

**Perceptions of the Use of Virtual Reality Games for Chemical Engineering Education and Professional Training**

Chioma Udeozora, Ryo Toyoda a, Fernando Russo Abegãoa, Jarka Glasseya\*

a School of Engineering, Newcastle University, Newcastle upon Tyne, United Kingdom.

\*jarka.glassey@newcastle.ac.uk

|  |  |
| --- | --- |
| Journal: | *Higher Education Pedagogies* |
| Manuscript ID | RHEP-2019-0095.R1 |
| Manuscript Type: | Special Issue Article |
| Keywords: | Virtual Reality, Games, Education, Training, UTAUT2 |
| Abstract: | As an alternative to traditional teaching methods, Virtual Reality (VR) games and simulations are 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. With the proliferation of VR tools, understanding the intention of users towards this technology for education and training purposes is 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 (H&S) education and training, and discusses the implications of findings to practice. The study found that both students and professionals believe that IVR games are useful for learning. A comparison of the two groups under study 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 classroom practice. |
|  | |



Perceptions of the Use of Virtual Reality Games for Chemical Engineering Education and Professional Training

# Abstract

As an alternative to traditional teaching methods, Virtual Reality (VR) games and simulations are 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. With the proliferation of VR tools, understanding the intention of users towards this technology for education and training purposes is 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 (H&S) education and training, and discusses the implications of findings to practice. The study found that both students and professionals believe that IVR games are useful for learning. A comparison of the two groups under study 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 classroom practice.

Keywords: Keywords: Virtual Reality, Games, Education, Training, UTAUT2, Chemical Engineering Education.

# 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). This paper seeks to present and compare the perceptions of chemical engineering students and professionals towards the use of innovative technologies, in this case immersive virtual reality games, for education.

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 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 and 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 et al., 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 processes.

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, and discuss the implications of findings to practice. This contribution provides quantitative and qualitative evidence of factors that can affect the use of VR games and simulations by HE students. 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, & 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. However, 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 they keep players engaged while having them invest time and energy into game play for no extrinsic reward other than the game play itself (Garris et al., 2002). Another popular rationale for game-based learning is its ability to engage learners (Boyle et al., 2011; Garris, Ahlers, & Driskell, 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, 2009a). 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 et al., 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, 2009a, p. 45). A systematic review by Connolly, Boyle, MacArthur, Hainey, & 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 et al., 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, 2019; 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 active learning, where the intention is to be able to understand and apply knowledge and skills across contexts (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 (Chittaro & Buttussi, 2015). Chittaro and Buttussi attributed this to the full engagement and high emotional and physiological arousal that learners experience when in IVR environment in an experimental study with 48 participants.

Although there are currently limited studies on the use IVR games in HE, a few have reported using IVR in different domains. Chittaro & 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 et al., 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 & 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 in developing practical knowledge and skills (Lambert, 2012) and non-engaging to learners (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 et al., 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 prepares them for the tasks ahead. It can also prepare 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 organisations who have more robust budgets. In this case, understanding factors that can influence students’ adoption of IVR games and whether they differ from those of professionals is of interest. Understanding the perceptions of students 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 the overall perceptions of chemical engineering students 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.

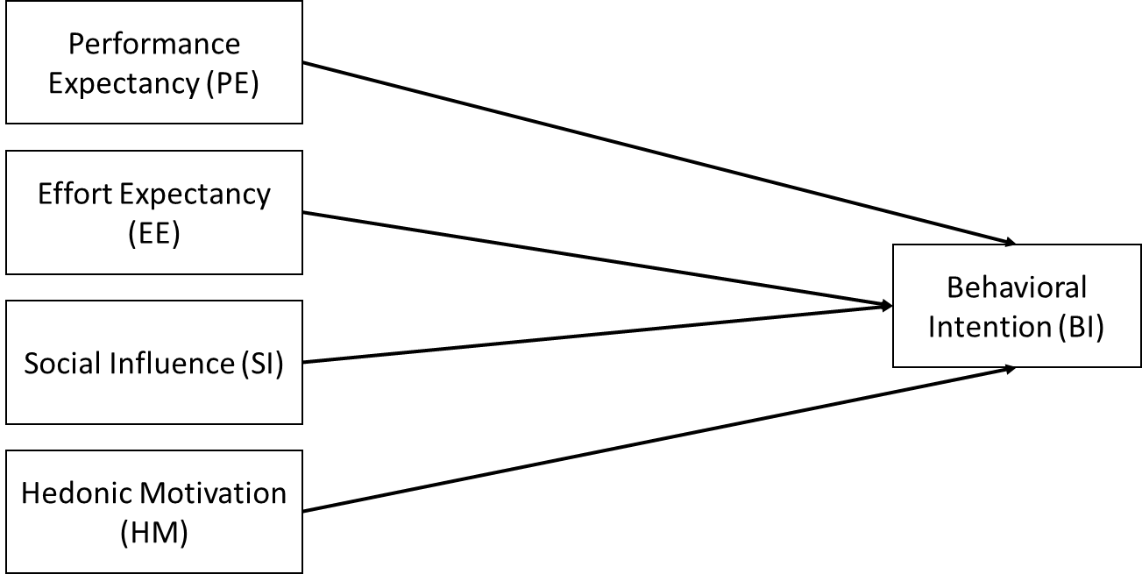


Figure 1. The modified UTAUT2 model

The 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). 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 et al., 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 et al., 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

This study adopted the quantitative research method using survey research design for data collection (Creswell, 2011). The participants of this study were chemical engineering undergraduate students and chemical industry professionals. Convenience sampling was used to recruit participants for this study (Etikan, 2016). Student participants were 2nd, 3rd and 4th years undergraduates recruited from two European universities with the help of gatekeepers. 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 informed opinions towards IVR games for H&S education. A total of 27 students (23 from Newcastle University and 4 from KU Leuven) 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 had prior VR experience.

Professional chemical engineers were recruited online from various chemical industries in the Philippines. 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 from the Philippines 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. 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 item was appropriately 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 as part of the survey research design. Before sending out the questionnaires, ethics approvals were obtained from the Ethics Committee at Newcastle University. This covered data collection from both universities. 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, what data will be collected, how these will be stored and used, and the rights of participants to opt out of the study at any time. It also included a consent page that asked participants to consent to the use of their anonymised data for research purposes. 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

## RQ 1: Perceptions of students towards IVR games

### 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 et al., 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 (AVE) and Fornrell-Larcker criterion tests were carried out, respectively (Hair et al., 2017). As shown in table 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.

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Constructs** | **Items** | **Mean** | **Standard Deviation** | **Cronbach'sAlpha** | **CRa** | **AVEb** |
| 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 |

Note: 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 2**. Discriminant validity analysis using Fornrell-Larcker criterion for students.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **PE** | **EE** | **SI** | **HM** | **BI** |
| **PE** | **0.823** |  |  |  |  |
| **EE** | 0.177 | **0.83** |  |  |  |
| **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

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, seven themes emerged from the NVivo analysis on these data as shown in Figure 2. Four themes were from Q1 and these include better learning experience, cost effectiveness, safety and advanced technological skills. The other three themes emerged from Q2 and were suitability concerns, implementation concerns, and false reality. All the data collected were first read through while main points (codes) were highlighted during the process. The codes were compared, and similar ones grouped in themes. This was done iteratively until no new themes emerged.

Immersive virtual reality for engineering education

Q1:

Benefits

Q2:

Drawbacks

Better learning experience

Cost effectiveness

Safety

Advanced technological skills

Suitability concerns

Implementation concerns

False reality

Themes

Better than lab sessions, …Interactive and realistic experience, More engagement, … like training in real life, More memorable experience, …more fluid learning experience, …a lot more interesting, …make learning more pleasant, …lead to a longer attention, hands on experience, …without having to leave the classroom and have expensive class trips, More enjoyable, More fun, immersion and interaction, …easy to simulate situations without putting people in unnecessary danger, could make a session more memorable, Easy way to introduce a number of hazards safely, …inline with the way technology is progressing

..take away from seriousness of H&S, …not everyone can use it, … instructors may not agree with this technology, …not too sure how easy it would be to implement and operate, May distract people from their actual learning outcomes, It is only a simulation not real life so other situations can still happen, Focus might be too much towards playing…over acquiring knowledge, May not be totally realistic, …not useful to every student, Distracting play games, Motion sickness, Mixed ability of students with video games, …cost and time, Physical problems may cause inadequacy to even use the VR games, people feel motion sick, …some people may not be able to use it and may be excluded from the class

Figure 2: Themes from qualitative data

*Themes from Q1:Better Learning Experience*

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 could provide better learning experience. Several codes were identified in the data which can be described as: realistic simulations, immersion, interactivity, visualisation, situated learning, memorable experience. In addition to promoting engagement, students also believed that using IVR games could enhance learning and retention as described below:

‘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’.

These findings have pedagogical benefits given that higher education students seem to have positive views of the strengths of educational IVR games which is certainly a first step towards ensuring the adoption of this technology for learning purposes. Some factors that can affect learning experiences in IVR games were also made implicit in their responses, and these include level of immersion and interactivity. Educators would have to pay attention to the quality and features of IVR games or similar technologies deployed for classroom use. Deploying low quality games that fail to engage as well as enhance learning will likely lead to low adoption and use, which could consequently fail to enhance learning.

*Safety*

Safety was another factor that was raised by two students as a benefit of IVR games for H&S education. This is certainly one of the most significant benefits of virtual simulations and games for engineering education, where access to industrial equipment for safety training is limited and could raise concerns on the safety of the students and equipment (Shi, et al., 2019). Engineering students are aware of this challenge and how IVR games can mitigate it:

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

In terms of pedagogical benefits, IVR games have the capacity to enable experiential learning in otherwise dangerous environments without the physical safety risks (Czarnek et al., 2019). Students could gain experience and develop confidence to work in high-risk environments in laboratories and chemical plants through the IVR environments, becoming better prepared to work in more demanding safety environments and accident response at later stages in their studies and careers. This could potentially improve their chances of employment and safe working behaviour later on.

*Cost-Benefit*

In addition to safety, another theme that emerged from the data was the cost-benefit of using IVR games for engineering education. With a significant part of what engineers are trained to do involving design and improvement of products and processes that require expensive set-ups, many institutions are unable to create such environments within their schools. This then requires that students either go on expensive trips to factories, or miss out on such experiences entirely for cost reasons (Martirosov & Kopecek, 2017). IVR games offer cost-effective means of simulating very advanced environment that requires little or no additional cost to use, and make these inclusive to more students, as described by this student:

‘(IVR games) give a hands-on experience without having to leave the classroom and have expensive class trips’.

Additionally, it is expected that this will allow students to maximise the benefit of field trips to laboratories and industrial sites. The familiarisation with the environments through previous exposure to industry through IVR should, in theory, enable more advanced and in-depth discussions to take place during the site visits (Garcia Fracaro et al., 2021; Shamsuzzoha et al., 2019).

*Advanced technological skills*

One other theme that emerged from the data was advanced technological skills. One student mentioned that:

‘… (using IVR games for learning is) more in line with the way technology is progressing’.

Besides the pedagogical benefits of IVR games and other innovative technologies, additional important benefits of these technologies include their relevance to future employability. The rapid advance in technology and the push towards the use of digital technologies in chemical industry through movements such Industry 4.0 (Ghobakhloo, 2020) means that knowledge and experiences with these technologies could differentiate one graduate from another in job applications. Exposing students to these technologies has immediate and future benefits.

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).

*Implementation Concerns*

In terms of the implementation concerns, participants mentioned cost, the challenge of educational games design, gameplay distractions, ineffectiveness of games, as well as the lack of acceptance of games by students and teachers. All these factors mentioned are indeed some of the pedagogical limitations of IVR games use. Whereas games offer cost benefits when compared to visiting the real-life environment, designing of these games and purchasing required hardware could be costly, and that could hinder the adoption of the technology by educators (Siddhpura, V. I, & Siddhpura, 2020). As a relatively new pedagogical tool, and with rapid advances in technology, continuous training is also needed to help educators use these tools effectively, and so is the need for research on best practices when designing games that are both fun and educational as described by these students:

‘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’.

For educators who might not necessarily be in the position to design games fit for their specific needs, it is necessary to select well designed games that deliver on the learning objectives while also engaging learners. Mini games with limited number of levels and specific learning outcomes might minimize distractions (Bontchev, Terzieva, & Paunova-Hubenova, 2021)

*Suitability concerns*

Students also showed concerns about the suitability of IVR games for pedagogical purpose. Motion sickness, gaming competency, accessibility issues and desensitisation effects were factors identified in the data as shown:

‘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’.

Motion sickness attributed to VR use and gaming competencies and interest could exclude some students from classroom activities requiring use of this technology (Chattha et al., 2020). However, with continuous improvement of VR technology, it is expected that motion sickness will be limited or completely eradicated in the nearest future (Lovreglio et al., 2018). Simulating dangerous environment in IVR games without experiencing any negative effects during use, while beneficial, could also lead to desensitization effects (Elmore, 2012). Using IVR games for such activity would require extra caution from educators on the real-life implications of errors when working in such environment.

*False Reality*

Two students mentioned the limitations of simulations, particularly when dealing with complex systems such as those of the chemical industries.

‘…only a simulation, not real life so other situations can still happen’.

‘May not be totally realistic’.

When simulating real-life chemical systems in VR environment, it is still not possible to account for every factor and cause-and-effect relationships of the real environment. This could limit the pedagogical applicability of VR games to certain domains and would require that educators strategically combine existing pedagogies with IVR games to ensure that both complement each other. Understanding this challenge should also help with the design of effective immersive learning environments that takes into account their limitations when simulating real-life situations.

In conclusion, 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 as all participants who mentioned motion sickness as a barrier had used VR in the past. However, students who were weary of gaming abilities/competencies affecting performance with the technology were found to have no previous VR experience.

## RQ 2: Differences between students and professionals in perceptions of IVR games for education and training

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** | **CRa** | **AVEb** |
| Performance Expectancy | PE1 | 5.056 | 0.916 | 0.921 | 0.95 | 0.863 |
| PE2 | 5.101 | 0.835 |
| PE3 | 4.753 | 0.903 |
| Effort Expectancy | EE1 | 5.011 | 0.772 | 0.731 | 0.881 | 0.787 |
| EE2 | 4.674 | 0.969 |
| EE3 |  |  |
| Social Influence | SI1 | 4.169 | 1.124 | 0.792 | 0.878 | 0.706 |
| SI2 | 3.775 | 1.129 |
| SI3 | 4.067 | 1.130 |
| Hedonic Motivation | HM1 | 4.449 | 1.180 | 0.711 | 0.837 | 0.632 |
| HM2 | 5.146 | 0.855 |
| HM3 | 4.326 | 0.992 |
| Behavioural Intentions | BI1 | 4.820 | 0.919 | 0.913 | 0.946 | 0.853 |
| BI2 | 4.798 | 0.889 |
| BI3 | 4.831 | 0.797 |

Note: \* - 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 | **0.84** |  |  |
| HM | 0.523 | 0.587 | 0.147 | **0.795** |  |
| BI | 0.69 | 0.692 | 0.394 | 0.617 | **0.923** |

Note: 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.

**Table 5.** A comparison of students and professionals on VR experience.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **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 |  |  |  |  |  |

# 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 (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 suggests that professionals have a stronger belief in the usefulness 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, & 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 given the possibility of simulating real life practices in virtual 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, that is, they should be relevant to the intended learning outcomes. 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.

Acknowledgements: Thanks are due to Dr Bert Slof and Dr Lisette Hornstra who provided feedback on the questionnaires.

Declaration: This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No 812716

# REFERENCES

Ahmad, W. F. W., Sarlan, A., & Rauf, N. A. (2018, June). ESCAPE: Interactive fire simulation and training for children using virtual reality. In *International Conference of Reliable Information and Communication Technology* (pp. 670-679). Springer, Cham.

Almanza-Arjona, Y. C., Vergara-Porras, B., García-Rivera, B. E., & Venegas-Andraca, S. E. (2019). Research-based approach to undergraduate chemical engineering education. 2019 IEEE Global Engineering Education Conference (EDUCON), 526-534.doi: 10.1109/EDUCON.2019.8725195

Bahadoorsingh, S., Dyer, R., & Sharma, C. (2016). Serious game integration into the engineering curriculum-a game-based learning approach to power systems analysis. *International Journal of Computational Vision and Robotics*, *6*(3), 276–289.

Baillie, C., & Fitzgerald, G. (2000). Motivation and attrition in engineering students. *European Journal of Engineering Education*, *25*(2), 145–155. https://doi.org/10.1080/030437900308544

Bontchev, B. P., Terzieva, V., & Paunova-Hubenova, E. (2021). Personalization of serious games for learning. *Interactive Technology and Smart Education*, *18*(1), 50–68. https://doi.org/10.1108/ITSE-05-2020-0069

Boyle, E., Connolly, T. M., & Hainey, T. (2011). The role of psychology in understanding the impact of computer games. *Entertainment Computing*, *2*(2), 69–74. https://doi.org/10.1016/j.entcom.2010.12.002

Chattha, U. A., Janjua, U. I., Anwar, F., Madni, T. M., Cheema, M. F., & Janjua, S. I. (2020). Motion sickness in virtual reality: An empirical evaluation. IEEE Access, 8, 130486–130499. https://doi.org/10.1109/ACCESS.2020.3007076

Chen, M. (2016). Process safety knowledge management in the chemical process industry. *American Journal of Chemical Engineering*, *4*(5), 131. https://doi.org/10.11648/j.ajche.20160405.16

Cheng, Y., & Wang, S. H. (2011). Applying a 3D virtual learning environment to facilitate student’s application ability - The case of marketing. *Computers in Human Behavior*, *27*(1), 576–584. https://doi.org/10.1016/j.chb.2010.10.008

Chittaro, L., & Buttussi, F. (2015). Assessing knowledge retention of an immersive serious game vs. a traditional education method in aviation safety. *IEEE Transactions on Visualization and Computer Graphics*, *21*(4), 529–538. https://doi.org/10.1109/TVCG.2015.2391853

Coller, B. D., & Scott, M. J. (2009). Effectiveness of using a video game to teach a course in mechanical engineering. *Computers and Education*, *53*(3), 900–912. https://doi.org/10.1016/j.compedu.2009.05.012

Colombo, S., Nazir, S., & Manca, D. (2014). Immersive virtual reality for training and decision making: Preliminary results of experiments performed with a plant simulator. *SPE Economics and Management*, *6*(4), 165–172. https://doi.org/10.2118/164993-PA

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers and Education*, *59*(2), 661–686. https://doi.org/10.1016/j.compedu.2012.03.004

Creswell, J. W. (2011). *Educational research* (4th ed.). Boston, MA: Pearson Education. Retrieved from http://basu.nahad.ir/uploads/creswell.pdf

Cronin, P. (1997). Report on the application of virtual reality technology to education. *HCRC, University of Edinburgh, 4.*

Czarnek, G., Strojny, P., Strojny, A., & Richter, M. (2019). Assessing engagement during rescue operation simulated in virtual reality: A psychophysiological study. *International Journal of Human–Computer Interaction*, *0*(00), 1–13. https://doi.org/10.1080/10447318.2019.1655905

de Freitas, S. (2006). Learning in immersive worlds: A review of game-based learning. *JISC E-Learning Programme*, *3*, 73. Retrieved from http://www.jisc.ac.uk/uploaded\_documents/Summary\_report.

Dede, C. (2009, January 2). Immersive interfaces for engagement and learning. Science, Vol. 323, pp. 66–69. https://doi.org/10.1126/science.1167311

Dib, H., & Adamo-Villani, N. (2014). Serious sustainability challenge game to promote teaching and learning of building sustainability. *Journal of Computing in Civil Engineering*, *28*(5). https://doi.org/10.1061/(ASCE)CP.1943-5487.0000357

Elmore, W. R. (2012). The effect of violent video game play on emotion modulation of startle. University of Missouri–Kansas City. Retrieved from https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/14082/ElmoreEffVioVid.pdf;jsessionid=AF4EDA859C5E1B11ED0DFCB4B89DEF59?sequence=1

Etikan, I. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1-4. https://doi.org/10.11648/j.ajtas.20160501.11

Fagan, M., Kilmon, C., & Pandey, V. (2012). Exploring the adoption of a virtual reality simulation: The role of perceived ease of use, perceived usefulness and personal innovativeness. *Campus-Wide Information Systems*, *29*(2), 117–127. https://doi.org/10.1108/10650741211212368

Fällman, D., Backman, A., & Holmlund, K. (1999). VR in education : An introduction to multisensory constructivist learning environments.  In *Conference on University Pedagogy*

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. *Computers and Education*, *127*(May), 252–266. https://doi.org/10.1016/j.compedu.2018.09.002

Fitzpatrick, J., Cronin, K., & Byrne, E. (2011). Is attending lectures still relevant in engineering education? *European Journal of Engineering Education*, *36*(3), 301–312. https://doi.org/10.1080/03043797.2011.585226

Garcia Fracaro, S., Chan, P., Gallagher, T., Tehreem, Y., Toyoda, R., Bernaerts, K., Glassey, J., Pfeiffer, T., Slof, B., Wachsmuth, S., & Wilk, M. (2021). Towards design guidelines for virtual reality training for the chemical industry. Education for Chemical Engineers, 36, 12–23. https://doi.org/10.1016/j.ece.2021.01.014

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation and Gaming*, *33*(4), 441–467. <https://doi.org/10.1177/1046878102238607>

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, *252*, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Grant, C. D., & Dickson, B. R. (2006). Personal skills in chemical engineering graduates: the development of skills within degree programmes to meet the needs of employers. *Education for Chemical Engineers, 1*(1), 23–29. https://doi.org/10.1205/ece.05004

Ha, I., Yoon, Y., & Choi, M. (2007). Determinants of adoption of mobile games under mobile broadband wireless access environment. *Information and Management*, *44*(3), 276–286. https://doi.org/10.1016/j.im.2007.01.001

Hair, J. F. J., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2017). *A primer on partial least squares structural equation modeling (PLS-SEM)* (Second ed.). SAGE Publications Inc.

Handa, M., Aul, E. G., & Bajaj, S. (2012). Immersive technology – uses, challenges and opportunities. International Journal of Computing & Business Research ISSN (Online, 2229–6166. Retrieved from http://www.researchmanuscripts.com/isociety2012/12.pdf

Herzog, M., & Katzlinger, E. (2011). Influence of learning styles on the acceptance of game based learning in higher education: Experiences with a role playing simulation game. *Proceedings of the European Conference on Games-Based Learning*, *2011*-*Janua*(October), 241–250.

IChemE. (2019). *Accreditation of chemical engineering programmes: A guide for university departments and assessors - Based on learning outcomes*. Retrieved from www.engc.org.uk/ukspec.aspx

Imlig-Iten, N., & Petko, D. (2018). Comparing serious games and educational simulations: Effects on enjoyment, deep thinking, interest and cognitive learning gains. *Simulation and Gaming*, *49*(4), 401–422. https://doi.org/10.1177/1046878118779088

Johnson, D., & Singh, R. (2019). Utilizing simtronics, a chemical engineering process simulation software, in chemical engineering coursework to reduce the skills gap. *Computer Applications in Engineering Education*, *27*(2), 519–525. https://doi.org/10.1002/cae.22079

Joiner, R., Iacovides, I., Darling, J., Diament, A., Drew, B., Duddley, J., … Gavin, C. (2013). Racing academy: A case study of a digital game for supporting students learning of physics and engineering. In *Cases on Digital Game-Based Learning: Methods, Models, and Strategies* (pp. 509–523). https://doi.org/10.4018/978-1-4666-2848-9.ch026

Kharvari, F., & Hohl, W. (2019). The role of serious gaming using virtual reality applications for 3d architectural visualization. *2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, 1–2. https://doi.org/10.1109/VS-Games.2019.8864576

Lambert, C. (2012). Eric Mazur on new interactive teaching techniques | Harvard Magazine Mar-Apr 2012. *Harvard Magazine*. Retrieved from https://harvardmagazine.com/2012/03/twilight-of-the-lecture

Lovreglio, R., Gonzalez, V., Feng, Z., Amor, R., Spearpoint, M., Thomas, J., Trotter, M., & Sacks, R. (2018). Advanced engineering informatics prototyping virtual reality serious games for building earthquake preparedness : The Auckland city hospital case study. Advanced Engineering Informatics, 38(August), 670–682. https://doi.org/10.1016/j.aei.2018.08.018

MacFarland T.W., Yates J.M. (2016) Mann–Whitney U Test. In: Introduction to Nonparametric Statistics for the Biological Sciences Using R. Springer, Cham. https://doi.org/10.1007/978-3-319-30634-6\_4

Maciel, F., Miyagawa, T., Melo, P., & Souza, M. (2018). Evaluating the UX of a VR game using a mixed methodology. *Advances in Intelligent Systems and Computing*, *608*, 249–257. https://doi.org/10.1007/978-3-319-60639-2\_26

Manca, D., Brambilla, S., & Colombo, S. (2013). Bridging between virtual reality and accident simulation for training of process-industry operators. *Advances in Engineering Software*, *55*, 1–9. https://doi.org/10.1016/j.advengsoft.2012.09.002

Martirosov, S., & Kopecek, P. (2017). Virtual reality and its influence on training and education - Literature review. *Annals of DAAAM and Proceedings of the International DAAAM Symposium*, 708–717. https://doi.org/10.2507/28th.daaam.proceedings.100

McMorran, C., Ragupathi, K., & Luo, S. (2017). Assessment and learning without grades? Motivations and concerns with implementing gradeless learning in higher education. *Assessment and Evaluation in Higher Education*, *42*(3), 361–377. https://doi.org/10.1080/02602938.2015.1114584

Menin, A., Torchelsen, R., & Nedel, L. (2018). An analysis of VR technology used in immersive simulations with a serious game perspective. *IEEE Computer Graphics and Applications*, *38*(2), 57–73. https://doi.org/10.1109/MCG.2018.021951633

Nazir, S., Totaro, R., Brambilla, S., Colombo, S., & Manca, D. (2012). Virtual reality and augmented-virtual reality as tools to train industrial operators. In *Computer Aided Chemical Engineering*, *30*(December), 1397–1401. Elsevier https://doi.org/10.1016/B978-0-444-59520-1.50138-X

Ouyang, S. G., Wang, G., Yao, J. Y., Zhu, G. H. W., Liu, Z. Y., & Feng, C. (2018). A Unity3D-based interactive three-dimensional virtual practice platform for chemical engineering. *Computer Applications in Engineering Education*, *26*(1), 91–100. https://doi.org/10.1002/cae.21863

Pallavicini, F., Ferrari, A., Zini, A., Garcea, G., Zanacchi, A., Barone, G., & Mantovani, F. (2018). What distinguishes a traditional gaming experience from one in virtual reality? An exploratory study. In *International Conference on Applied Human Factors and Ergonomics,* *608*, 225–231. Springer. https://doi.org/10.1007/978-3-319-60639-2\_23

Perini, S., Luglietti, R., Margoudi, M., Oliveira, M., & Taisch, M. (2018). Learning and motivational effects of digital game-based learning (DGBL) for manufacturing education –The Life Cycle Assessment (LCA) game. *Computers in Industry*, *102*, 40–49. https://doi.org/10.1016/j.compind.2018.08.005

Prensky, M. (2003). Digital game-based learning. *Computers in Entertainment*, *1*(1), 21. https://doi.org/10.1145/950566.950596

Ringle, C. M., Wende, S., & Becker, J.-M. (2015). SmartPLS 3. *Boenningstedt: SmartPLS GmbH*.

Shamsuzzoha, A., Toshev, R., Vu Tuan, V., Kankaanpaa, T., & Helo, P. (2019). Digital factory–virtual reality environments for industrial training and maintenance. Interactive Learning Environments. https://doi.org/10.1080/10494820.2019.1628072

Shi, Y., Du, J., Ahn, C. R., & Ragan, E. (2019). Impact assessment of reinforced learning methods on construction workers’ fall risk behavior using virtual reality. *Automation in Construction*, *104*(October 2018), 197–214. https://doi.org/10.1016/j.autcon.2019.04.015

Shute, V. J., Ventura, M., & Ke, F. (2015). The power of play: The effects of Portal 2 and Lumosity on cognitive and noncognitive skills. *Computers and Education*, *80*, 58–67. https://doi.org/10.1016/j.compedu.2014.08.013

Siddhpura, A., V, I., & Siddhpura, M. (2020). Current state of research in application of disruptive technologies in engineering education. *Procedia Computer Science*, *172*, 494–501. https://doi.org/10.1016/j.procs.2020.05.163

Stuyts, J., & Driesen, J. (2016). Lumen: Educating youngsters about energy, using Minecraft. *IEEE Power and Energy Society General Meeting*. https://doi.org/10.1109/PESGM.2016.7741147

Szczurowski, K., & Smith, M. (2018). ’Woodlands’-A virtual reality serious game supporting learning of practical road safety skills. *2018 IEEE Games, Entertainment, Media Conference, GEM 2018*, 427–435. https://doi.org/10.1109/GEM.2018.8516493

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: toward a unified view. In *Source: MIS Quarterly,* 425-478.

Venkatesh, V., Thong, J., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology. *MIS Quarterly*, 36(1), 157–178. https://doi.org/10.2307/41410412

Venkatesh, V., Thong, J., & Xu, X. (2016). Unified theory of acceptance and use of technology: A synthesis and the road ahead. *Journal of the Association for Information Systems,* 17(5), 328–376. https://doi.org/10.17705/1jais.00428

Whitton, N. (2009). Learning and teaching with computer games in higher education. In *Games-Based Learning Advancements for Multi-Sensory Human Computer Interfaces: Techniques and Effective Practices*, 18–33. IGI Global. https://doi.org/10.4018/978-1-60566-360-9.ch002

Whitton, N. (2009a). *Learning with digital games: A practical guide to engaging students in higher education*. https://doi.org/10.1111/j.1467-9647.2011.00770.x

Wu, W.-H., Hsiao, H.-C., Wu, P.-L., Lin, C.-H., & Huang, S.-H. (2012). Investigating the learning-theory foundations of game-based learning: a meta-analysis. *Journal of Computer Assisted Learning, 28*(3), 265–279. https://doi.org/10.1111/j.1365-2729.2011.00437.x

# APPENDICES

Appendix 1: Professionals Questionnaire

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Items | 6-point Likert Scale | | | | | |
| 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. |  |  |  |  |  |  |
| 1. Using VR environment will probably enable me to learn the H&S procedures more quickly. |  |  |  |  |  |  |
| 1. If I use this VR environment, I will improve my performance on H&S procedures. |  |  |  |  |  |  |
| 1. I think using the VR environment will be clear and understandable. |  |  |  |  |  |  |
| 1. I think that it will be easy for me to operate the platform in which the VR environment is running. |  |  |  |  |  |  |
| 1. I think that the organization will support me in learning how to use the VR environment. |  |  |  |  |  |  |
| 1. People who influence my behavior at work think that I should use this VR environment. |  |  |  |  |  |  |
| 1. I think my supervisor will be very supportive of the use of this VR environment for my job. |  |  |  |  |  |  |
| 1. I feel that it will be a bad idea to use the VR environment for H&S training. |  |  |  |  |  |  |
| 1. I think that the actual process of using the VR environment for H&S training is fun. |  |  |  |  |  |  |
| 1. I think that using VR environment for H&S training will be very frustrating. |  |  |  |  |  |  |
| 1. If made available to me, I would recommend using the VR environment for learning to apply the H&S procedures to my colleagues. |  |  |  |  |  |  |
| 1. If made available to me, I plan to continue to use VR environment for H&S training frequently. |  |  |  |  |  |  |
| 1. 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 |  |  |  |  |  |  |
| 1. I think that using Virtual Reality game would increase my Health and Safety knowledge |  |  |  |  |  |  |
| 1. I think that using Virtual Reality game would increase my Health and Safety knowledge |  |  |  |  |  |  |
| 1. I expect that my interaction with the Virtual Reality game would be clear and understandable |  |  |  |  |  |  |
| 1. I expect that it would be easy for me to become skillful at using Virtual Reality game for Health and Safety learning |  |  |  |  |  |  |
| 1. I expect to find the Virtual Reality game easy to use |  |  |  |  |  |  |
| 1. My teachers think that it is important that I use Virtual Reality game for Health and Safety education |  |  |  |  |  |  |
| 1. My peers will be supportive of my use of Virtual Reality game for learning purpose |  |  |  |  |  |  |
| 1. My teacher will be very supportive of my use of the Virtual Reality game for Health and Safety learning |  |  |  |  |  |  |
| 1. I think that playing Virtual Reality game is boring |  |  |  |  |  |  |
| 1. I think that playing Virtual Reality game is fun |  |  |  |  |  |  |
| 1. Virtual Reality games will not hold my attention |  |  |  |  |  |  |
| 1. I intend to use VR game for H&S education as soon as it's made available at the university |  |  |  |  |  |  |
| 1. I plan to use VR game to improve my learning effectiveness in H&S education |  |  |  |  |  |  |
| 1. I predict that I will use VR game for H&S education in the future |  |  |  |  |  |  |