (D), while arrows and boxes were highlighted with white holograms.

Three students, from Industrial Design Engineering and from Business Administration, were involved in the first qualitative case study. They are representative for their study years since none of them had previously followed any safety instructions for the PICOMAX. Initially, each student independently underwent a simulation of HoloLens operation that demonstrated how to use the HoloLens. In addition, a printout of instructions for accessing and starting the safety procedures for the PICOMAX were also provided. After receiving full instructions, the participants completed a questionnaire assessing the usability of the machine, ease of use, clarity, potential negative side effects, study background, and prior experience with the device. The participants were monitored during their training via the live feed from the HoloLens. After completing the questionnaire, participants had a brief interview to expand upon their responses. They were asked to provide further clarification on the questions presented in the questionnaire.

The second case study involved a workshop employee and a 'Health, Safety and Environment' (HSE) employee. The purpose was to gather objective data on the conventional training methods, machine regulations, and relevant information. A questionnaire was used to collect this information. Additionally, the case study explored the feasibility of AR training as a replacement for conventional approaches to safety training. The staff members were provided with the questionnaire upon completion of the AR safety training. Subsequently, a brief interview took place to resolve certain responses. The employee activities were supervised by means of a HoloLens live stream.

General safety guidelines are introduced at the outset of the instruction, and the rationale for the safety measures is elucidated. The user is asked to confirm compliance with all necessary safety gear. If the user selects an incorrect answer that indicates incomplete safety understanding, a dedicated result screen informs the user what they need to do to proceed. The instructions include a digital blue navigation line projected in AR, which guides the user to the location of the safety gear. The instructions take the user through all stages of the machine, from powering on to activating specific settings. The instructions provide the context for specific information by guiding the user with an AR navigation line and hologram to the origin or relation of the information. At all moments the user could ask support, in the AR interface, on how to perform tasks if anything is unclear.

4.2. Outcome student case study

All student participants reported that the AR training was more understandable and coherent than conventional methods, such as written manuals and video tutorials. A number of students stated that their improved understanding was the result of being able to perform the actions during (so, integrated with) the instructions. Furthermore, it was stated that the AR training fostered higher engagement in the learning process. On a scale of 1 to 5, the participants rated their overall satisfaction with a score of 4.17. All participants noted that the AR component of the prototype improved their understanding of the machine's operation steps. Additionally, one respondent highlighted that prompt feedback aided in comprehending the machine's functions. Another participant reported that they encountered difficulties locating the hologram, while another participant stated that they had made an error but were able to correct it with the aid of the instructions. Most participants encountered difficulties during the training session. Certain aspects were regarded as beneficial and enjoyable, including the opportunity to complete the training at individual pace and the ability to combine physical machine operation with AR training tailored to the machine status.

Regarding the AR tool itself, all participants expressed their appreciation for the holograms of the machine, while some participants specifically mentioned their liking of the AR arrows on the machine that clearly indicated which activities needed to be performed. One participant reported that the option to inquire "how do I do that" whilst asking a question

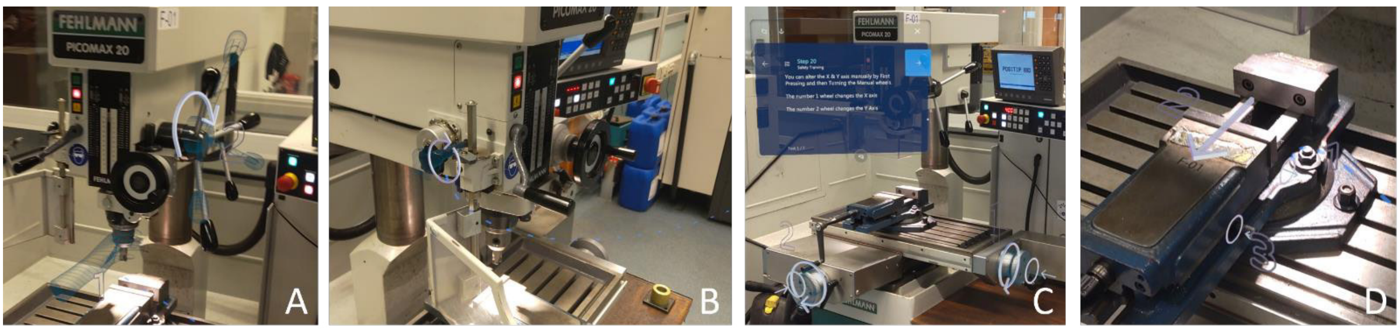

Fig. 2. Various screenshots of the AR experience during the case study

was a useful additional feature for summarising information. All participants in the experiment deemed the live support, via remote assistance, offered by the AR tool to be advantageous.

The students provided feedback for enhancing the prototype. One student recommended incorporating an option for listening to instructions during training as an additional feature. Another suggestion was to add a timeline for tracking progress in the process. The AR instruction received a learning curve rating of 4.3 out of 5, with 1 being easy and 5 being challenging. The participants reported that becoming familiar with operating the HoloLens, locating, and accurately positioning the guide in space, proved to be especially challenging. Nevertheless, they unanimously agreed that the instructions themselves were easy to follow. All three participants indicated that they did not experience nausea or discomfort while receiving the AR instructions.

Two of the three participants reported feeling confident in their ability to safely operate the PICOMAX 20 after receiving the AR instructions. One participant suggested attempting the tutorial again, or with manual instructions, as they found the amount of information overwhelming. However, they did acknowledge that the instructions provided were clear.

4.3. Outcome employees case study

The staff members stated that they believed that AR training might serve as a suitable addition to traditional methods provided it allows for continuous improvements. The training was acknowledged to be well-suited for practical session repetition. The interviewees indicated that more data is required in order to evaluate the overall safety enhancements compared with conventional methods. No adverse side effects such as nausea or dizziness were reported. The workshop employees stated that they trust the system enough to permit unsupervised student use. However, AR training is considered to heavily rely on technology and technological issues, which may impede student learning. They acknowledged that AR training is a beneficial initial instruction, however, machines with many functions, such as the PICOMAX, require further training before ensuring sufficient safety compliance.

The workshop employees mentioned that the compliments that are incorporated into the training are a good touch for motivating students. At the same time, the observation is made that a supervisor is better able to quickly help a student in case something goes wrong. Suggestions are made that currently, the conventional approach is more suitable for providing safety training to a large group of students, citing issues with logistics and the required quantity of HoloLens and machines. However, the employee acknowledges the potential of the prototype for refreshing knowledge. The AR training has the benefit of being the same training for everyone who follows the training, while with the conventional method there can be differences in perceived information per training due to individual interpretation. The possibility of real-time (remotely) monitoring student activity on the machines offers several advantages, it avoids disrupting or distracting students with the presence of an observer and can enhance student confidence.

Some HSE employees recognized the potential of AR training and termed it a 'goldmine', but also indicated some risk. For example, when a machine that was used in a training receives an update or is replaced, a risk assessment must be conducted to identify any new risks associated with the use of this updated technology, and potential changes to the training. The HSE employee stated that utilizing the HoloLens technology has the advantage of preventing the user from becoming entirely isolated from the social sphere. Furthermore, it is mentioned that it is important for the developer of the safety training, to make the instructions and implications as robust as possible, while considering the consequences of users disregarding the instructions. In the event of an accident, employers must be able to demonstrate that they took all reasonable steps to prevent it, including providing clear instructions. Instructions are an integral aspect of such an explanation. The ability of the AR tool to track which training courses have been completed can serve as crucial evidence for the employer that the employee has received appropriate instruction.

5. Implementation roadmap

Following from the case study, it has become apparent that there is a potential for the utilisation of AR. However, seamless integration with the current environment is crucial. The incorporation in the current, digitalized, workshop requires support on how to achieve and maintain that. The AR system should be situated within the existing data infrastructure in a workshop highlighting the need for seamless integration with existing data sources. Its effectiveness is reliant on accessing and merging information from diverse repositories within the workshop ecosystem. The AR headset serves as a conduit to transform data into actionable insights and personalised instructions. The effectiveness of the AR headset depends on appropriate access to relevant data, ensuring that instructional guidance is tailored to the current conditions. To achieve this, a correlation between the AR system and the workshop's data infrastructure is necessary. The information obtained by the AR headset provides information about the surrounding environment but also contextual factors, user traits, and the ongoing user task. In figure 3 the relationship between these different data entities is visualised. The data originating from the AR system can be used in further processing steps, together with other data sources, to extract useful information. For safety monitoring the operator (or workshop employee) can interfere with the AR experience via the (manual or automated) safety monitoring.

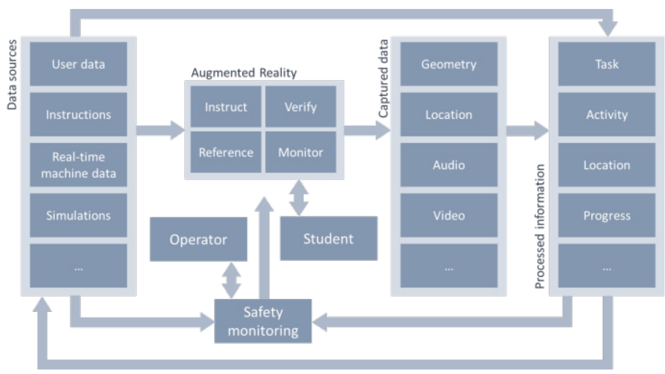

Fig. 3. Relation between multiple data entities in the AR system

6. Concluding remarks

The case study indicates an affirmative reaction towards the AR instruction with high satisfaction and engagement levels. In comparison to traditional methods, trainees found the AR training to be more user-friendly and comprehensible. The ease of operation steps was increased by the part-specific holograms and instructional arrows that were particularly appreciated. The second case study with employees yielded positive feedback on the potential substitution of AR instructions for safety training. However, the need for more information and significant testing to evaluate safety improvement and implications was stressed. Additionally, concerns were raised regarding technology failures. Due to logistical challenges, the workshop employee preferred the conventional method for safety training large groups of students. The prototype has the potential to refresh knowledge for the entire or partial safety training course.

Incorporating AR into machine operation training has the potential to offer significant benefits. Primarily, it improves safety by providing real-time safety alerts and ensuring strict adherence to safety protocols, which is valuable in environments where improper machine usage can cause accidents and damage. Furthermore, AR plays a significant role in personalized and tailored learning by aligning to their diverse backgrounds, experiences, and learning speeds. The incorporation of sensor data and AR technology is considered an advancement in the field of machine operation training. This innovative amalgamation of tools empowers workshop employees to supervise and aid learners while operating machinery, reinforcing the essential pillars of a secure and effective learning setting. In the future, the real-time monitoring abilities afforded by this integrated approach not only facilitate compliance with safety protocols, but also allows for prompt intervention in the event of unsafe practices.

Overall, the approach promotes AR enriched learning within the workshop setting. By harnessing the combined power of AR and sensor data, this approach converts the training of machine operation into an effective and secure learning experience and forms the fundament for future advancements in supervising engineering workshops.

6.1. Future research

Real-time insights can contribute to the level of security, ensuring that students can learn effectively whilst minimizing potential risks. The system potentially can detect and prevent potential errors before they occur. For this the captured data should be used in advanced algorithms and machine learning, safeguarding both students and machinery. . Future research should investigate how generational differences impact the adoption and effectiveness of educational technology to optimize learning for various age groups. Furthermore, this integration surpasses immediate safety measures by offering a platform for ongoing foresight, allowing for the prediction and prevention of potential misuse or errors. This approach not only augments safety but also fosters the constant advancement of machine operation training, permitting the refinement education based on immediate insights.

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