Enhancing Educational Effectiveness in Safety Education -Improving Student Engagement and Proficiency through AL and VR-

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The industrial sector is vital for societal development, but accidents remain a major concern. While serious incidents such as entanglement were once common, accidents caused by operator error have increased recently. In response, safety training programmes and ICT-based courses have evolved. Traditional safety education primarily involves lecture-style sessions with slides and machinery demonstrations. However, it can be challenging to connect these lectures effectively to real-world machine operations, and VR training using head-mounted displays often lacks depth and practical skill development. This paper presents two safety training initiatives at KOSEN Sendai College, focusing on electrical experiments and machining practice. The first initiative is a participatory training programme that uses active learning, in which students engage in group work to encourage active thinking and participation. The second initiative combines hands-on workshop training with VR-based immersive experiences incorporating gamification elements. Developed in collaboration with Nagaoka University of Technology and a VR content company, this training approach fosters active engagement and enhances effectiveness. Designed for smartphones and VR goggles, the VR system supports off-campus use and multi-user environments, offering personalised learning. It also uses gaze-based selection to contribute to research on learners' interests and concentration levels.

Keywords: *Safety training program, Participatory training , Lecture-based training ,VR-based training*

Introduction

The number of accidents in the industrial sector, which is crucial for societal development, has remained relatively stable. However, the nature of these accidents has evolved. While major incidents such as entanglement and crushing used to be more common, there has recently been an increase in accidents caused by operator error, such as sudden movements, excessive force and falls.

The importance of safety training programmes has increased, leading to the creation of educational content and the organisation of training sessions and classes that utilise these materials. In educational settings, safety training is primarily delivered via lectures using slides and videos, or through live demonstrations in front of machining equipment. While both approaches have their advantages, it is important to create balanced content that considers factors such as location and class size.

Lecture-based training, which involves passively acquiring knowledge, makes it difficult for first-time learners to visualise and understand how real machinery operates. Additionally, although VR-based training using head-mounted displays (HMDs) enables learners to experience simulated accident scenarios, these experiences often remain mere simulations, failing to lead to deeper comprehension or skill acquisition.

In this paper, we present two initiatives related to safety training. Within experimental classes at our institution, two types of safety training sessions are conducted: one for electrical experiments and another for machining practice.

One initiative involves a participatory training programme incorporating active learning. Unlike traditional lecture-based training sessions, which rely on pre-existing content, this approach makes students active participants in the learning process by engaging them in group work.

Another initiative combines hands-on training with actual machinery in a physical workshop with immersive, VR-based training. The VR content, which incorporates gamification elements, is experienced through HMDs. This content was developed in collaboration with Nagaoka University of Technology and a VR content development company, with the aim of encouraging proactive participation and enhancing the effectiveness of safety training.

To ensure accessibility in off-campus and multi-user classroom settings, the VR training system has been designed to function with smartphones and VR goggles. This enables each participant to enjoy a personalised learning experience, reinforcing their understanding of safety education.

SAFETY EDUCATION AT OUR CAMPUS

Our KOSEN has two campuses: Hiroshi and Natori. The Hiroshi Campus primarily focuses on electrical, electronic and information-related fields, and its training workshop is smaller than those of other national colleges of technology in Japan. However, it is equipped with basic machine tools capable of performing fundamental mechanical work and conducts machining operations such as KOSEN ROBOCON, the creation of special fixtures for research purposes and the development of electric vehicles (Eco-Run). There are also numerous laboratories where experiments and practical training on motors, electrical circuits and related subjects are conducted.

To ensure the safety of students using machine tools, we provide practical training and issue certificates to those who complete it. Only those who have obtained a certificate are permitted to use the machining equipment in the workshop. Since 2019, we have been holding safety training sessions for all students to foster safety awareness. Safety education has been incorporated into the experimental and practical courses for third-year students, and this continues to this day.

Two types of safety training are conducted at the Hirose Campus as part of the third-year electrical circuit and mechanical processing laboratory safety education programme. Designed to help students acquire and utilise knowledge through active learning and student-led group work, the training is crucial for equipping students with the skills they need to work safely in a laboratory environment. Therefore, common safety training is conducted for the entire class. Due to space limitations in the laboratory and the need to observe demonstrations, however, practical training is divided into two groups. Training content includes explanations of equipment, as well as guidelines on attire, tidying up before and after use (5S) and other measures to enhance overall safety awareness in mechanical processing.

The lectures are conducted over three sessions. The first session covers the attire required for electrical engineering experiments and the safety precautions to be taken during them. The second and third sessions cover the attire required for mechanical engineering work and the safety precautions to be taken during machining. Throughout the three lectures, we promote 5S awareness (based on 3S) and encourage active learning and group work through spontaneous participation. The safety training avoids one-way instruction and includes active learning in the form of group work to discuss how to apply knowledge gained, including examples of near misses (minor accidents that could have resulted in injury). Students first make their own hazard predictions and then share them within their groups. They summarise the incidents and reach a consensus on countermeasures within the group. Following this, the entire class shares information between groups to enhance safety awareness. Additionally, when explaining machine tools in a lecture format where concrete images are difficult to convey, we demonstrate the operation of machine tools in an actual training workshop, including their movements and usage precautions. Due to space constraints in the workshop, students are divided into groups to effectively demonstrate real-life examples of accidents that could occur with machine tools.

Figure 1 shows part of the content for group work in electrical experiments and Figure 2 shows part of the content for group work in mechanics. Rather than adopting a traditional knowledge-transmission approach, students are encouraged to predict hazards at an individual level. This is followed by consensus-building within the group, with the final step being to share findings with the class through group presentations. This approach aims to foster new insights and consensus-building.

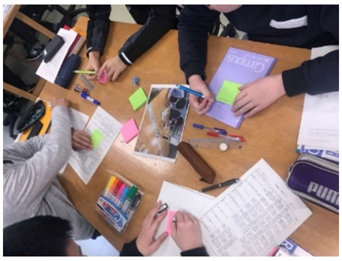


Figure 1. Group work in electrical experiments

(a) demonstration1

(b) demonstration2

(c) Safety Precautions 1

(d) Safety Precautions 2

Figure 2. Group work in machine experiments

As mentioned above, encouraging students to learn voluntarily enables them to develop an awareness of post-incident prevention, which is an important aspect of safety education. Rather than simply teaching students, we can help them to predict dangers and prevent accidents. Additionally, encouraging students to share their opinions can raise awareness of accident prevention in relation to clothing and items brought to experiments and practical training.

Due to the size of the factory, it is difficult to conduct the third session on the safe use of machine tools for 40 students at once. Therefore, the students are divided into two groups of approximately 20 students each. They receive explanations on the use of machine tools and safety precautions using videos and other materials. At the practical training facility, the students are divided into two groups of approximately 10 students each. They experience the dangers posed by noise and air vibrations from actual machining equipment. They also learn about the importance of proper preparation and adherence to operating procedures to ensure safe machining.

While implementing this safety education programme, it was confirmed that understanding was not significantly affected by the order in which the content was presented. However, some video explanations focus on what the instructor wants to teach rather than what the students want to learn. Additionally, some general explanations of how machines operate may not capture the students' interest, raising concerns about their engagement during lectures.

EVALUATION AND IMPROVEMENT THROUGH THE DEVELOPMENT AND USE OF VR CONTENT FOR SAFETY EDUCATION

As previously mentioned, at the training factory, we provide specific explanations of the dangers of actual machine tools and accident prevention measures through clothing. However, due to space limitations, it is sometimes difficult for everyone to review the information in detail. As a solution, the following options are proposed: 1) surveillance-type content using a fixed-angle camera, 2) panoramic content using a 360-degree camera and 3) immersive content using VR technology. Options 1) and 2) are currently under development as part of a graduation research project. Here, we will focus on option 3).

In the 2023 financial year, we applied for and were selected to develop safety education content for machine work as part of a virtual reality (VR) educational material development project at Nagaoka University of Technology. By creating VR content, our goal is to enhance the effectiveness of education through simulated experiences, which are more impactful than videos and explanations alone. Although safety training content for mechanical engineering often focuses on specific equipment, the objective of this project is to develop content that covers the fundamental principles of machine tools categorised by major types, such as cutting and drilling, as well as the associated risks. The focus is on creating fundamental safety education content to prevent accidents rather than detailing the specific differences between individual machines.

A. Development of prototypes

The most effective measure to prevent accidents during processing was the creation of development content, which focused on selecting safe clothing for machining operations and training to anticipate clothing-related hazards. For VR content, the goal was to enable users to confirm machining operations in a basic VR environment, so immersion was prioritised over high-precision VR space development. Therefore, the following elements were excluded in order to prioritise lightweight operating environments and reduce development costs: 1. An environment in which avatars can be operated freely;2. Coexistence with other avatars;3. A workspace for collaborative tasks with other avatars;4. Realism achieved through consideration of the surrounding environment (factory facilities).

However, our priority for the content was to create something in which users could actively participate rather than simply watch. To achieve this, we made the selection of work attire (e.g. safety gear, goggles and footwear) optional instead of allowing users to select avatars, as safety education begins when users attempt to perform tasks in a training factory. Depending on the machine's movements, different clothing choices may be necessary, as machine tools require basic equipment for operation. For instance, cloth work gloves are not worn when using a lathe due to the risk of them getting caught in the tools; however, leather work gloves are an option. By making the items required for preparing to operate machine tools optional, users can enhance their sense of participation and apply the safety education they have learned. As well as determining whether the avatar's clothing is correct before machining, we also explain how clothing affects work.

After selecting their work clothing, users can confirm accidents that occur during machining using the machine tool in a VR environment. As previously mentioned, in view of the need for lightweight operation and low-cost development, we have opted to establish observation points within the content rather than enabling users to select arbitrary viewpoints (continuous description). Allowing users to view accident scenarios from multiple angles makes it possible to consider preventive measures alongside the training session content. Figure 3 shows the scenario for this system's content. Although the basic process is straightforward, it illustrates typical accidents involving machining tools.

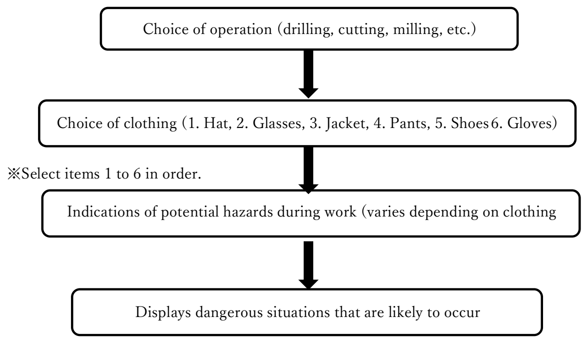


Figure 3. Content scenario

Examples of hazard warnings

- Hair getting caught (hat)
- Splinters flying into the eyes (glasses)
- Clothing with strings getting caught (jacket)
- Injuries from wearing short sleeves (jacket)
- Tripping hazard due to long hems (pants)
- Falling objects (shoes)
- Getting caught due to wearing gloves (gloves)

(If the vise is not securely fastened, it may fly off. Applying excessive force may cause drills or blades to break.)

※Even when selecting clothing that considers safety, ensure that the above hazards are clearly indicated.

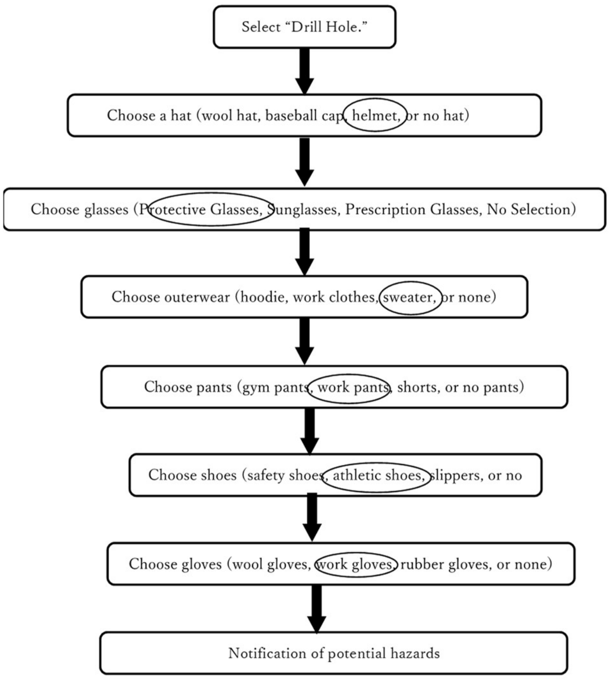
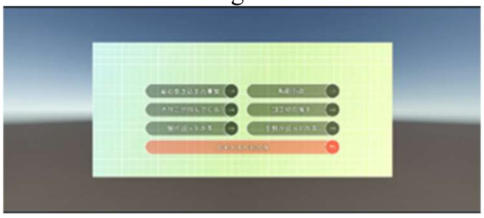


Figure 4. roved content scenario

This This system was developed using Unity. Content development was commissioned from SOLIZE Co., Ltd. (https://www.solize.com/). The key decision when determining the system specifications was whether to operate the VR space via an internet connection or as a mobile app. As previously mentioned regarding the development and operational environment, our aim was to keep costs low. As the system would be used by multiple people in a classroom setting, our focus was on creating accessible content for as many students as possible during the same time slot (lecture time), rather than highly advanced VR content. To this end, we kept the cost of operational equipment low and opted for an app-based system that does not require a specific playback environment. Additionally, as we considered the possibility of using the system outside school premises (e.g. for public lectures), we ensured that the content could be used off-campus. Based on the above, the playback equipment consists of Android OS-equipped mobile phones and smartphone-compatible head-mounted display holders. As the app includes item selection, it has been configured with a Bluetooth-connected controller to ensure ease of operation. The equipment used is shown in Figure 5. The prototype screen developed is shown in Figure 6.


(a) Operating equipment (b) Experiment

Figure 5. Practical training environment



(a) Tittle of contents

(b) VR contents (for monocular)

Figure 6. Developed VR contents

B. *Evaluation of prototype content usage*

The VR content was introduced into safety training sessions for third-year students across three courses during the 2024 academic year. Safety education was delivered through a combination of VR content and hands-on demonstrations of machine tools. After the lectures, a survey was conducted using Forms to evaluate the VR content. Although the VR goggles provided an immersive experience, the content was monocular, so evaluations of the visuals were not anticipated.

The survey consisted of three simple questions. 1) Have you ever watched VR content? 2) What were your impressions after experiencing it? and 3) What suggestions do you have for improvement? Approximately 100 students were surveyed.

Regarding question 1, 48% of respondents had experience, while 52% had none. For question 2, positive feedback included comments such as 'sense of presence and immersion', 'quick and easy-to-understand video progression', and other points that differed from regular video viewing. Negative feedback included comments about insufficient VR immersion, a lack of realism in computer-generated (CG) graphics, unclear hand movements or collisions with objects, visibility issues, and dizziness, particularly in single-eye VR. There were also concerns about cost-effective visuals. Overall, there were no complaints about the safety training elements.

Since the prototype content was monocular, improvements to create stereoscopic VR content were urgently pursued. The results of the questionnaire analysis are presented in Table 1.

Table 1Analysis of Questionnaire on

HMD/Controller	+	2
	−	10
VR experience	+	11
	−	19
Content/Video	+	15
	−	20
Screen fatigue/motion sickness	−	25
Sound desired	−	4

The prototype was developed to enable students to actively practise what they had learnt in safety training rather than simply observing it. Prior to teaching students about machining equipment, we believed that educating them about the necessary safety attire would enhance accident prevention. Therefore, we provided options for each item of safety attire, such as hats and protective gear, and allowed students to select the appropriate items. The avatar's attire changes based on the items selected, and the final attire is displayed alongside an explanation of why it is correct. To improve focus on the content, we are continuing to refine the prototype by adjusting the viewpoint, switching to a dual-view VR format and adding sound effects.

C. Content revision and utilization evaluation

Based on the survey results, the following improvements were made to the content:

- improving the quality of the content through multi-view VR

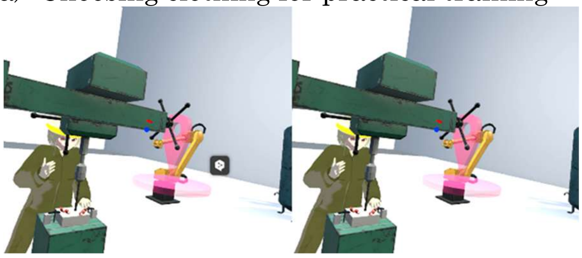
- enhancing the sense of nature by adding sound

- enabling users to experience dangerous scenes from various viewpoints within the content

- allowing users to select what they want to see by focusing on it for a few seconds The viewpoint movement system was changed to semi-fixed position selection. The controller was removed to encourage concentration on the content itself. Figure 7 shows the revised content. A version with added sound effects was also developed.

Similar to the prototype, the post-use survey of the content showed that the objectives of improving visibility through changes in perspective, enhancing quality through the use of stereoscopic VR and increasing realism had largely been achieved. As the quality improved, interest shifted from the safety education content to the characters, with an increasing number of requests for changes to their clothing and hairstyles. This suggests that the safety education elements have been fulfilled and that the focus is now shifting towards decorative elements and the realism of the surrounding environment.

(a) Choosing clothing for practical training



(b) Selectable viewpoint (pink pin)

Figure 7. Development of VR content(for binocular)

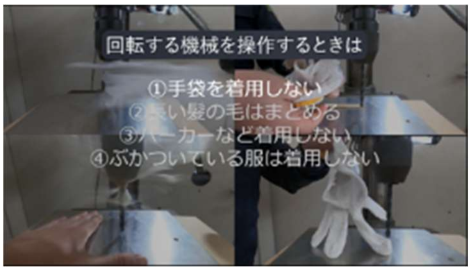
This time, we developed content using a ball mill. In the future, however, we will add other types of machine tool and create content that reflects the different types of clothing required for each one. In addition to VR, we will add effective annotations to improve safety education. Specifically, we plan to add videos of real accidents, like the ones shown in Figure 8, as well as panoramic photos that allow users to adjust their viewpoint.

Furthermore, to enhance the effectiveness of the training, we plan to add photos like those shown in Figure 9, which include annotations on safety measures and proper processing postures.

(a) Examples of dangerous video created by mock hands

(b) Panoramic image (360-degree image)

Figure 8. Content for annotation (accident)



(a) Explanatory Video

(b) Correct Operation Video

Figure 9. Content for annotation (safety)

Conclusions

Since 2019, we have been taking voluntary safety courses incorporating AL. The course covers basic electrical experimentation and machine tools, and includes the 5S and KYT (Kiken (danger), Yochi (prediction) and Training) methods. Students learn to apply their knowledge through awareness.

The VR content is not an expensive, high-precision HMD, but rather a low-cost VR environment that uses a mobile phone and an HMD kit. The content is developed using a mobile phone (Android) application and involves the removal of restrictions on communication and other factors to enable the creation of portable, multi-view VR content. This enables multiple contents to be used at the same time, creating an effective environment for safety education practice in the classroom. It also made the course more engaging for students.The next step is to incorporate machine tools using a 3D scanner.

We believe that improving the game aspect could increase concentration on the content. For example, a confirmation test could be set up in the VR environment to confirm safety training knowledge. We will also improve the content through the annotation effect and examine the objective improvement of learning efficiency through analysis to enhance the content.

Acknowledgements

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