INCULCATING SAFETY MINDSET IN CHEMICAL ENGINEERING STUDENTS USING AR / VR

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ABSTRACT

This paper shares the experience of the Diploma in Chemical Engineering (DCHE) of Singapore Polytechnic (SP) in using suitable information communication technology (ICT) tools to develop a safety mindset in chemical engineering students through its skill-based modules. In particular, it focuses on the usage of virtual reality to provide a meaningful learning experience. The paper first introduces the four skill-based modules in the DCHE curriculum, where the spiral curriculum model was adopted to provide a systematic structure to build up student competencies spanning across 5 semesters. The spiral curriculum introduces simple concepts first, which are then revisited and re-construed in a more in-depth and elaborated manner through the instructional process over time. The competencies are built on basic key concepts at the beginning of the course, and complex concepts are developed more elaborately over time through various learning activities. The knowledge and skill competencies are leveled up from one semester to another, which allow students to progress from basic know-how to application of principles in various context. The paper then provides a brief explanation of the use of augmented reality / virtual reality (AR/VR) in safety training. It presents our approach to progressively developing safety competency consisting of the spiral curriculum course structure, culminating in the attainment of the desired safety mindset. The first attempt aims to develop workplace safety awareness so that students become aware of safety practices. In subsequent efforts, students learn to identify workplace hazards, evaluate risks posed by various hazards, and eventually demonstrate a safety mindset in a suitable work environment, which signifies the advances in student learning to inculcate a safety mindset. A simple quantitative survey was carried out to evaluate the effectiveness of the training package in terms of engagement of learning and knowledge retention. The preliminary findings indicate that the training package has a positive impact on student learning. The last section of the paper outlines the broad areas where we can continue to improve the development of the safety mindset in chemical engineering students.

KEYWORDS

Chemical Engineering, Spiral Curriculum, Safety Mindset, Augmented Reality / Virtual Reality (AR/VR), Standards 1, 2, 3, 5, 6, 7, 8, 11

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs." A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules,"; which in the university contexts are often called “courses.” A teaching academic is known as a "lecturer," which is commonly referred to as "faculty" in the universities.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) produces graduates to meet the manpower needs of the chemical processing industries. Safety is of paramount importance to all personnel working in the chemical plants. In DCHE, we strive to instill in students a safety mindset right from the beginning when they start their study in Semester 1, Year 1. We have the opportunity to improve on our safety training when we changed our course structure based on spiral curriculum design. Details of the work done had been covered previously by Cheah & Yang (2018). For this paper, it is sufficient to note that one aspect of the DCHE curriculum needs to be enhanced is the use of Augmented Reality / Virtual Reality (AR/VR) in safety management. With the roll-out of the DCHE spiral curriculum course structure, the teaching of process plant safety will be progressively enhanced via 4 skills-based modules, as shown in Figure 1 (Cheah, Wong & Yang, 2019).

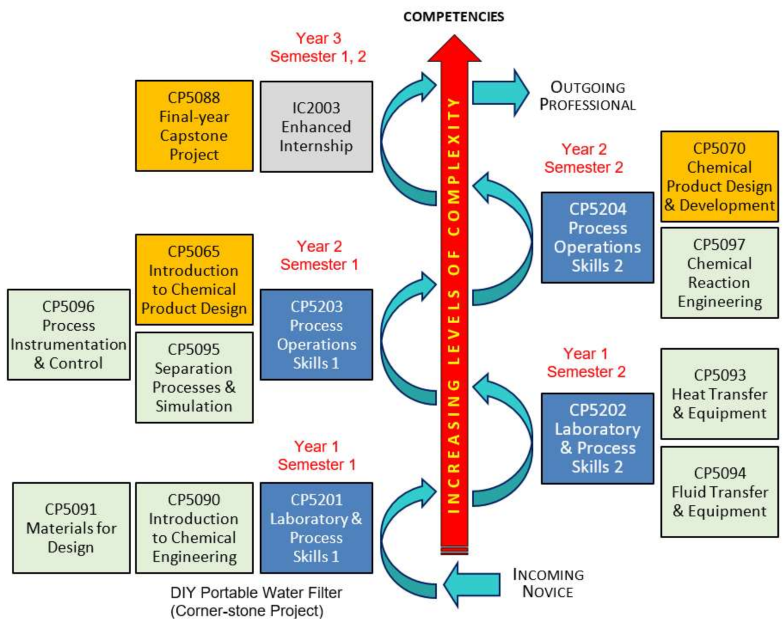

Figure 1. Progressive Learning via Spiral Curriculum

Furthermore, a study by Cheah & Leong (2018) on the relevance of CDIO Framework in the advent of Industry 4.0 suggested that one can expand on the interpretation of the existing 12 CDIO Standards to continue guiding curricular redesign. For example, engineering workspaces (Standard 6) can be "enlarged" to include virtual workspaces as well as shop floor in companies. The ways students are engaged actively and experientially (Standard 8) can be enhanced by the use of 3-D visualization afforded by AR/VR in an immersive learning environment (Standard 7). In this paper, we share our approach of using CDIO standards to guide us in the design of a progressive learning pathway from Year 1 to Year 3 to develop in students the necessary safety mindset that is absolutely essential while working (often alone) in the chemical plant to ensure not only personal safety but also process and equipment safety in terms of hazards associated with chemical processing using various dedicated equipment.

BRIEF OVERVIEW OF AR/VR IN SAFETY TRAINING

The use of VR for education in science, technology, and engineering was covered by an excellent review by Potkonjak et al. (2016). In the engineering domain, AR/VR had been widely used in safety training in construction, aviation, naval, mining, and rail operations. Comparatively, its use is not so prevalent in the chemical processing industries. This could be due to the more diverse nature of chemical plant operations in terms of the large numbers of different types of chemical reactions involved, producing a variety of products, which requires the use of several specialized types of equipment; and henceforth the operation and control of the processes and equipment over a range of temperatures and pressures. Training of engineers, technologists, and technicians had traditionally relied on on-the-job training that reinforces the knowledge gained in institutes of higher education. Some companies also use the dynamic simulation for its employees' training; however, this is more oriented towards developing competency in plant operations instead of process safety. It is only recently that AR/VR found increasing use in the chemical processing industries in safety training.

In terms of training effectiveness, Koskela et al. (2005) reported on the results of their work on the effect of the virtual learning environment (VLE) on student learning that showed VLE students outperforming lecture-based students. They concluded that, based on these results and previous case studies, the VLE is suitable for higher education. In the area of chemical process safety, Konstantinos (2002) investigated the use of VR in hazard spotting and several typical chemical plant operations, including a virtual boiler plant. They concluded that VR training could improve the safety awareness of the participants. However, as reported by Kassem et al. (2017), the evidence of the effectiveness of VLE as an intervention for safety learning across the entirety of the risk management process is still limited. The authors further noted that the most investigated phase in safety training is hazard identification, which is the initial stage of the overall risk management process. In other words, VLE applications in different risk management phases such as hazard evaluation, risk assessment, risk control, etc., receive minimal attention thus far. We would add that VLE applications can further advance one’s safety competency beyond risk management, and that is towards developing a safety mindset.

OUR APPROACH TO INCULCATING SAFETY MINDSET USING CDIO APPROACH

Various learning tasks are designed to integrate safety concepts while performing works that mimic real-world jobs in the chemical processing plant (Standard 1 – The Context). More specifically, the learning tasks require students to exercise safety awareness and precautions at all times when performing a simulated job role, while at the same time making use of the relevant technical know-how (Standard 3 – Integrated Curriculum) to assess the hazards posed by the job at hand. These tasks take place in our newly renovated training center, equipped with state-of-the-art instrumentation and control systems (Standard 6 – Engineering Workspaces). For example, a chemical engineering technician often needs to collect gas and/or liquid samples from the chemical plant for laboratory analysis. The technician needs to understand not just the chemical properties of the said sample, but also the conditions under which it is being produced, that is he/she needs to also understand how the equipment works, its operating temperature, and pressure, besides just following a set of pre-determined steps of sample collection. A distillation column presents different hazards compared to a reciprocating compressor, so one must be mindful when collecting samples from these two pieces of equipment. The technician must also remain in contact with the central control room (via walkie-talkie) on his/her whereabouts in the chemical plant (Standard 7 – Integrated

Learning Experiences). The learning tasks are designed with an increasing level of complexity, and their learning outcomes are clearly communicated to students (Standard 2 – Learning Outcomes). The lecturer-in-charge gives demonstrations to students on the proper behavior expected while working in the chemical plant, often reinforced via "negative demonstration," obviously without compromising his/her own safety. Students are then given time to practice before proceeding to apply the safety practices in later activities, under the observation of the lecturer-in-charge. As such, the learning experiences that students go through are active and experiential in nature (Standard 8 – Active Learning). Students are given real-time feedback on their safety practices while carrying out a given job, e.g., collecting a liquid sample (Standard 11 – Learning Assessment).
Table 1 shows how we have planned to progressively develop a safety mindset among our students for the first four semesters of study using the spiral curriculum model.

Table 1. The progressive development of safety mindset

Year of study	Module	Learning Outcome
Year 1 Semester 1	CP5201 *Laboratory & Process Skills 1*	• Understand the meaning of hazards in the workplace and appreciate the importance of identifying them at the workplace • Understand the fundamental principles of structured job hazards identification and key steps involved in the process of identification • Apply the key steps to identify potential job hazards
Year 1 Semester 2	CP5202 *Laboratory & Process Skills 2*	• Identify potential hazards when operating a chemical process plant according to a given set of operating procedures • Apply Job Safety Analysis (JSA) in the identification of potential job hazards
Year 2 Semester 1	CP5203 *Process Operation Skills 1*	• Understand the hierarchy of safety control measures • Understand the importance of using appropriate safety control measures to mitigate potential workplace hazards
Year 2 Semester 2	CP5204 *Process Operation Skills 2*	• Understand and know how to do a Risk Evaluation & implement Risk Control • Understand how to perform Risk Assessment
Year 3	IC2003 *Internship Program*	• Understand safety practices in a working environment • Practice workplace safety in accordance with safety requirements • Understand Risk Management in a company

Note that students start learning laboratory safety skills, in the module *Laboratory & Process Skills 1*, in Year 1 Semester 1, which is mainly done in a laboratory setting, although many students would have some familiarity with the handling of chemicals when they were in secondary schools. In Year 1 Semester 2, through the module *Laboratory & Process Skills 2,* students learn to apply the key steps to identify potential job hazards when operating a chemical process plant, which is a shift from laboratory safety skills to process operation safety skills. Job Safety Analysis is used to lay the foundation where students identify the procedures for operating a pilot plant, determine what is to be performed and the tools or materials required, visualize how the procedure is performed together with the tools or materials, envisage potential hazards based on the manner each step is performed and finally identify safety measures for each step performed to prevent potential injury. Here, students use pilot plants that are relatively simple in construction to identify job hazards related to the pilot plants, such as the shell-and-tube heat exchanger, pump rig, and others. At this point, the major challenge for students is the visualisation of how the procedure is performed with tools or materials and the associated potential hazards. This is mainly due to their lack of knowledge and experience in handling the tools or materials and plant operations. In addition, the majority of the students, if not all, have not operated a pilot plant before. Hence, this affirms that it is even more crucial for us to facilitate this learning process with them as early as possible in the three-year course and gradually develop the safety mindset in them over several semesters.

Progressively from Year 1 to Year 2, the safety skills foundation is laid and continuously applied in Year 2 when they go on to take *Process Operation Skills 1* and *Process Operation Skills 2* modules. After knowing how to identify potential hazards, students learn the hierarchy of safety control measures and understand the importance of using appropriate safety control measures to mitigate potential workplace hazards. This is then followed by learning how to perform a risk assessment for the work activities in the chemical engineering laboratories, which includes perform risk evaluation and implement necessary risk control to mitigate risk.

With the progressive learning of safety practices in the laboratory setting, the students are expected to apply these safety practices learned in the working environment, appreciate and practice workplace safety requirements when they are placed on a 22-weeks internship program in a company.

Pedagogical Basis for Design of Learning Progression

Before these progressive learning can take place in each semester, all students must undergo a safety orientation. The safety orientation consists of an e-learning platform for students to understand the general laboratory safety guidelines and a VR learning application for students to acquire the necessary safety knowledge before they are allowed to carry out any activities in the chemical engineering laboratories. The VR learning application is likely to be the first encounter for the students to be exposed to workplace safety, although students may have worked in a laboratory setting in secondary schools. However, safety awareness then may not be thorough.

Figure 2 shows a generic model of how information communication technology (ICT) is used in education, adapted from Anderson (2010); as an “update” of advances in ICT to reflect the use of AR/VR in education in the context of our work to inculcate safety mindset.

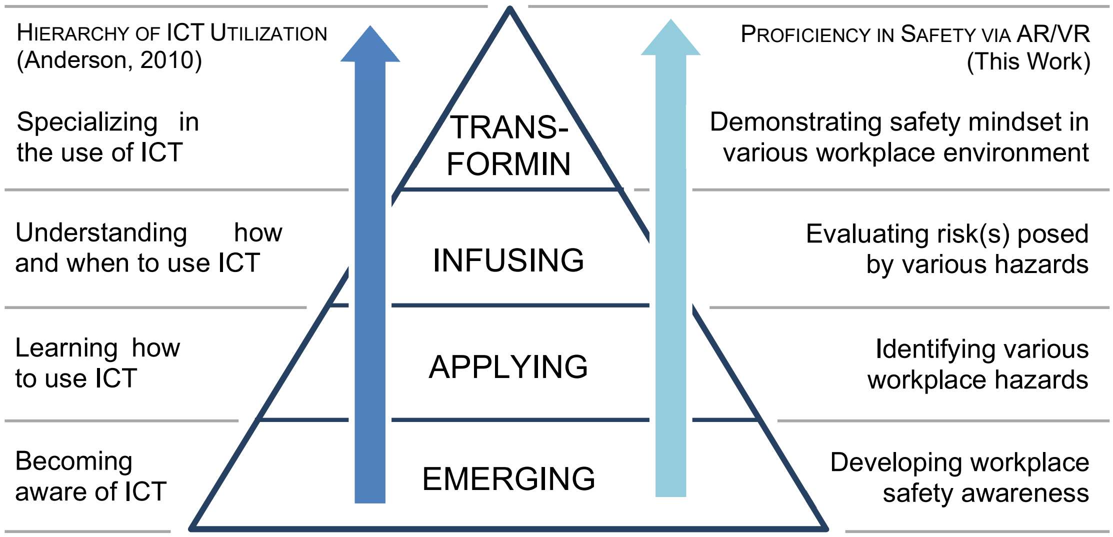

Figure 2. The progressive development of safety mindset using AR/VR

Notwithstanding the above, during the design of any learning tasks, we remind ourselves and members of our team to be cognizant of the use of ICT: i.e., "pedagogy before technology" (Watson, 2011). Another important consideration is the constructive alignment (Biggs, 2003) between the intended learning outcomes, learning tasks design, and learning assessment.

Hence, with reference to Figure 2, the use of VR learning applications in the DCHE course is currently at the EMERGING stage because it was developed to create workplace safety awareness in students. It covers the basic knowledge of safety, such as using appropriate personal protective equipment (PPE) in various situations, knowing the emergency evacuation procedure and routes in chemical engineering laboratories, how to respond to minor and major spillages in a laboratory setting as well as medical and fire emergencies. With the basic knowledge covered, students then proceed to the APPLYING stage to identify various hazards in the workplace, which will be progressively developing the safety mindset among our students through the first four semesters of study through the spiral curriculum in the DCHE course, as shown in Table 1.

DISCUSSION ON WORK DONE TO-DATE

A safety orientation package has been developed using ICT, which consists of a set of learning materials placed on an e-learning platform and a VR learning application for students to acquire basic knowledge of safety.

Previously, this was achieved by getting the students to watch a safety video in the laboratory. Then, a Technical Executive was made to ask several safety-related questions, and students randomly shout out the correct answers. This practice could not assure that all students were paying attention to the safety video nor knew the correct answers to the questions asked. Hence, the Course Management Team (CMT) initiated a revamp to design and develop a safety orientation package that is more engaging and compels all students to learn the importance and seriousness of workplace safety.

In this "newly" developed safety orientation package, every student must complete all learning activities in the learning package in order to be deemed "competent" to use the laboratory. The learning activities must be completed individually, where the time and date of their completed attempts are recorded. Several safeguards have been put in place to ensure students progressively complete all the activities in the VR learning application. For each question, the student must provide the correct answer before he/she can move on to the next section. The questions can be attempted multiple times until the student answers the questions correctly. This trial-and-error approach allows a student to learn from their mistakes in a "fail-safe" environment so that they are able to make the right decision in actual practice.

The DCHE CMT carried out a preliminary survey to evaluate the effectiveness of the safety orientation package as part of the continuous improvement effort. The Kirkpatrick Evaluation Model is used to guide the evaluation exercise as follows:

- Level 1 – Reaction. Evaluation on this level measures how those who participate in the training react to it and the extent to which trainees were satisfied with the training program.
- Level 2 – Knowledge/learning. Learning can be defined as the extent to which trainees change their attitudes, improve their knowledge, and/or increase their skills as a result of participating in the program.
- Level 3 – Behaviour. The extent to which behavioural change has occurred as a result of the training program.
- Level 4 – Results. The final results that occurred due to the training program, including increased productivity, improved quality, decreased costs, reduced frequency and/or severity of accidents, increased sales, reduced staff turnover, and higher profits.

A quantitative survey was designed to evaluate Level 1 and 2 in the Kirkpatrick Evaluation Model using the following questions on a Likert scale of 1 to 5, with 1 being strongly disagree and 5 being strongly agree:

Table 2. Survey questionnaires for evaluating student learning

No.	Statement	Likert Scale 1 being strongly disagree; 5 being strongly agree				
		1	2	3	4	5
1	The e-learning package and VR safety training engaged me to learn and remember the safety requirements and practices in the laboratory.					
2	After going through the e-learning package and VR safety training, I can remember the safety requirements and practices in the laboratory better.					

The survey was administered to 112 students from all years of studies in the DCHE course. Random classes were selected in each year of study, with at least one class being selected to complete the survey questionnaire. The survey respondents are either in Year 1, Year 2, or Year 3. Student names were not collected during the survey to keep the identity of the survey respondents anonymous and enabled the data to be analysed objectively. A non-probability sampling (Creswell, 2012) was used to obtain students' responses to the survey questionnaire. Specifically, convenience sampling was used because the students were readily available to provide responses to the survey questionnaire immediately after they have completed the safety orientation package. Lecturers who are on-site assisted in administering the survey to the students. These students represent the characteristics of the students in the course, in terms of age group and the ratio between male and female students.

The purpose of survey question #1 is to ascertain that the "newly" developed safety orientation package engages the students to learn the safety requirements and practices in the laboratory. Survey question #2 was targeted at students who had experienced the previous safety briefing using video and verbal questioning. These students are mainly in Year 2 and 3 of their studies, and they have compared their prior experience with the newer approach to affirm that the "newly" developed safety orientation package is more effective in helping them remember the safety requirements and practices.

The survey responses are shown in Figures 3 and 4, respectively. With reference to Figure 3, more than 90% of the students agree that the safety orientation package engaged them to learn and remember the safety requirements and practices in the laboratory. This is likely due to the immersive environment created in the simulated virtual environment that increases the level of student engagement. One student commented that "this semester's use of VR was more engaging," where he compared the didactic delivery of safety briefing with the use of VR.

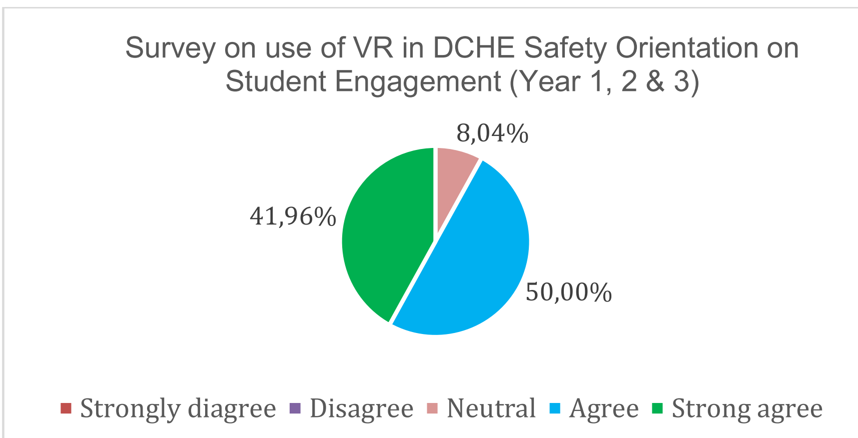

Figure 3. Survey responses from Year 1, 2 and 3 students on safety orientation package engaged them to learn and remember safety requirements and practices in the laboratory

With reference to Figure 4, more than 85% of the students agree that the safety orientation package enabled them to remember the safety requirements and practices in the laboratory better. These students have experienced the safety briefing that includes watching a safety video and answering verbal questions in the previous semester, and they are able to compare it with the newer approach of using VR as a means of delivering the knowledge. As each student must complete the learning activities individually, this improves knowledge retention. In support of this observation, one student commented that "the self-check quiz helped" to reinforce the knowledge.

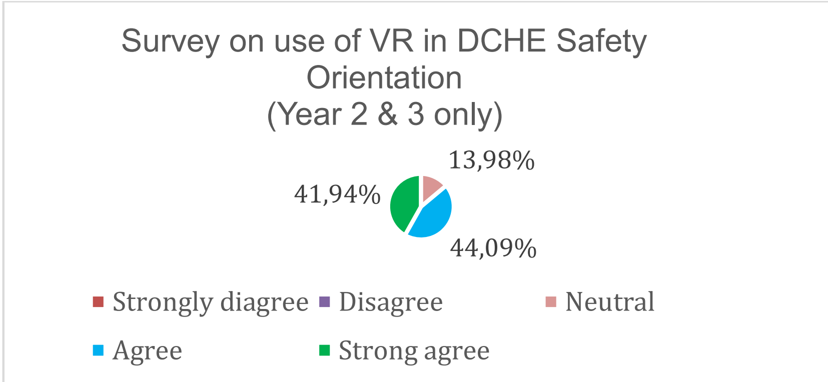

Figure 4. Survey responses from Year 2 and 3 students on safety orientation package enabled them to remember safety requirements and practices in the laboratory better

Level 3 in the Kirkpatrick Evaluation Model will require observation during lesson time to examine and monitor students' behaviour towards safety practice. According to Ekenes (2001) and Weidner et al. (1998), the effectiveness of training can be determined by a change in the behaviours of those trained. The safety orientation package was rolled out for the first time in the semester started in October 2019. We will continue the observation effort in subsequent semesters to ascertain if there is a positive development in students' safety practices.

Level 4 also requires long term observation, perhaps in a longitudinal study. If we observe students are able to execute tasks in a safe manner, with fewer reminders given on safety practices as they progress through the course, it is a positive indication that the curriculum put in place is effective and the safety mindset is progressively developed.

Through the evaluation, the DCHE CMT also aims to establish if ICT helps increase the retention of knowledge and accelerates the learning process, which is found in Lanzotti et al. (2018)'s study that technology allows workers to experience a simulated hazardous environment in a safe scenario, helps increase the concentration and speed up the learning process. In another similar study, Sacks et al. (2013) found that VR training was more effective in terms of maintaining participants' attention and concentration than traditional safety training approaches. The comments below were gathered from student feedback following from the use of the safety orientation package, and they support the studies done by Sacks et al. (2013) and Lanzotti et al. (2018):

- "I feel that the VR video helps us to remember things easier than a teacher's instruction."
- "VR safety training is made more interesting for us to remember and learn, which is definitely effective for us to visualise it."
- "I feel like this experience is more engaging and helps me to prepare for any emergencies in the future."
- "I feel privileged to have such equipment to help me remember these instructions."

PLANS FOR MOVING FORWARD

Based on the outcome of the quantitative survey, the survey questionnaire will be revised to obtain responses that better measure the effectiveness of the safety orientation package in helping students to remember the required safety practices, preference for using safety orientation package than the previous face-to-face type of training and whether more of such technology should be used for briefings. Open-ended type questions will also be incorporated to solicit after-thoughts from students to find out why the use of technology is preferred for learning than a face-to-face type of training/briefing.

Studies have found that training not only enhances individuals' motivation to engage in safe behaviour but also increases the personal ability and desire to recognise and deal effectively with hazards (Leiter et al., 2009). Hence, with reference to Figure 2, the VR learning application can be further enhanced to provide scaffold learning in accordance with the spiral curriculum model. For example, at the EMERGING stage, students identify the PPE that is needed when they carry out different tasks in the laboratory, be aware of the location of fire extinguishers, and emergency evacuation routes; as well as know what to do when they encounter minor chemical spillages on body and benchtop. Then, at the APPLYING stage, various hazards could be purposefully inserted into different scenarios for students to use the Job Safety Analysis approach learned earlier to identify workplace hazards, choose the proper PPE to use, or the correct emergency evacuation route to take.

Leveling up to the INFUSING stage, it is possible for students to learn fire emergency procedures without first showing a fire in the virtual laboratory setting. For example, a fire could randomly appear, and the student will need to decide whether the fire is small enough to be put out by a fire extinguisher or call for help. For small fires, the student could learn how to handle the fire extinguisher and put out the fire. In the process, they can also be assessed in their ability to choose the correct type of fire extinguisher to use based on the type of fire present.

By randomly triggering a location where a hazard can appear, students are not able to regurgitate the correct answer when attempting the scenarios multiple times. This is the essence of using VR learning where scenarios can be changed using appropriate software and without the need to make a physical change to an existing setting in the laboratory. A real change in a physical setting could impose more hazards and put other students and users at risk, and also potential damage to costly equipment and downtime.

With the learning put in place at the EMERGING, APPLYING and INFUSING stages, it is hopeful that students reach the eventual TRANSFORMING stage where they demonstrate a safety mindset in the workplace environment and perform the tasks safely and conscientiously. This can be ascertained when they truly demonstrate safe practices in a real environment. This is important when dealing with serious operational problems such as major spillage caused by pipe rupture or equipment failure, where one had to deal simultaneously with multiple hazards. Also, in the TRANSFORMATION stage, we can integrate students' safety awareness with other competencies such as critical thinking, such as when proposing a modification job to implement certain design change, to take into consideration of potential hazards specific to the job at hand. In this manner, we can better prepare our students for their internship program, where they will be attached to real companies and subjected to real hazards at the workplace.

Lastly, we noted that training effectiveness and the influence of training on safety performance could be affected by a number of factors such as the method of training, delivery medium, and tutor style. This can culminates in the extent to which skills, knowledge, attitudes, and experience are developed through training. Salas et al. (1999) acknowledged that the transfer of training would be influenced by trainees' characteristics and motivation and pre-existing competence levels. And interestingly, even though a meta-analysis by Merchant et al. (2014)

showed that the use of VR is effective in attaining the learning outcomes, these studies were all based on games and virtual worlds. Clarke and Flitcroft (2013) noted that there is little research relating to the longer-term effectiveness of training as an intervention in the specific aspect of improving safety. Thus, we can go beyond inculcating safety mindset among our students, to look into the use of AR/VR to review the applicability of the training content to the delegates' day to day work activities, transference to the workplace, the reality of the work environment. All these can be possible areas of future research into factors affecting the effectiveness of safety training using AR/VR.

CONCLUSION

In conclusion, the safety orientation package developed using ICT has created better learning experiences for students as compared to the previous practice. Based on preliminary findings, the VR learning application created workplace safety awareness amongst students and formed the foundation of developing a safety mindset for chemical engineering students at Singapore Polytechnic. Nonetheless, the learning application can be further enhanced to allow students to level up their knowledge and skills as well as culminate good safety practices in accordance with the spiral curriculum model. The approach is to introduce simple concepts related to safety first; then, these are revisited and re-construed in a more in-depth and elaborate manner through the instructional process over the four skill-based modules. The competencies are built on basic key concepts on safety at the beginning, and complex concepts are developed more elaborately over time sequentially from one module to another.

The VR learning application will be enhanced for students to revisit knowledge and content at different stages of the curriculum, activate prior knowledge, and integrate knowledge and skills. The terminal objective is to provide students with a comprehensive understanding of the key concepts in safety so that they can apply these thoughtfully across a range of real-life contexts. They gradually develop a safety mindset in which they make personal meaning of the knowledge and see how it is used in the real working environment. According to Clarke & Flitcroft (2013), when safety training is integrated into a broader safety intervention program, training can have a wide range of benefits, particularly in terms of enhancing employee safety motivation and participation. Our students are potential employees of the future for the industry; hence, it is important that they possess the right safety mindset when they graduate so that they are able to induct into the new workplace with ease, without having to go through a rigorous safety training. This can potentially reduce resources that companies need to spend on training the new hires.

REFERENCES

Anderson, J. (2010). *ICT Transforming Education: A Regional Guide*, UNESCO Bangkok

Biggs, J. (2003). Aligning Teaching and Assessing to Course Objectives, *International Conference on Teaching and Learning in Higher Education: New Trends and Innovations*, University of Aveiro, April 13 – 17; Aveiro, Portugal

Cheah, S.M., & Leong, H. (2018). Relevance of CDIO to Industry 4.0 – Proposal for 2 New Standards, *Proceedings of the 14th International CDIO Conference,* Kanazawa Institute of Technology, June 28 – July 2; Kanazawa, Japan

Cheah, S.M., & Yang, K. (2018). CDIO Framework and SkillsFuture: Redesign of Chemical Engineering Curriculum after 10 Years of Implementing CDIO, *Proceedings of the 14th International CDIO Conference,* Kanazawa Institute of Technology, June 28 – July 2; Kanazawa, Japan

Cheah, S.M., Wong, Y., & Yang, K. (2019). A Model to Explicitly Teach Self-Directed Learning to Chemical Engineering Students, *Proceedings of the 15th International CDIO Conference*, Aarhus University, Jun 24-28; Aarhus, Denmark

Clarke, S., & Flitcroft, C. (2013). *The Effectiveness of Training in Promoting a Positive OSH Culture*, Manchester Business School, University of Manchester

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th Ed.). Boston, MA: Pearson Education.

Ekenes, J. M. (2001). Effective Safety Training Programmes for Aluminium Cast Shops, *Journal of the Minerals, Metals and Materials Society*, 53: pp.14-15

Kassem, M., Benomran, L., & Teizer, J. (2017). Virtual Environments for Safety Learning in Construction and Engineering: Seeking Evidence and Identifying Gaps for Future Research, *Visualization in Engineering*, Vol.5:16, pp.1-15

Koskela, M., Kiltti, P., Vilpola, I., & Tervonen, J. (2005). Suitability of a Virtual Learning Environment for Higher Education, *The Electronic Journal of e-Learning*, Vol.3, Issue 1, pp.23-32

Konstantinos, N. (2002). *Improving Chemical Plant Safety Training Using Virtual Reality*, Ph.D. Thesis, University of Nottingham, available from http://eprints.nottingham.ac.uk/10039/1/CostasThesis.pdf

Lanzotti, A., Tarallo, A., Carbone, F., Coccorese, D., D'Angelo, R., Di Gironimo, G., Grasso, C., Valerio Minopoli, V., & Papa, S. (2018). Interactive Tools for Safety 4.0: Virtual Ergonomics and Serious Games in Tower Automotive, *Proceedings of the 20th Congress of the International Ergonomics Association*, Aug 26-30; Florence, Italy

Leiter, M. P., Zanaletti, W., Argentero, P. (2009). Occupational Risk Perception, Safety Training, and Injury Prevention: Testing a Model in the Italian Printing Industry, *Journal of Occupational Health Psychology*, 14, pp.1-10

Merchant, Z., Goetz, E.T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T.J. (2014). Effectiveness of Virtual Reality-based Instruction on Students' Learning Outcomes in K-12 and Higher Education: A Meta-Analysis, *Computers & Education*, Vol.70, pp.29-40

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrovic, V.M., & Jovanovic, K. (2016). Virtual Laboratories for Education in Science, Technology, and Engineering: A Review, *Computers & Education*, Vol.95, pp.309-327

Sacks, R., Perlman, A., & Barak, R. (2013). Construction Safety Training using Immersive Virtual Reality, *Construction Management and Economics*, Vol.31, Issue 9, pp.1005-1017.

Salas, E., Cannon-Bowers, J.A., Rhodenizer, L., & Bowers, C.A. (1999). Training in Organizations, *Research in Personnel and Human Resources Management*, 17; pp.123-161

Stiles, S., Ryan, B., & Golightly, D. (2018). Use of Virtual Reality: Evaluating the Effectiveness of Safety Training Interventions on Rail Engineering Projects, *Irish Rail Safety Council Conference*, Oct 21 – 26; Dún Laoghaire, Dublin, Ireland

Watson, D.M. (2001). Pedagogy before Technology: Re-thinking the Relationship between ICT and Teaching, *Education and Information Technologies*, 6:4, pp.251-266

Weidner, B.L.R., Gotsch, A.D., Delnevo, C.B., Newman, J., & McDonald, B. (1998). Worker Health and Safety Training: Assessing Impact among Responders, *American Journal of Industrial Medicine*, 33, pp. 241-246

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