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Using augmented reality (AR) in vocational education programs to teach occupational health and safety (OHS)

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Abstract
The aim of this research is to design a system that will raise awareness among vocational education students about occupational health and safety and the integration of Augmented Reality (AR) systems into the application/concept. Simply, projected on the work force surface, the AR system warns the students as they perform actions that pose a risk, need caution and may result in accidents. Therefore, by repetitive warnings, students learn the faultiness of actions in a faster pace and develop and insightful awareness. The research involves a literature review and two experiments studies in Çınarlı Vocational and Technical High School (CVHS) with high school and Dokuz Eylül University Mechanical Engineering (DEU ME) students. A system is designed according to the findings from these studies. As a result, students learnt to be more cautious, and the number of mistakes they make decreased. This will result in decrease in the number of occupational accidents, deaths and financial loss. The project presents an innovative method applicable both to the industry and the training a qualified work force.

Keywords
OHS training Vocational Education, Augmented Reality, Occupational Health and Safety, Education, Machining

Introduction
The problem that is stated in this paper tackles with the lack of courses and inability of the teaching of occupational health and safety (OHS) for vocational and industrial education. The great efforts of keeping the occupational health and safety standards high also makes the subject harder to teach. Without exposure to risky or dangerous situations, the workers may develop a false belief of being safe without precautions. Especially the inexperienced workers get injured more often. Otherwise, the worker becomes experienced and starts working as a form of a reflex, which may result in the false belief of being safe without the precautions. Although it is true that the inexperienced ones are the most likely to be involved in work accidents, experienced workers also make mistakes that result in injuries, or even death. Both employers and employees see OHS as a burden. Employers consider it a financial burden and time consuming because of all the inspections and training. The employees consider personal protective equipment needed makes them incapable of moving freely and consider training is not necessary.

This research has been undertaken to understand the effect of a fairly new technology on OHS training. The research phases are:

- Creating a guideline for industrial designers to start their research on OHS and augmented reality (AR) systems.
- Designing an education system to teach occupational health and safety in vocational schools.
- Creating a discussion on OHS and what can be accomplished about it.
- Understanding the effect of AR systems in the field of education.

Methods and Research Questions

This research consists of two parts; a preliminary study to understand the problem and its approximate solutions; secondly, a main study, the experiment of the developed system in vocational education. The main study had a systematic data collection and analysis, which made it available to be analyzed as both qualitative and quantitative research. The study's experimental and comparative data was examined with quantitative methods.

This experiment was a controlled field experiment with between-subjects design. Controlled experiments have control and test groups to find out the effect of the independent variable. Field experiments are experiments conducted in the field the person lives/studies/works in, in this case the educational field, vocational school. Between-subjects design is about changing one condition of the independent variable at a time. In the first experience, for example, vocational high school students of the same age and same year, and the only difference between the groups was the source of the warning in cases of violations. Between-subjects design is a commonly used method in education which requires at least 20 participants for each group. A broader study can be conducted with more participants. In such a study, types of warnings given by the machine can be investigated in terms of effectiveness.

The research questions were

- Are AR systems effective in OHS training and if they are effective, how effective are they?
- Can a system be designed for an existing machine to make it safer to operate?

Significance of the Study

This research clarifies the significance of OHS, guiding the designers into a different path and a way of thinking in order to design systems that help teach the students OHS.
OHS training has been a matter of professionals. It has been changing for a while. Even the Ministry of Education in Turkey has made it compulsory to employ OHS experts in every department. These experts inspect schools and other educational areas, such as courses, in terms of safety and have the authorization to take action in order to make education safe for the students, teachers and other people using these premises.

The main difference of this research is it does not rely on the technology or the innovations of the machines that makes them safer to operate, rather relies on the learnability of OHS in the early stages of professional life or even while studying.

The main difference between a person and this system is the system cannot be tricked, and it is always there, watching the mistakes, while teachers and inspectors move around to inspect other students. It also cannot be hacked while most machines in small businesses are hacked by either the workers or the employers themselves in order to operate more quickly.

Limitations of the Study

The experimental design was conducted in CVHS. Although a lathe is used in many applications today in industry, most of the students at the high school do not get the necessary education to be a lathe operator and the demand for these courses are decreasing every year. Because of that, the test was conducted with 14 high school students as participants. In order to increase the number of subjects, DEU ME students were included in the study as a second experiment. The suggested system is intended to be used for educational purposes; therefore, it has been tested with students only. However, as a further study, it could be tested with professionals working with lathe machines.

Theoretical Background

According to International Labor Organization (ILO), OHS is the science of expectation, acknowledgment, decision and control of dangers emerging from the workplace or the work itself that has a negative impact on the health of the laborers.

Precautions and Losses

Preventing work accidents need a systematic approach exactly like preventing car accidents. Although legal regulations are effective methods, non-punitive methods are also used. The most important non-punitive methods are OHS education or training, Prevention through Design, INFO cards and checklists (Jørgensen, 2016). These applications are known as injury and illness protection programs. Safeguards in machines and systems that prevent the worker to get or reach into the dangerous zones have been found to be useful. For example, the number of injuries in power-presses decreased after the installation of two hand operating systems (Suokas, 1983). Similarly, accidents and injuries in lathe operations have decreased in great numbers with the improvement of lathe safeguards (Varonen, 1995). However, using safeguarded machinery is not legally obligated and accidents that could have been avoided by simple guards happen every day. Since legal precautions in Turkey are not specific enough, non-punitive methods are the primary type of precautions. They depend on the decisions of employers or managers.

Losses in work accidents are divided in two, human loss and financial loss. Most of the time human loss or an injury results in financial losses due to accident benefits given to the injured worker or in case of loss of life the worker's family, stopping the manufacturing in a factory and long-term effects such as the workers' unions demanding higher wages in order to work under dangerous circumstances. In addition to these, the employer of a high risked factory will not be able to find the workforce they need since workers would not want to work in a factory that has a bad reputation with OHS.

Occupational Health and Safety in Turkey

OHS gained importance in Turkey after the horrific accidents in Tuzla shipyards in 2008. Enforcement law regarding work accidents and occupational safety were accepted in the Turkish parliament with an omnibus bill afterwards. This law included the obligation to have the necessary training or education for dangerous work fields or jobs that require training in order to work safely. Professional competence certificates obtained after education and training are given by the vocational qualification authority in The Ministry of Education.

EUROSTAT data shows that Germany, UK, Norway, Finland and Ireland have the least number of deaths at work, with numbers varying from 1.0 to 1.8 in 100,000 while it is 12.3 in 100,000 in Turkey. According to the data obtained from the report of The Social Security Institution of the Republic of Turkey (Sosyal Güvenlik Kurumu, SGK) in 2014, main metal industry and metal product manufacturing are the most dangerous economic activities in case of the number of accidents and the number of days spent in recovery. According to the Turkish Statistical Institute's (TÜİK) report on work accidents and work-related medical problems, most accidents happened among machine operators and assemblers with 4.8%, which is more than twice as much as the average of 2.3%. The same report states that the eye strain and visual focusing is a highly encountered problem among the workers, with 10.4% of all workers contributing the survey.

In order to teach safety in vocational education, in Turkey, 11th grade students are given at least 8 hours of OHS education at school. This course does have certification. Their education also includes a career development course in 9th grade, which also includes OHS education.

Vocational Education

Vocational education is crucial for developing countries. It provides qualified manpower. Vocational education costs 2 to 4 times more than the mainstream education (Psacharopoulos 1997). It also has a financial effect on the students, since they cannot work while having this education. However, this financial burden is paid back accordingly, since educated and qualified manpower earn a lot more than unqualified workers. The important issue in this matter is not losing qualified manpower due to an accident. This can be achieved through giving proper work safety education to these people during their time in the vocational education.

In Turkey, students with the lowest high school entrance exam grades apply to vocational schools. Going to a vocational school is mostly not a choice of the student but an obligation in order to continue their education. The choice of vocational schools is not made by the students since they do not know their fields of interest nor do they know themselves completely. This choice is made with the guidance of the parents, the grades they achieved in the exams and their success in courses before (Hepkul, 2014). According to a study implemented with vocational high school students in Bursa, Turkey, these students see themselves capable of understanding technical and mechanical matters although they think that they are incapable of the social skills (Bağatır et.al, 2004). This also shows their sense of self is affected by their education and their choice of high school.

According to Andersson et al. (2015), vocational school teachers teach OHS based on their own experiences. They found that only a small percentage of teachers search for teaching materials for this subject. This kind of education bases itself on the risks; teachers warning the students according to what have happened to them in their professional life or their own training phase. This type of education lacks pedagogical methods, therefore may result with the student not understanding the subject. Andersson et al. (2014) found that an OHS education based on teacher's experience results in the student believing they are the only responsible people and the key to avoiding accidents.

Augmented Reality
AR enables us to attach computer generated elements from the virtual environment into the real world (Graham et al., 2013). Technology and computer science enables us to go beyond our limits of visual perception through showing us the world with the information which was not there before.

AR is used in many fields from education to tourism, medical applications to military. Research has been done by Serio et al. (2013) on the effects of augmented reality in education. In this research, students claimed that these methods are more stimulating than the traditional education methods. Other researchers have supporting these results: use of AR and sensors is effective for awaking students' attention (Enyedy et al. 2012; Kamarainen et al. 2013). AR enriched textbooks are proven to catch students' attention, make the class more enjoyable and arousing the curiosity for the courses. However, AR's use in education is limited to the enrichment of the teaching materials. According to the predictions made by Abdoli-Sejzi (2015), it will be used in OHS in the future.

Experimental Design
This study consists of two experiments and their results; an experiment conducted with the high school's students in May 2016 and a second experiment with DEU ME students who have completed their second semester in August 2016.

Case studies were implemented in order to find out what can be done to increase occupational safety without changing the setups of the machines or the workplace and without adding extra safety materials or machines other than the ones in use. While working on the system implementing the experiment, data to understand the workplace hazards was gathered by photographing and interviews with teachers of the vocational school. This data helped us to understand how accidents can be avoided in such environments where the operators are not professionals. This data also helped us make guidelines to make better machines in terms of safety. Further information regarding this matter will be given in results and conclusion chapters.

Population and Sample
Students who participated in the test were chosen randomly among the technical high school students and industrial high school students. 14 students were randomly divided into two equal numbered groups. The first group, which was the test group, used the test setting and got the warnings from the machine rather than the teacher. The second group, which was the control group, did not use the test setting and the students were warned by their teacher when they make mistakes. Both groups' mistakes and the incidence frequencies were noted down. A week later, the same students were gathered again, this time without the test setup. Their mistakes were noted down again. Both weeks' results were compared in order to see if the system has made a difference in the behaviors of the students.

The experiment was repeated with DEU ME students as a second experiment. 28 students participated in this second study. All steps of the previous experiment were repeated.

Students were expected to machine the parts given to them by their teachers as a part of their term projects, for university students, parts given by their instructor and the experiment was implemented while they were machining these parts. All parts and tasks given to the students were similar.

Experimental Setup

The device planned to be used is an autonomous device, meaning it will decide if the student is making a dangerous move or an action and warn them accordingly. These dangerous actions and violations are identified according to the observations of vocational school teachers, directly reported to the research team. They stated the most common mistakes made by their students, that are dangerous in terms of OHS.

Although there are many options to automatize this device, the most effective option would be machine learning. The first reason for choosing this method is that it takes less coding, and any dangerous move can be added to the system easily even after the setup has been finished. This would be helpful if another dangerous action was spotted among the students or if there is a fault or a missing part in a machine that the students need to be careful of. Matters of programming the final system will not be explained further. Examples of this kind of system in Turkey can be seen in portfolio of “Hedef Sıfır” (Aim: Zero) projects, which aim to end occupational fatalities. They produce machine learning based OHS systems with cameras as input devices. These cameras send the information to a computer which detects a hazardous move or action and warn the worker or even shuts down the systems. Another project of this group detects a worker’s outfit to find out if it is correct for their line of work, with safety guards and equipment. This system also works with machine learning, for teaching the computer which kind of visual is the correct and if the computer does not perceive this image, it gives a warning. Unfortunately, these projects are inactive today and the term “Hedef Sıfır” (Aim: Zero) is used in environmental sustainability matters in Turkey.

Other violations that cannot be detected by such systems can be detected via attaching other cameras to the system. These types of systems are available. A system that can detect if the worker is wearing appropriate Personal Protective Equipment (PPE) is made by the Hedef Sıfır project, mentioned before. Also, other companies have similar systems that can detect the missing or not appropriate PPE by cameras that feed a computer and AI detecting these mistakes. Such system can ban the worker from worksite, or if it is connected to our research’s system, it can either give a red-dot warning or even can shut the machine down if the violation continues.

Software used in the prototype, called “red-dot” named by the programmer, is programmed for this project. This software is designed with Unity Software Development Kit. It enables the user of the computer or a smartphone to put a red dot on the screen where they click or touch, depending on the device. The red dot on the screen can be erased after the student realizes and corrects their mistake. With this software, the prototype was controlled by the researcher and the warnings were projected on the working surface by the projection device hanged above the lathe. The color of the light in this prototype was chosen according to the accepted color norms in machinery; as for blue machines having orange warnings and green machines having red warnings, due to the negatives of the colors. Most of the lathe machines in CVHS are green with some exceptions of blue. This system was tested on a green lathe. Additionally, the software can produce warnings of different sizes, for example, a small dot is needed for a precise warning and a big red dot for getting too close to the machine which can happen really quickly and is a whole-body mistake.

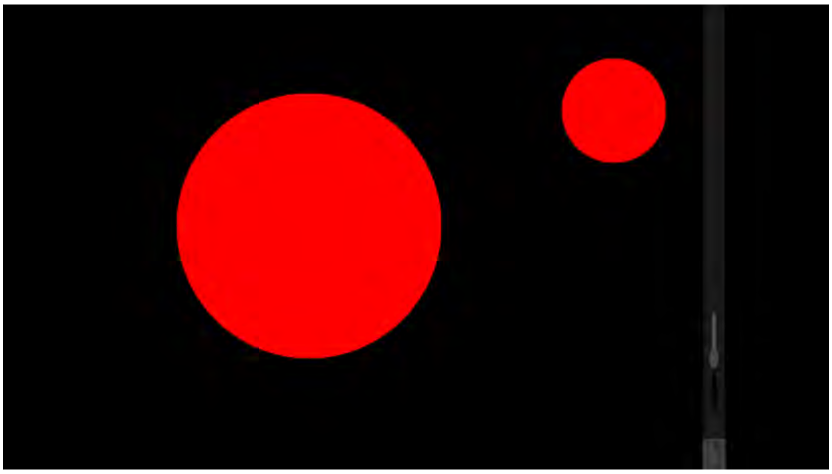

Figure 1. Screen capture of the Red-Dot Software

The projector used is chosen according to the uncontrollable lighting conditions in the workplace. The projector has to have high lumen value in order to be visible in the highly sun-lit workshop.

Figure 2. Experimental setup in CVHS

Figure 3. Warning seen on chuck

Final product is intended to be encased and will consist of the following parts:

- Single Board Computer
- Camera
- Sensors
- Smartphone
- Projector
- Case

The block diagram of the prototype and the system are presented in Figure 4 and Figure 5, respectively.

Figure 4. Block diagram of the prototype used in the experiments

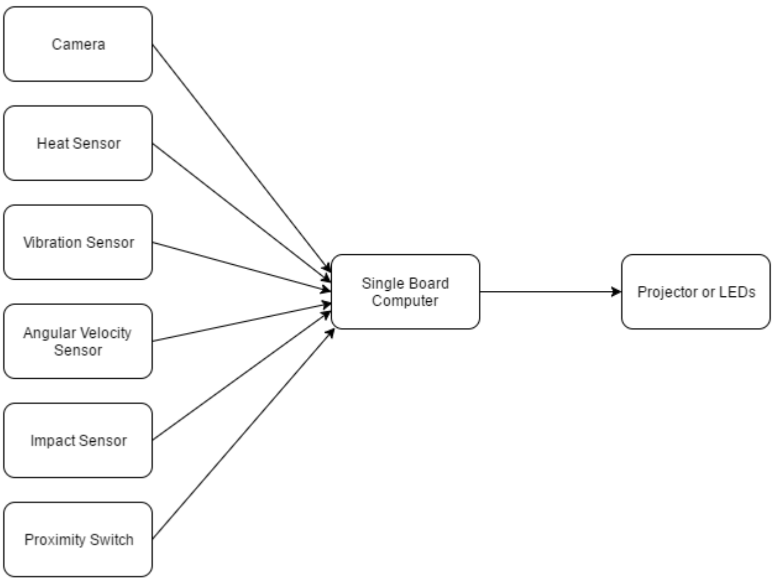

Figure 5. Block diagram of the system

In the experiment, the manual input of warning is done by the researcher. However, students in the test group did not receive direct warnings from the researcher nor from their teachers. As seen in the block diagrams of both the prototype and the system, the prototype is researcher-dependent while the system will be independent.

The real system will have, cameras, heat, vibration, velocity, impact sensors, proximity switches. Cameras will be used as intelligent systems to detect the hazardous movements such as standing too close to the machine, having people around the machine other than the operator, leaving a workpiece, key etc. unattended.

The testing setup was intended to have a camera to record the hazards and movements of the student but due to nervous behavior of the students and their unwillingness to be recorded while working, the camera was detached from the device. Recordings were done with another camera for some of the students. During the test and also during the no test setup in the workshop, students' behaviors, hazardous moves, hazardous actions and surroundings, simple mistakes that are not hazardous by nature, were observed and noted down.

Photography was another method used to gather data, especially when the student continues to make the dangerous action. This method was also used to gather data around the workshop in order to find the mistakes made about occupational health and safety in terms of surroundings and machinery.

Data collection was made throughout the days; the experiment was not implemented in a specific time of the day.

Data Analysis

Data gathered from the 2 days of studies with each group of students were organized as day 1 and day 2; on the first day, control and test groups, without and with the system operating respectively; on the second day both test and control groups worked without the system. Again, their mistakes and hazardous/risky actions were noted down. Data was analyzed in order to see if the system is an efficient method of teaching high school students about OHS and the problems that are confronted. Data was obtained with between-subjects design. In this type of experiments, only one independent variable is changed. In this experiment's case, this variable is the source of warning.

Findings and Results

The information and insight gathered with the literature review suggested that most of the accidents are avoidable through taking proper precautions and with the use of required personal protective equipment.

The test group of high school students showed positive reactions to the system. Their first reaction was investigating the system by putting their hands in front of the projector and asking questions about it such as "does this record our actions" or "will this affect our grades?". After gaining their trust they began to work with the system on, without further concern.

The test group students did not repeat their mistakes. Four out of seven of them did not make any mistakes again. Every one of them started using safety goggles after being warned by the system. However, one of the students failed to understand the hazards caused by the tool bit.

He did not remove the unused tool bit and did not tighten the tool bit and got warnings from the system both times. Even when he did not do the exact same mistakes, he cleaned the tool bit with his bare hands, without thinking about the consequences. This shows that such systems will need upgrades in order to teach the dangers of a certain part. A positive reaction towards the system was from another student, who was in test group. He warned his friends about the importance of the safety goggles after being warned by the system. He even asked his friends, who were watching him while he was operating the machine, to put their safety goggles on.

Students in the control group did not put their safety goggles on even when they were warned by their teachers multiple times. They continued working without safety goggles and without a closing chip shield, which was extremely dangerous. Eventually, an incident happened during the experiment and a student had a flying chip get into his eye. Luckily, no permanent damage was done, however, he continued working without the safety goggles even after this accident. Another student in the control group, failed to understand the dangers of getting his limbs close to rotating parts and standing away while the machine is working. He did similar mistakes both days. Another student measured the work piece without getting the tool bit away both times, which indicates he did not learn from the warnings made by the teachers. Another student held the work piece with bare hands and burned his hand the first day, did not need warning from the teacher but he learned from his mistake and did not hold the hot piece next time, but he made his friend to do so, which indicates that he lacked discipline and failed to understand the consequences of his actions. Another student in control group made exactly the same mistake both days. He left too many tools on tool kit platform. Even when he was warned, he made the same mistake, failed to understand how these tools could cause hazard.

None of the control group students avoided all incidents on the second day. This showed that the system is an effective method of warning the students. The study also indicated that the students do not listen to their teachers' warnings as much anymore. The students did not change their attitudes for the safety gear even after the teachers warned them. This may be the result of the teachers not using this gear too.

DEU ME students made different mistakes than CVHS students. The main mistake made by university students were forgetting to use safety goggles and chip guards. Difference in these two experiments can be explained by the students' level of expertise in terms of machining; none of the DEU ME students had worked on lathe before the first day of the experiment. Therefore, the level of difficulty of the work pieces given to them was much lower than the vocational education students. However, the teachers at vocational school call these students fast learners. Although they did not have OHS training at school, yet these students were more aware of the hazards.

Safety goggles were not used by 12 of 28 DEU ME students, this being the most common mistake by 32%. Either the machine or the teacher warned some of these students more than once; one of them was warned 4 times. Total warnings for the goggles were 20. However, only 2 students in test and control groups forgot to use safety goggles on the second day.

The second most common mistake made by university students was about their outfits. The mistakes about outfits were not wearing a smock/work uniform, not buttoning up the outfit properly and wearing jewelry on their hands.

The least common mistake in both groups was accidental start-ups which occurred only twice, which equals to 3%. Standing close to the non-operating machines was the second least common mistake. Four warnings had been made for standing too close to the machine.

Chip guards were not used by 8 out of 28 and these students had been warned only once. None in the test group forgot to use the chip guard on the second day.

In order to understand the effectiveness of the system in both groups, having different number of subjects, the average of mistakes made by students have been systematically adapted into a graphic where test and control groups in both experiments can be seen in the same image.

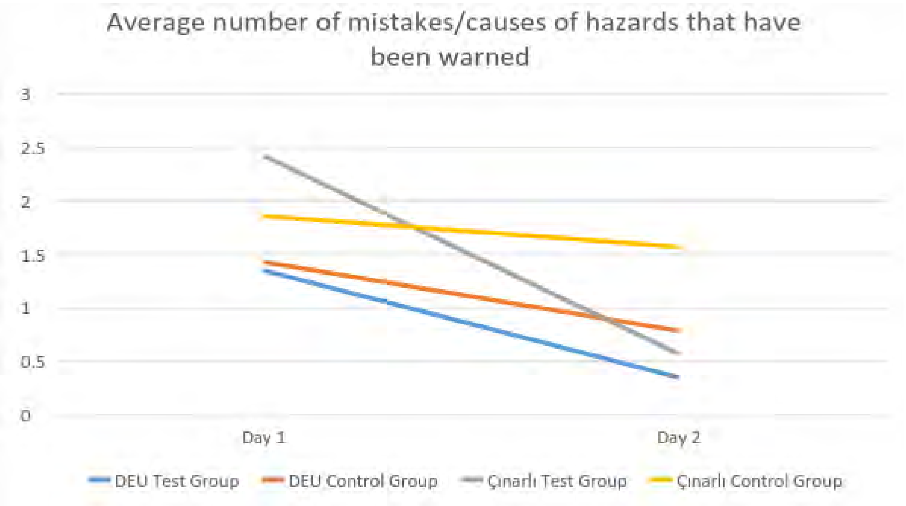

Figure 6. Average number of mistakes/causes of hazards that have been warned

The graphic in Figure 6 shows the average number of mistakes/causes of hazards that were warned either by teacher or by the system. Day 1 shows the first day of the experiment. Day 2 shows the second day of the experiment. Warnings did not take place on Day 2, only students' errors were noted.

The average number of mistakes was higher in CVHS students than DEU ME students. The decrease in the number of mistakes between Day 1 and Day 2 had been expected. The incline of the graphic shows the degree of effectiveness of the source of warning, either it is the teacher or the system. This graphic shows that in both experiments, the average number of mistakes decreased both in test and control groups.

The most drastic change, however, is seen in the test group of CVHS. In both experiments, this test groups made fewer mistakes than the control groups in their second days.

Final Design of the System

As final design, a system without built in projection, is considered to be more cost efficient and more applicable for schools in Turkey since the government supplies every school with projectors.

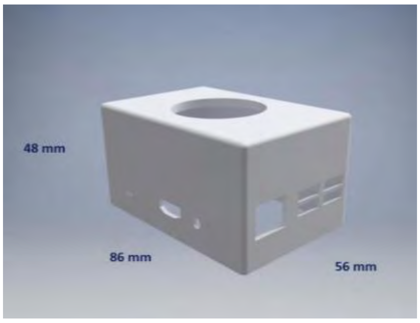

Figure 7. Case design for the system

In cases of a low budget, the system will be installed in one, or a few lathes; the students in that workshop will work on that lathe by turns. As mentioned before, with additions to the software, this system can work on any machinery, so this system can be demounted from the lathe when all students have been trained with it and can be mounted on another piece of machinery such as milling machines or bench drills. This system can also be used in factories or workshops. With this system, OHS inspection can be made easily by switching the “red dot” warnings off.

If there will be more than one machine in a machine park with systems connected to them, these systems will also be connected via wi-fi or ethernet. A sensible option would be to connect all the inputs (sensors, cameras etc.) to a main computer with higher computing power. This would result in a smaller box for each machine, easy management of the system, better and faster machine learning.

Conclusion

OHS trainings and machinery used in the school lack safety and the teachers’ warnings are found to be not effective enough on the students. These teenager students’ attention is hard to catch since they did not choose to be in vocational high schools in the first place. However, new technology caught their interest with this system. Future methods of education in vocational schools should depend more on technology.

The system designed to teach vocational education students and mechanical engineering students is found to be efficient and taught students about OHS and it enabled the students to understand the hazards caused by specific parts of the machine. With the use of the system, the average of the mistakes made by students dropped significantly. The biggest decrease was in CVHS; from nearly 2.5 mistakes to 0.5. In both experiments, high school students and mechanical engineering students, the test groups had more reductions in the number of mistakes per person than the control groups. This confirms that this system is more effective than the warnings coming from the teacher and was most effective on high school students, who are with their teachers all year.

AR is found to be effective for an education system and spatial AR is found to be cheap and applicable in vocational high schools since these schools lack budget and cannot afford expensive systems or cannot afford to change all their machinery.

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