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Perceptions of the use of virtual reality games for chemical engineering education and professional training

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ABSTRACT

Virtual Reality (VR) games and simulations are increasingly being used to provide highly interactive, engaging and contextual learning experiences for learners in otherwise risk-prone environments, such as those obtained in chemical engineering and industrial domains. Understanding the intention of users towards this technology for education and training purposes is thus of paramount importance for academics and practitioners. This study examines the perceptions of chemical engineering students and professionals towards the use of VR games for health and safety education and training, and discusses the practical implications of findings. The study found that students and professionals believe that IVR games are useful for learning. A comparison of the two groups revealed that professionals were more accepting of the technology compared to students. Students presented concerns with the use of the technology for classroom learning. The paper concludes by outlining the implications of the findings to higher education practice.

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Introduction

In chemical engineering education, fundamental chemical engineering concepts and calculations form a large part of what students learn in their undergraduate studies, while the learning of industrially based practical skills is limited by the lack of exposure to this environment (Johnson & Singh, 2019). Like most students in higher education (HE), chemical engineering students have been traditionally taught using predominantly the didactic lecture-based method (Baillie & Fitzgerald, 2000). However, debates on the effectiveness of lecturing as a pedagogic tool continue to engage the academic community (Fitzpatrick, Cronin, & Byrne, 2011; Lambert, 2012; Roberts, 2019). One of the major shortcomings of lectures is the fact that they do not sufficiently support the acquisition of skills required by chemical engineers to design, develop, and to maintain chemical process (Almanza-Arjona, Vergara-Porras, García-Rivera, & Venegas-Andraca, 2019).

To bridge the gap between the chemical engineering curriculum and the practical skills desired by employers in the chemical industry (Grant & Dickson, 2006), new methods of teaching and learning are needed. Pedagogical tools that enhance situated

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and experiential learning, active learning, and the development of 21st century transferable skills are most needed in chemical engineering education. Digital game-based learning (DGBL) and Virtual Reality (VR) technologies have gained popularity as pedagogical tools that can promote the acquisition of knowledge and skills expected of HE graduates and professionals (Ouyang et al., 2018; Shute, Ventura, & Ke, 2015; Whitton, 2009a). Similarly, Immersive Virtual Reality (IVR) technologies enable students to experience full immersion and a sense of presence in a simulated environment. When digital games are played in IVR environments, players experience high immersion and presence, and these have been found to result in 'more difficult to forget' memories (Chittaro & Buttussi, 2015, p. 536).

One of the areas where IVR games can be of potential benefit for teaching and training chemical engineering students and employees is Health and safety (H&S). Process safety as well as H&S education are integral parts of most chemical engineering curricula in the UK universities required as part of a professional accreditation (IChemE, 2019). This is also true for chemical engineering curricula in other countries, accredited by other professional bodies, e.g. Accreditation Board for Engineering and Technology (ABET).

Process safety education and management begins at the universities and continues while working within a process plant. Since most of the chemical industries believe that newly hired employees have insufficient safety training and background from their university lectures, they usually adapt a set of interconnected learning methods to reduce the occurrence and severity of events resulting from releases of hazardous materials and other sources of energy (Chen, 2016). Most accidents in the industry either result from lack of awareness and/or overconfidence that may lead to severe disasters, according to the recent studies (Chen, 2016; Nazir, Totaro, Brambilla, Colombo, & Manca, 2012). In order to improve the development of professional skills in process safety, it is crucial to create innovative approaches to mimic real industrial safety scenarios without compromising students' engagement, exposure, and learning process.

Although IVR games are considered beneficial for learning, their design and development can be expensive. For this reason, it is common to find studies using available off-the-shelf games for classroom use. Given this, HE educators also have an opportunity to adopt games and simulations used for professional training for classroom use. However, it is necessary to understand how students and professionals perceive IVR games for learning, and what factors influence their intentions to use them. New technologies have been known to fail to deliver expected results when the views and expectations of the users differ from those of the administrators (Herzog & Katzlinger, 2011; McMorran, Ragupathi, & Luo, 2017). Therefore, the goal of this paper is to present the perceptions of chemical engineering students towards IVR games for education, how these differ from those of chemical engineering professionals, as well as discuss the implications of findings to practice. This contribution provides quantitative and qualitative evidence of factors that could affect HE students' use of VR games and simulations. Based on the information obtained from the data, broader implications to practice are drawn for the benefits to the education and professional community with respect to the skills needs for industry 4.0.

Background

Digital game-based learning

Digital game-based learning (DGBL) is defined by Bahadoorsingh, Dyer, and Sharma (2016) as an instructional method that integrates educational content into video games with the purpose of engaging learners. It involves the use of digital games, whether off-the -shelf entertainment games or educational/serious games, for learning purposes. Entertainment games are readily available and have the advantage of engaging students in high-end game designs. Nevertheless, games developed solely to be entertaining often fail to match curriculum learning outcomes. Furthermore, entertainment games can be expensive, with complex interfaces and steep learning curves (Whitton, 2009). Educational or serious games, especially those designed with particular learning outcomes in mind, create an effective match between the learning and gameplay outcomes. Nevertheless, creating games specifically for educational purposes can be very expensive, and in some cases, games designed exclusively for educational purpose may fail to engage learners. As a compromise, many studies have successfully modified entertainment games for educational purposes (for examples see Coller & Scott, 2009; Stuyts & Driesen, 2016).

Rationale and benefits for DGBL

The most discussed rationale for DGBL is their perceived motivational benefit (Boyle, Connolly, & Hainey, 2011; Prensky, 2003; Whitton, 2009, 2009a). Digital games are believed to be intrinsically motivating because these keep players engaged while having them invest time and energy into game play for no extrinsic reward other than the game play itself (Garris, Ahlers, & Driskell, 2002). Another popular rationale for game-based learning is its ability to engage learners (Boyle et al., 2011; Garris et al., 2002; Whitton, 2009a). Computer games are considered a very engaging learning environment because of their potential to create convincing narratives within challenging and immersive worlds, while providing valuable interactions and feedback (Whitton, 2009aa). Furthermore, DGBL is considered relevant in HE because of its ability to foster contextual and authentic learning, active learning, experiential learning, collaborative learning, problem-based learning, constructivist learning approach, and its ability to provide adaptive and appropriate feedback (Whitton, 2009, 2009a).

Digital games provide an active, engaging and immersive learning environment, which is important for effective learning based on a constructivist learning perspective (Wu, Hsiao, Wu, Lin, & Huang, 2012). DGBL provides an avenue for meaningful interaction among players and games. It also enhances the development and application of 'high-level transferable skills' in HE (Whitton, 2009aa, p. 45). A systematic review by Connolly, Boyle, MacArthur, Hainey, and Boyle (2012) showed that the use of both commercial and educational games is linked to enhanced cognitive, perceptual, behavioural, affective and motivational outcomes. Although the most reported use of digital games for higher education is in the medical domain, a few researchers have described their use and benefits in engineering domain (Coller & Scott, 2009; Dib & Adamo-Villani, 2014; Perini, Luglietti, Margoudi, Oliveira, & Taisch, 2018). Perini and his colleagues found differences in the types of knowledge acquired in the DGBL context and traditional learning methods. Their study found that students who took part in the life cycle assessment computer game showed significantly higher improvement on procedural knowledge than those who used a more traditional approach. Conversely, the results showed that students who took part in the non-game-based learning approach performed significantly better than the game-based group on factual knowledge. Other studies, such as that by Joiner et al. (2013), found no significant learning gains in students who used DGBL.

Virtual reality

Virtual Reality (VR) technology is based on computer graphics which can simulate real life scenarios and create dynamic, immersive, and interactive virtual reality environments and items through visual, auditory, and tactile senses of computer media manipulation (Burdea, 2003). Depending on the quality of the immersion experience, VR can be categorised as non-immersive, semi-immersive, or fully immersive (Cronin, 1997). Studies have shown that immersion (i.e. the state of consciousness where the awareness of the user's physical self is lost by being surrounded in an artificial world) in digital environments can enhance learning without exposing learners to physical safety risks and cost of the real-world environment (Dede, 2009; Handa, Aul, & Bajaj, 2012).

Fully Immersive VR (IVR) supports realistic and immersive simulations and enhances transferability of skills learned in the IVR environment into real life context (Cheng & Wang, 2011). VR technology provides the user with a safe 3D training/educational space where they can construct their knowledge through trial and error techniques that reflect real-life situations and events (Fällman, Backman, & Holmlund, 1999). With VR technology, it is possible to create real-life representations of events such as fire outbreaks that could be used to train firefighters, rescue operators or the general public on dealing with such catastrophic event within a safe, yet stressful setting (Ahmad, Sarlan, & Rauf, 2018, June; Czarnek, Strojny, Strojny, & Richter, 2019; Shi, Du, Ahn, & Ragan, 2019). VR technology offers the possibility of changing one's frame of reference, allowing the user to interact with the virtual scene from different perspectives in order to maximise in-depth understanding of the conceptual framework (Fällman et al., 1999). VR applications which are typically used for educating and training of professionals can be presented either as games with a serious purpose (i.e. serious games), or as simulations (Imlig-Iten & Petko, 2018; Menin, Torchelsen, & Nedel, 2018).

Immersive virtual reality games (IVR games)

Interactivity is believed to be the most fundamental aspect of effective learning (Martirosov & Kopecek, 2017). When game characteristics embedded into an IVR environment are used for teaching or training, learners tend to retain knowledge for much longer than when traditional methods are used. This is attributed to the full engagement and high emotional and physiological arousal that learners experience when in IVR environment (Chittaro & Buttussi, 2015).

Although there are currently limited studies on the use IVR games in HE, a few have reported using IVR in different domains. Chittaro and Buttussi (2015) carried out an interesting comparative study of an IVR-based serious game and traditional card game for aviation safety education. Results revealed better engagement and better knowledge retention in those who played the IVR game, compared to those who played the card game. Solving a challenge in an IVR environment allows for a greater sense of presence and is associated with reduced distraction and better engagement with the task (Feng, González, Amor, Lovreglio, & Cabrera-Guerrero, 2018). In another study by Pallavicini et al. (2018), it was found that a similar gameplay performance was achieved in both IVR and non-IVR video game groups. However, more appealing gameplay experiences were reported by IVR game users compared to tablet computer users. Kharvari and Hohl (2019) tested a prototype IVR game, Therme Vals, for architectural education and found that students were able to recall spatial configuration of the simulated building without physically visiting the site. They claimed that VR could be a simpler, cheaper, safe and effective way of accumulating 'highly specific architectural knowledge' compared to site visits.

IVR games are potentially very effective tools for developing higher-order knowledge and complex problem-solving skills. These are particularly useful for developing procedural knowledge (Szczurowski & Smith, 2018), critical thinking, and decision-making skills required to handle process safety situations. H&S training is a compulsory part of the induction process of every process plant engineer. The importance of H&S training cannot be overemphasised, as mistakes could lead to various catastrophic outcomes. H&S studies are common practices in both chemical engineering education and training. In HE, the focus is on the development of conceptual knowledge of process safety while in the chemical industry attention is paid to the acquisition of procedural knowledge.

The most widely used method of delivering process safety studies in HE is lectures with multimedia presentations. However, lectures have been criticised as ineffective (Lambert, 2012) and non-engaging (Fitzpatrick et al., 2011). As a solution, many chemical companies have incorporated IVR technologies into safety education and training programs to complement conventional training methods (Colombo, Nazir, & Manca, 2014; Manca, Brambilla, & Colombo, 2013; Nazir et al., 2012). Colombo et al. (2014) presented an accident scenario in IVR involving a collision between a work vehicle and a pipe near a distillation column. Their study showed that operators who were trained using IVR performed remarkably better (50% higher success rate in fault diagnosis) than those trained with conventional slide-supported presentation on all tested Key Performance Indicators (KPIs).

IVR games can be effective complements or alternatives to traditional pedagogies. The technology can support students' development of conceptual and procedural skillsets required in the current and future workplace. Equipping students with the skills for the future of work using similar advanced technologies used in the workplace would not only prepare them for the tasks ahead, but also prepares them to be lifelong learners. Although designing and developing digital games is currently cost and time intensive, openly available games have been successfully adopted for classroom use. There is also a potential opportunity for HE teachers to adopt games and simulations developed and used by corporate organisation who have more robust budgets. In this case, understanding factors that could influence students' adoption of IVR games and whether they differ from those of professionals is of interest. Understanding students' perceptions towards IVR games for learning is an important first step towards designing and implementing this technology in the classrooms. The goal of this paper is to present the perceptions of chemical engineering students and professionals towards IVR games for education, and discuss the implications of the findings to practice. Specifically, this study aims to answer the following research questions:

RQ1: What are chemical engineering students' overall perceptions towards IVR games for education?
RQ2: How do the perceptions of chemical engineering students towards IVR games for learning differ from the perceptions of chemical engineering professionals?

Methods

Conceptual model

To understand the perceptions of chemical engineering students and professionals towards IVR games for engineering education, this study adapted the Unified Theory of Use and Acceptance of Technology (UTAUT2) framework (Venkatesh, Thong, & Xu, 2012). The UTAUT2 model, developed to predict technology acceptance, has been validated by many studies and is claimed to be able to explain about 74% of variance in behavioural intention of use of new technology (Venkatesh, Thong, & Xu, 2016).

The UTAUT2 theorizes that Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), Hedonic Motivation (HM), Price Value (PV) and Habit (H) are direct determinants of the intention of an to use a new technology, while FC, HM, PV and H are direct determinants of usage (Venkatesh et al., 2012). As this study was purely focused on perception before the implementation of the technology, an adapted model was used as shown in (Figure 1).

As shown in (Figure 1), the adapted model comprises of four main constructs namely Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Hedonic Motivation (HM), which affect the Behavioural Intention (BI).

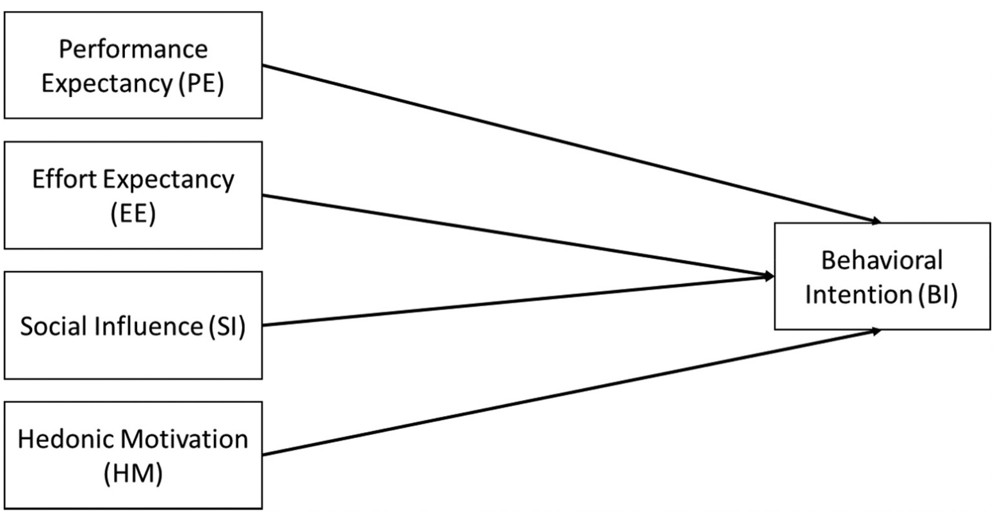

Figure 1. The modified UTAUT2 model.

Performance Expectancy (PE) describes the degree to which an individual believes that using a given technology will enable them to perform a certain activity (Venkatesh, Morris, Davis, & Davis, 2003). This variable is considered the strongest determinant for the prediction of behavioural intention (*ibid*). Effort Expectancy (EE) describes the perception of a user in terms of the degree of ease associated with a technology. Like PE, EE is found to be a significant determinant of behavioural intention (Fagan, Kilmon, & Pandey, 2012; Venkatesh et al., 2003). Social Influence (SI) describes the extent to which an individual perceives that people who are important to them believe that they should use a new technology (Venkatesh et al., 2003). Hedonic Motivation (HM) is referred to as the fun or pleasure one derives from using a technology (Venkatesh et al., 2012). HM is conceptualized as perceived enjoyment and has been found to have greatest influence on intentions to play games (Ha, Yoon, & Choi, 2007). Behavioural Intentions (BI) describes an individual's intentions to use a new technology (Venkatesh et al., 2012).

Research context and participants

The participants of this study were chemical engineering undergraduate students and chemical industry professionals. Convenient sampling was used to recruit participants for this study (Etikan, 2016). Student participants were 2nd, 3rd and 4th years undergraduates recruited from collaborating institutions with the help of a gatekeeper. The cohorts of students in this study are students who have taken at least one H&S class, and therefore are in the position to provide rational opinions towards IVR games for H&S education. A total of 27 students (took part in the survey with 72% under the age of 20. There were 18 (66.7%) male and 9 (33.3%) female participants and all were studying towards a bachelor or master's degree in chemical engineering. All participants declared having previous computer gameplay experience but only 51.9% of them have prior VR experience.

Professional chemical engineers were recruited online from various chemical industries. Professionals were invited to voluntarily take part in the online survey if they were employed as professional chemical engineers at the time of the study. The data were collected over a two-week period. A total of 89 professional chemical engineers completed the questionnaire. Most of the participants were aged 20–29 years (79.78%) and were slightly dominated by males (57.30%). Moreover, most of them had prior experience playing video games (98.88%) but only 31.46% of them have tried head-mounted display VR.

Questionnaire development

Two online questionnaires were used for data collection: one adapted for the student population and the other for the professionals. The questionnaires consisted of closed and open-ended questions. A total of 33 questions were included in each questionnaire (see tables in Appendix). The questions collected socio-demographic data, measured behavioural intentions to use IVR games, and collected qualitative data on perceptions. The questions were rephrased to fit the purpose and population under study. Both questionnaires used a 6-point Likert scale, ranging from 1 (strongly disagree) to 6 (strongly agree).

The items included in the questionnaires were adopted from Venkatesh et al. (2012) and each items were properly reworded to suit the use of IVR games for education. Face validity checks were carried out by academics in the field and subsequently, pilot studies were conducted with postgraduate chemical engineering students and some volunteers from the chemical industry to check for misconceptions in the formulation of the questions. Changes were made based on feedback and corrections received.

Data collection procedure

Both quantitative and qualitative data were collected using an online questionnaire. Before sending out the questionnaires, ethics approvals were obtained. All expected ethical procedures were followed in the development and administration of the questionnaires.

The online surveys comprised of a cover letter explaining the aim of the study and the rights of the participants . Emails were sent to all chemical engineering undergraduate students in their 2nd, 3rd and 4th years of study at the universities. The emails contained a link to the online questionnaire and a brief description of the research purpose. Students were offered the opportunity to enter a prize draw at the end of the survey to stand a chance to win one of ten £10 gift vouchers.

Data analysis

Quantitative data were analysed using Structural Equation Modelling (SEM) with the Partial Least Square (PLS) algorithm employed in SmartPLS 3 (from Smart PLS GmbH) (Ringle, Wende, & Becker, 2015). This model involves a two-step approach. However, given the scope of the research, only the first step – measurement model, was completed in this study to evaluate the correlation between each construct and its observed indicators. In order to identify whether there are differences among students and professionals, the Mann-Whitney U test was carried out in SPSS (from IBM SPSS Statistics) . For the qualitative data analysis, NVivo (from QSR International) was used to identify themes in the responses.

Results

Research question 1

Quantitative results

To determine the overall perceptions of students towards IVR games for H&S education, validity and reliability tests of the constructs of the research model were carried out first (Hair, Hult, Ringle, & Sarstedt, 2017). From (Table 1), the Cronbach's Alpha and the Composite Reliability (CR) (measures of internal consistency) coefficients of all measured constructs, with the exception of the 'Social Influence' were above the 0.7 recommended minimum threshold. This implies good internal consistencies between items in each construct. To measure the convergent and discriminant validities of the constructs, i.e. to measure whether constructs that should be related are related, and to test if the constructs that should not be related are not related, the average variance extracted

Table 1. Descriptive statistics, internal consistent reliability, and convergent validity of constructs for students.

Constructs	Items	Mean	Standard Deviation	Cronbach's Alpha	CR[a]	AVE[a]
Performance Expectancy	PE1	4.667	0.816	0.798	0.863	0.677
	PE2	4.667	0.861			
	PE3	4.593	1.063			
Effort Expectancy	EE1	4.889	0.737	0.822	0.867	0.69
	EE2	4.741	0.843			
	EE3	4.815	0.818			
Social Influence	SI1	3.000	1.155	0.616	0.772	0.535
	SI2	3.852	1.145			
	SI3	3.926	1.086			
Hedonic Motivation	HM1	4.963	0.881	0.718	0.753	0.517
	HM2	4.963	0.693			
	HM3	4.593	1.163			
Behavioural Intentions	BI1	3.963	0.962	0.837	0.902	0.754
	BI2	4.000	1.018			
	BI3	4.037	1.071			

[a]– Composite Reliability
[a]– Average Variance Extracted
Ratings are on a 6-point Likert Scale: 1 = Strongly disagree 2 = disagree 3 = slightly disagree 4 = slightly agree 5 = agree 6 = strongly agree

Table 2. Discriminant validity analysis using Fornrell-Larcker criterion for students.

	PE	EE	SI	HM	BI
PE	**0.823**				
EE	0.177	**0.830**			
SI	0.042	−0.008	**0.732**		
HM	0.619	0.423	−0.087	**0.719**	
BI	0.515	−0.295	0.305	0.324	**0.869**

Note:The boldfaced numbers are the square root of AVE; the other numbers are the correlation coefficient between constructs.

(AVE) and Fornrell-Larcker criterion tests were carried out, respectively (Hair et al., 2017). As shown in (Tables 1 and 2), all constructs have AVE values higher than the minimum recommended level of 0.5, and stronger association between similar constructs, implying good convergence and discriminant validities.

The scores of participants on all measured constructs were calculated to give an indication of their views toward IVR games for H&S education. As shown in (Table 1), the mean scores of students on all constructs were relatively high, ranging from 3.6 to 4.8 with Hedonic Motivation and Effort Expectancy having the highest mean scores. Additionally, students scored relatively high on the Behavioural Intention construct, indicating enthusiasm towards adopting IVR games for H&S education.

Qualitative results

Qualitative data were collected using two open-ended questions in the questionnaire. The first question (Q1) was, 'Why do you think using IVR games for H&S education could be a good idea?'. The second (Q2) asked the opposite, 'Why do you think using IVR games for H&S education could be a bad idea?'.

From the collected data, eight themes emerged from the NVivo analysis on these data. Four themes were from Q1 and these include better learning experience, cost effectiveness, safety and keeping up with technological advancement. The other four themes emerged from Q2 and were suitability concerns, implementation concerns, false reality, and novelty effect.

Themes from Q1

When students were asked why they thought using IVR games for H&S education was a good idea, 88% (n = 15) of the responders agreed that IVR games would provide a better learning experience. Several terms were used by responders to describe this: realistic simulations, immersion, interactivity, visualisation, situated learning, memorable experience. Students believed that using IVR games could enhance learning and retention as described by these students:

> 'Games have already been shown to be an effective method of learning when done correctly. The more immersive level of interaction in VR, as compared to traditional games, could make a session more memorable and aid the learning experience. Also, the experience of being in a virtual space could allow activities that aren't otherwise possible'.

> 'The immersion and interaction would help to understand real life situations better, instead of just reading and studying rules'.

Safety was another factor that was raised by two students as a benefit of IVR games for H&S education:

> 'It would be easy to simulate situations without putting people in unnecessary danger, which could help in crucial situations'.

Another student emphasised the cost benefits, responding to Q1:

> 'Gives a hands-on experience without having to leave the classroom and have expensive class trips'.

Generally, these qualitative data suggest that students (with or without VR experience) see potential in the use of IVR games for educational purposes. It was noted that students with previous VR experience had more to say in terms of overall benefits of the use of IVR games for H&S education compared to students with no VR experience.

Themes from Q2

On the question about why students think using IVR games for H&S education was a bad idea, implementation concerns and suitability issues were the two most frequently occurring themes (n = 11 and n = 7 respectively). In terms of the implementation concerns, participants mentioned cost, the challenge of the educational games design, gameplay distractions, ineffectiveness of games, as well as the lack of acceptance of games by students and teachers.

Some interesting responses from students to Q2 that reflect implementation concerns include:

> 'Perhaps cost and time that it would require to train people'.

> 'Focus might be too much towards playing and doing well in the game over acquiring knowledge'.

'It can be very hard to balance the educational side with an engaging gameplay loop'.

'Likely some students would not take it seriously . . . .And old school instructors may not agree with this technology to take part in education'.

Students also elaborated on suitability issues as a possible reason why the use of IVR games for H&S education might be a bad idea. Motion sickness, gaming competency, accessibility issues and desensitisation effects were mentioned, as demonstrated below:

'They can make people feel motion sick so some people may not be able to use it and may be excluded from the class'.

'Mixed ability of students with video games'.

'Physical problems may cause inadequacy to even use the VR games'.

'Might take away from the seriousness of H&S events if it's a game'.

These results present important concerns regarding the use of this technology for classroom educational purpose. Students' responses were found to come from past experiences with the technology given that all participants who mentioned motion sickness as a barrier had used VR in the past. Additionally, students who were weary of gaming abilities/competencies affecting performance with the technology were found to have no previous VR experience.

Research question 2

To compare chemical engineering students and employees on their overall perception towards IVR games for H&S education, the mean scores of employees on all constructs were computed. From (Tables 3 & 4), the reliability, convergent validity and discriminant validity of the constructs were established.

Table 3. Descriptive statistics, internal consistent reliability, and convergent validity of constructs for professionals.

Constructs	Items	Mean	Standard Deviation	Cronbach's Alpha	CR[a]	AVE[b]
Performance Expectancy	PE_1	5.056	0.916	0.921	0.95	0.863
	PE_2	5.101	0.835			
	PE_3	4.753	0.903			
Effort Expectancy	EE_1	5.011	0.772	0.731	0.881	0.787
	EE_2	4.674	0.969			
	EE_3*					
Social Influence	SI_1	4.169	1.124	0.792	0.878	0.706
	SI_2	3.775	1.129			
	SI_3	4.067	1.130			
Hedonic Motivation	HM_1	4.449	1.180	0.711	0.837	0.632
	HM_2	5.146	0.855			
	HM_3	4.326	0.992			
Behavioural Intention	BI_1	4.820	0.919	0.913	0.946	0.853
	BI_2	4.798	0.889			
	BI_3	4.831	0.797			

* – Removed due to the lack of outer loading reliability (< 0.7)
[a]– Composite Reliability
[b]– Average Variance Extracted
Ratings are on a 6-point Likert Scale: 1 = Strongly disagree 2 = disagree 3 = slightly disagree 4 = slightly agree 5 = agree 6 = strongly agree

Table 4. Discriminant validity analysis using Fornrell-Larcker criterion for professionals.

	PE	EE	SI	HM	BI
PE	**0.929**				
EE	0.673	**0.887**			
SI	0.419	0.429	**0.840**		
HM	0.523	0.587	0.147	**0.795**	
BI	0.690	0.692	0.394	0.617	**0.923**

The boldfaced numbers are the square root of AVE; the other numbers are the correlation coefficient between constructs.

The scores of professionals on all measured constructs were calculated to give an indication of their views toward IVR games for H&S training. As shown in (Table 3), the mean scores of professionals on all constructs were relatively high ranging from 3.8 to 5.1 with performance expectancy and effort expectancy having the highest mean scores of 5.0 and 4.8, respectively. Additionally, professionals scored relatively high on the behavioural intention construct, indicating enthusiasm towards adopting IVR games for H&S training.

To determine if there are any statistically significant differences in mean scores of students and employees, the non-parametric Mann-Whitney U test was conducted (MacFarland & Yates, 2016). As shown in (Table 5) there are statistically significant differences (p values ≤ 0.05) between the two groups in their mean scores on PE, SI, and BI.

Discussion

The aim of this study was to investigate the perceptions of chemical engineering students and professionals towards the use of IVR games for H&S education and to discuss the implications of the findings on classroom use. Using the UTAUT2 model, this study explored the perceptions of students and professionals towards the use of IVR games for H&S education using five constructs: Performance Expectancy (PE), Effort Expectancy

Table 5. A comparison of students and professionals on mean scores.

Ranks					Test Statistics		
	Population	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	P
PE	Professionals	89	62.03	5521.00	887.00	−2.080	0.038
	Students	27	46.85	1265.00			
	Total	116					
EE	Professionals	89	55.65	4953.00	984.00	−1.677	0.094
	Students	27	67.89	1833.00			
	Total	116					
SI	Professionals	89	61.84	5504.00	904.00	−1.962	0.050
	Students	27	47.48	1282.00			
	Total	116					
HM	Professionals	89	56.28	5009.00	1004.00	−1.307	0.191
	Students	27	65.81	1777.00			
	Total	116					
BI	Professionals	89	65.13	5796.50	611.50	−3.937	0.000
	Students	27	36.65	989.50			
	Total	116					

(EE), Social Influence (SI), Hedonic Motivation (HM), and Behavioural Intentions (BI). Additionally, qualitative data describing the perceived benefits and concerns regarding the use of IVR games for education by students were analysed. The findings suggest that students and professionals had positive perceptions towards the use of IVR games. From the ratings of the constructs, the highest mean scores of students were in HM and EE, whereas professionals scored PE and EE constructs higher than the other constructs. These observations suggest that students value enjoyment and ease of use more, as factors that would determine adoption of games for learning. On the other hand, professionals seemed to value usefulness and ease of use more when deciding to use the technology for learning. These differences indicate that while professionals would be most likely to adopt IVR games because it would enable them learn and become better at their jobs, students would most likely use this less conventional pedagogical tool to learn as it is engaging and enjoyable to use. Although participants' ages and experiences with games and VR may have played a role in these results, consideration should be given to attributes that make these technologies attractive to HE students when adopting those designed for professional use for the classroom use.

Comparing the mean scores of students and professionals on all measured constructs showed that professionals scored statistically significantly higher than students on SI, PE and BI. Motivation seemed to have played a role in the differences on SI. While the motivation to use provided technology for workplace training could be tied to impressing colleagues and bosses or even job retention and promotion, this is hardly the case in the HE setting. The difference in mean scores on PE suggest that professionals have a stronger belief in the useful of IVR games for H&S training compared to students. This could be attributed to the difference in knowledge dimensions addressed in the workplace compared to HE. While chemical engineering professionals are expected to demonstrate conceptual and procedural knowledge in their everyday work, engineering students are generally assessed for factual and conceptual understanding (Timmermann & Kautz, 2015) that would not necessarily require the use of new technologies to master. IVR games and other similar technologies offer opportunities to teach and assess workplace required skills hence bridging the gap between curriculum and the practical skills required by employers. Like professionals, students will find the technology useful if it aligns with the curriculum learning outcomes. Lastly, the higher mean scores on BI of professionals imply that compared to students, professionals are more likely to adopt IVR games for H&S education. This is expected given that professionals find the technology more useful for H&S education than students do.

Furthermore, the qualitative data showed that students generally perceive IVR games for education as beneficial, stating that the technology could lead to better learning experience, cost reduction, and safe learning environment. They also raised a wide range of concerns with using IVR games for classroom learning. Students mentioned the possibility of this technology being unsuitable for every student due to learning styles, disabilities or gaming competencies. Students also expressed scepticism on the effectiveness of IVR games for learning, suggesting that games and simulations are unable to account for all possible variables in a real-world setting. They also added that the gameplay itself might distract students from the learning contents of the game, rendering it ineffective. Additionally, cost and implementation challenges were raised. Some students worried that designing educational games that are both engaging and pedagogically relevant pose a difficult and expensive challenge. This highlights some of the concerns of game-based learning raised by de Freitas (2006) and Maciel, Miyagawa, Melo, and Souza (2018). Lastly, some students worry that persuading teachers as well as students to adopt IVR games for classroom education might pose a difficult challenge and a barrier to use.

Implications for design and practice

All of these findings have implications for the use of not just IVR games but most new technologies for higher education practices. Advances in technology are making it possible to bridge the gap between classroom education and workplace practices, hence facilitating a more rapid transition of graduates into a changing workplace. It is now easier than ever for students to learn both concepts and practical application of knowledge and skills throughout the undergraduate years without the limitations of real-world environments. The current generation of students understands the value that these technologies offer and would use them for classroom learning if made available to them. However, several issues should be considered when adopting, designing or using these technologies to teach students in higher education:

- IVR games should be fit for purpose. Games should be designed to align with curriculum and assessment. Adult learners are unlikely to adopt a new technology if it does not help them achieve learning goals. To ensure that students use these technologies as expected, they should be designed with intended learning outcomes at the heart of the design. When adopting existing technologies, it is necessary that they match curriculum learning outcomes. Furthermore, it should be made clear to students what they are expected to learn from the games when deploying them.
- Finding the right balance between quality of immersion, representation and fidelity when designing an educational IVR game is important. Games must be engaging for students to play them. This can be achieved through engaging and realistic narratives as well as good game aesthetics. While good levels of representation and fidelity are important in epistemic games, they do not always lead to better outcomes. Unnecessary fine details in games can be distracting and result in higher cognitive loads.
- IVR games and similar pedagogical tools should be used to complement existing pedagogies rather than stand-alone. Learning preferences and accessibility issues mean that these technologies might not be suitable for every student's need. Motion sickness is still an issue with VR and this can prevent some students from taking part in the learning activities. Therefore, when deploying IVR games (or any advanced technology) for learning, alternatives should be available for students who might be excluded from the activities.
- Students can be encouraged to be co-designers of games. Designing games can be expensive and time-consuming, and for many institutions, tight budgets could hinder such activities. One way to solve this problem is to involve students in the design and development process. Students can collaborate with colleagues from other faculties to exchange ideas and skills required for game design. This approach does not just have cost benefits; it provides students with the opportunity to develop

21st century skills, such as collaboration, creativity, and technology and information literacy skills.

- Integrating debriefing sessions into the learning activities would be beneficial. New technologies often fail to deliver expected outcomes for many unforeseen reasons. Having debriefing sessions after learning with a new technology would offer students the opportunity to reflect on and share their experiences with teachers. Teachers would then be able to use the feedback to improve future learning activities.

Finally, teachers should be encouraged to explore new technologies given the many benefits on teaching and learning. Training resources should be provided for teachers to develop the skills needed to support learning with these technologies. Trying out different games on mobile, desktops and VR during leisure times could also boost teachers' confidence in using these technologies. Limitations and suggestions for future work

Overall, this study finds evidence that chemical engineering students and professionals believe that immersive virtual reality games are useful for health and safety education and they indicate that they would use the technology for learning purposes. There are, however, limitations to the research. The sample size of the student participants limits robust statistical analysis and results to an extent. The students in the study were only chemical engineering students from two universities, hence the results, although indicative, cannot be generalised to the engineering student population at large. Lastly, the difference in the sample sizes of students and professionals could have biased the result of the comparison.

Given the above, future studies will consider using a larger sample size of students. Students from different engineering disciplines will be targeted to provide a broader view of what engineering students think of the technology. Studies could also compare engineering students' use of games for learning and their perceptions towards educational games to determine whether high perceptions result in extensive use and high performance in the game.

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Appendices

Appendix 1. Professionals questionnaire.

	6-point Likert Scale					
Items	Strongly agree	Agree	Slightly agree	Slightly disagree	Disagree	Strongly disagree
1. I think that using the VR environment will be useful for practicing H&S procedures.						
2. Using VR environment will probably enable me to learn the H&S procedures more quickly.						
3. If I use this VR environment, I will improve my performance on H&S procedures.						
4. I think using the VR environment will be clear and understandable.						
5. I think that it will be easy for me to operate the platform in which the VR environment is running.						
6. I think that the organization will support me in learning how to use the VR environment.						
7. People who influence my behavior at work think that I should use this VR environment.						
8. I think my supervisor will be very supportive of the use of this VR environment for my job.						
9. I feel that it will be a bad idea to use the VR environment for H&S training.						
10. I think that the actual process of using the VR environment for H&S training is fun.						
11. I think that using VR environment for H&S training will be very frustrating.						
12. If made available to me, I would recommend using the VR environment for learning to apply the H&S procedures to my colleagues.						
13. If made available to me, I plan to continue to use VR environment for H&S training frequently.						
14. I think that after using the VR for H&S training, I will be ready to use this learning environment for another training course.						

Appendix 2. Students' questionnaire.

Items	6-point Likert Scale					
	Strongly agree	Agree	Slightly agree	Slightly disagree	Disagree	Strongly disagree
1. I think that I would find Virtual Reality game useful for Health and Safety education						
2. I think that using Virtual Reality game would increase my Health and Safety knowledge						
3. I think that using Virtual Reality game would increase my Health and Safety knowledge						
4. I expect that my interaction with the Virtual Reality game would be clear and understandable						
5. I expect that it would be easy for me to become skillful at using Virtual Reality game for Health and Safety learning						
6. I expect to find the Virtual Reality game easy to use						
7. My teachers think that it is important that I use Virtual Reality game for Health and Safety education						
8. My peers will be supportive of my use of Virtual Reality game for learning purpose						
9. My teacher will be very supportive of my use of the Virtual Reality game for Health and Safety learning						
10. I think that playing Virtual Reality game is boring						
11. I think that playing Virtual Reality game is fun						
12. Virtual Reality games will not hold my attention						
13. I intend to use VR game for H&S education as soon as it's made available at the university						
14. I plan to use VR game to improve my learning effectiveness in H&S education						
15. I predict that I will use VR game for H&S education in the future						