ORIGINAL ARTICLE

Perceived usefulness of, engagement with, and effectiveness of virtual reality environments in learning industrial operations: the moderating role of openness to experience

Eugene Yin-cheung Wong[1] · Ray Tak-yin Hui[2] · Hao Kong[3]

Abstract

The development of virtual reality (VR) in enhancing the effectiveness of the learning process, with its interactive, immersive, and intuitive pedagogical environment, has become a necessity for corporations with increasingly complex operations. However, VR users' perceptions, openness and learning effectiveness are seldom comprehensively evaluated, particularly in learning complex industrial operations. In this study, grounded in the technology acceptance model, a moderated mediation model of perceived usefulness, ease of use, openness to experience, and engagement in VR-based learning was developed. The model was empirically validated using responses collected from 321 users who were trained on aircraft and cargo terminal operations powered by a novel VR-based learning platform. A survey to measure openness to experience and a pre-training performance test were carried out, followed by a post-training survey of learners' intrinsic factors, including the influence of perceived usefulness, openness to experience, and attitude towards learning. The study revealed that learners with an open attitude towards experiencing new technology tend to perceive VR technology as a useful platform for training. In addition, the learners with more positive views of VR technology-supported training were more engaged in learning.

Keywords Virtual reality · Pedagogical development · Openness to experience · Perceived usefulness of VR · Attitude towards learning · Technology acceptance model

1 Introduction

The importance of virtual reality (VR) in education is growing as immersive technology increases in popularity and availability, more learning content requiring VR support is identified (Hamilton, McKechnie, Luo et al. 2021), at the same time as the cost of equipment declines. VR products were selected as among the top inventions of 2016 (Time 2016), with technology leaders actively inventing and trademarking VR technologies. The number of studies on the use of VR and meta technologies in teaching and learning is increasing, boosting demand for development of hardware and software for visualisation and cooperation, as well as expectations (Kalantari and Rauschnabel 2018; Won et al. 2021; Xu et al. 2021; Xi et al. 2022). Rising demand for VR headsets meant over 14 million VR and augmented reality (AR) devices were sold in 2019, while the number of VR users has already surpassed 171 million worldwide (Petrov 2019). The price of VR devices available to the consumer has gradually decreased, and they are more widely available in retail stores. The global VR, AR, and mixed reality (MR) market reached US$28 billion in 2021, rising to over US$250 billion by 2028 (Alsop 2022a). The commercial use cases for VR and AR that are expected to receive the largest investment in 2024 are training with US$4.1 billion forecast to be invested in this field (Alsop 2022b).

✉ Eugene Yin-cheung Wong
  eugenewong@hsu.edu.hk

  Ray Tak-yin Hui
  ray_hui@nucba.ac.jp

  Hao Kong
  hkong@hsu.edu.hk

[1] Department of Supply Chain and Information Management, School of Decision Sciences, The Hang Seng University of Hong Kong, Hong Kong, China

[2] NUCB Business School, Nagaya University of Commerce and Business, Nagoya, Japan

[3] Department of Management, School of Business, The Hang Seng University of Hong Kong, Hong Kong, China

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The dramatic surge in the use of VR has extended to professional education and training. This is the result of the greater complexity of data and operation processes in organisations, tighter operational security and safety standards, and an increasing awareness that VR can be used for cultural preservation (Fussell and Truong 2021; Zhang et al. 2022). Traditional modes of teaching and learning, such as classroom lecturing, textbook reading, video learning, and case-study discussions, do not capture the complexity of certain operations. They are also often unable to demonstrate multi-dimensional operations and statistics (Ding et al. 2020). Large datasets with multiple dimensions require a sophisticated virtual environment for visualisation (Wong et al. 2020). Tightened security and safety guidelines often limit the accessibility of restricted areas for field trips and onsite visits to areas such as cargo terminals in the logistics and transport sector, clinical and surgical suites in hospitals, and trading platforms in finance. Research into the use of VR in education is therefore increasing, and disciplines including engineering (Abulrub et al. 2011; Rovira and Slater 2017; Soliman et al. 2021), medicine (Lohre et al. 2020; Izard et al. 2018), industrial operations (Bourhim and Cherkaoui 2020; Chen et al. 2019), arts (Parker and Saker 2020; Han 2015), and geometry (Kaufmann and Schmalstieg 2006) are being examined.

The successful adoption and implementation of VR in teaching rely on the audience's acceptance and attitudes, as well as the perceived usefulness of the new technology. The technology acceptance model (TAM) has been used to study learners' acceptance of VR (e.g. Chang et al. 2018a, b; Durodolu 2016; Fussell and Truong 2021; Zhang et al. 2022). Durodolu (2016) reviewed learners' acceptance and use of new technology in instilling the skills needed for information literacy. Chang et al. (2018a, b) carried out a similar experiment to analyse users' perceptions of VR and whether they intended to adopt a VR-based mental rotation-training system. The study found that users' positive perceptions and intentions of using the system were amplified when better immersive and interactive experiences were provided. Fussell and Truong (2021) also adopted the TAM to explain and predict relationships between ease of use, usefulness, attitudes towards, and intentions regarding the use of AR for in-flight training, while Zhang et al. (2022) found that perceived usefulness and perceived ease of use directly predicted the attitudes of 1158 workers and students in the construction industry towards using VR technology. However, the majority of studies in the VR literature have focused mainly on the effect of the TAM on users' intention to use VR, whereas very few have studied users' actual learning (e.g. Zhang et al. 2017). To address this gap, this study aims to examine how the TAM influences the effectiveness of VR in learning.

To evaluate the acceptance and perceived usefulness of VR in teaching and learning, it is important to assess and analyse the effectiveness of VR in learning, especially where complex industrial procedures are concerned. Reznek et al. (2002) evaluated construct and content validity as well as learners' perceptions of a VR intravenous insertion simulator in a training session with 41 users. The usefulness, ease of use and overall appeal of the simulator were addressed. Huang et al. (2010) attempted to investigate the effectiveness of learning using Web-based three-dimensional (3D) technologies with VR features and proposed guidelines for the effective use of VR in learning environments. Zhang et al. (2017) reviewed the distinct features of VR regarding visualisation, interaction, representational fidelity, and immediacy of control to improve users' learning outcomes. A survey of 180 users was therefore conducted to evaluate the learning effectiveness of VR, which concluded that VR could influence reflective thinking and lead to further indirect improvement in perceived learning effectiveness. Similar studies were performed by Lee et al. (2009, 2010) and Jou and Wang (2013).

Based on the theory of reasoned action (TRA) (Ajzen and Fishbein 1980; Fishbein, and Ajzen. 1975), from which the TAM was adapted to apply to information systems, Devaraj and his colleagues (2008) argued that personality might be an external variable that interacts with TAM factors, such as perceived technology acceptance and ease of use, and thus affect users' performance and behaviour. For example, Kober and Neuper (2013) found that users' personalities, including aspects such as their imagination, perspectives, and immersive tendencies, were significantly correlated with their perceived presence in VR. Widyanti and Hafizhah (2021) showed that the Big Five personality traits, such as emotional stability and openness to experience, were significant for susceptibility to VR sickness but in different ways. However, research on the role of personality in VR-based learning remains scarce in the existing literature. To fill this gap, this study will examine the effect of users' openness to experience—one of the most widely studied, learning-related personality attributes in the Big Five Inventory (Chow 2018; Costa and McCrae 1992)—on the TAM of VR technology, and users' learning effectiveness.

Given the increasing complexity of operating aircraft and cargo terminals, learners are not able to fully understand the procedures with the use of traditional learning modes. Tighter security in these sites makes it more difficult for students, and even practitioners, to gain advanced technical knowledge or practise their skills. Therefore, a novel interactive, immersive, and intuitive VR learning environment that simulated an aircraft and cargo terminal is need is needed. The scene was developed to facilitate teaching and learning in the supply chain and logistics programmes. A pilot study was conducted to examine the interactive effects of openness

to information technology (IT) and the perceived usefulness of VR training and attitudes towards it. After the pilot study, a further extensive and detailed study was carried out to gauge various factors, including openness to experience, perceived usefulness, perceived ease of use, engagement in VR-based learning and learning effectiveness.

2 Virtual reality—from technology development to learning effectiveness

Inventions and experiments related to VR began in the 1950s. Heilig (1962) developed a mechanical device called a 'Sensorama', with 3D images, peripheral vision, and multiple senses, including sight, sound, smell, and touch. The computer scientist Ivan Sutherland developed a VR and AR head-mounted display in 1968, which was followed in 1978 by the 'Aspen Movie Map', a hypermedia and VR system from the Massachusetts Institute of Technology that showed a virtual simulation of Aspen, Colorado (Krueger et al. 1985). Lanier (1989) later developed various VR devices, such as the 'Data Glove', the 'Eye Phone', and the 'Audio Sphere'. Cruz-Neira et al. (1992) developed the first cubic immersive room, the Cave Automatic Virtual Environment (CAVE). This is a hollow cube with display-screens surrounding the viewer, who moved within the CAVE. These VR systems detected the position of the user and projected immersive, interactive scenes on to the corresponding field of view in stereo. Commercialisation began with the launch of devices, including the Sega VR headset (Horowitz 2004), the VFX1 headset (Chirieleison and Chirieleison, 2004), the Oculus Rift (Luckey 2013), the Google Cardboard (Lyons, 2016), and the HTC Vive (Hilfert and König 2016). Advanced features and functions were developed, including higher resolution wireless headsets, better sensor tracking and an improved user interface (Trentsios et al. 2020).

The invention of the CAVE in the early 1990s triggered extensive research to develop user-friendly and low-cost CAVE-like products for teaching, research and industrial applications. The CAVE consists of a cube integrated with screens, 3D projectors, a motion capture system, stereoscopic liquid crystal display shutter-glasses, and computer hardware and software for the VR system. Depending on the field of view, user experience, and system specifications, CAVEs can be built in various forms, such as a cube (North and North 2016; Lau et al. 2009; Czernuszenko et al. 1997), 'Fishtank' VR systems (Demiralp et al. 2006), the Star-CAVE (Sterling 2008), the L-shaped CAVE (Zimmermann 2008) and the dome-shaped CAVE (Li et al. 2014). For this study, a CAVE-based system was developed with a cube-like structure, four 3D projectors and screens, audio and acoustic systems, a server, a display system, two high-performance workstations, frame and tracking systems, 3D modelling and VR software and 12 sensors. Our CAVE setup is shown in Fig. 1.

VR has featured in many applications in recent years, including logistics and transport (Wong et al. 2020; Massei et al. 2013), manufacturing (Matsas et al. 2018), product design (Guo et al. 2018), construction (Sampaio and Martins 2014), healthcare (Aiken and Berry 2015), art appreciation (Huang and Han 2014), and education (Müller et al. 2007; Ott and Freina 2015). VR CAVE technology has been applied to teaching and learning in various disciplines, including science (Tarr and Warren 2002; Limniou et al. 2008), engineering (Wang et al. 2018), health care (Bracq et al. 2019), cultural heritage (Vasileva and Petrova 2019), and logistics (Lau et al. 2007). VR facilitates users to understand complex content in an interactive, immersive and multi-dimensional way. For example, through immersing into the designed VR scenes, users can understand material-handling systems in an air cargo terminal, practice crane operations in a container terminal or appreciate ancient art and culture.

The VR CAVE has been applied for years in various disciplines, including education. With the rapid advances in VR technology, will the public accept such new, advanced ways of learning? What are people's attitudes towards these innovative learning platforms? How effective is learning via VR compared with traditional classroom learning? Most VR research has focused on technological know-how and

Fig. 1 CAVE VR system: **a** system and equipment setup and **b** immersive VR scenes of oversized cargo loading in a 747-8F aircraft

(a) **(b)**
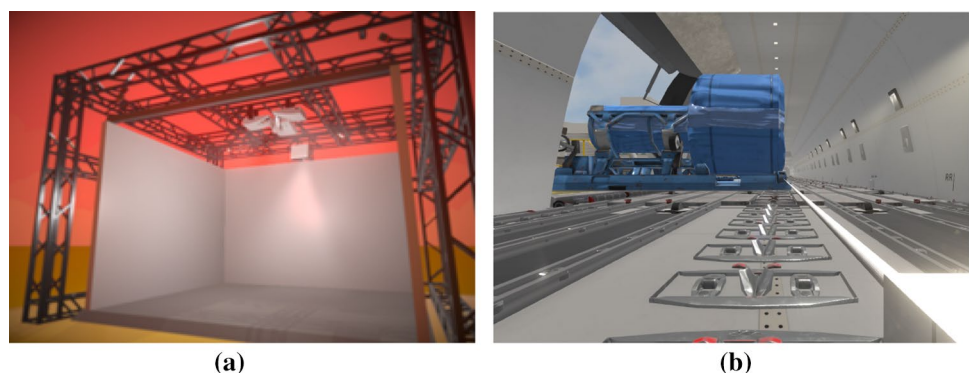
industrial applications. Few studies have investigated the attitudes, perceptions, and effectiveness of the VR CAVE in an educational context. Increased investigations have been carried out to examine the effectiveness of VR in education until recently, because of the outbreak of the COVID-19 pandemic (Gao et al. 2021; Birrenbach et al. 2021; Kapoor and Singh 2022). The results generally indicated that immersion made a greater contribution than interaction and imagination, whilst the capability of VR interaction aided the development of users' skills.

Acceptance of VR technology and the effects of personality variables on learning performance are of growing importance as adoption of VR in education and training increases, especially amidst the COVID-19 pandemic. Researchers have used models such as the TAM and the Big Five personality traits to investigate these human interactions and behaviours. Bertrand and Bouchard (2008) investigated the application of the TAM to the use of VR in clinical settings by sampling 141 adults with an interest in VR technology. Kober and Neuper (2013) studied 30 female participants to examine the relationship between personality variables and presence in VR. Their results indicated that absorption, mental imagination, perspective taking, and immersive tendencies showed significant correlations with presence. In contrast to the above research, this study focused on the attitudes and perceived learning behaviour of VR users and how does the users' openness to IT experience, an internal factor affect these attitudes and perceptions. Responses from over 300 participants were analysed to show the mechanism of how interactive and immersive VR simulation technologies assist learning.

3 Hypothesis development

3.1 Enhancing teaching quality and learning experience with VR

VR experience is described as any in which the user is effectively immersed in a responsive virtual world (Brooks 1999). An interactive and immersive environment facilitates teaching and learning, especially in gaining knowledge and practising the skills that are needed in complex operations and are not easily available to learners. Supply chain, transport, and logistics cover sophisticated container operations in aircraft, vessels, cargo terminals, warehouses, distribution centres and retail facilities and involve vast numbers of systems and large amounts of equipment (Burmester et al. 2008). Increasing security often limits the opportunities for onsite learning, meaning VR could be used to provide a virtual environment for learners to understand the end-to-end processes, practise technical skills, and solve simulated problems in sites such as cargo terminals (Lau et al. 2007). Thus,

our proposed VR CAVE system would facilitate a deeper understanding of the terminology (e.g., unit load device [ULD], container dolly, and quay crane) by immersing and illustrating trainees operations in a 3D setting. The system would also enable people to gain professional knowledge and skills by experiencing the various functions and flows, such as cargo load planning, container stowage, material handling system operations, and automation of conveyor belts (Martin and Bohuslava 2018). It would also provide a platform for learners to practise technical skills, such as warehouse operations, aircraft cargo loading and container stowage.

The learning effectiveness determines the degree to which learners benefit from VR-assisted teaching and training. These outcomes include knowledge acquisition and skill enhancement. High learning effectiveness can be achieved when learners perceive the technology as useful and easy to use so that they are willing to use it for learning. Therefore, many studies evaluated these users' perceptions on VR (Akbulut et al. 2018; Chang et al. 2018a, b; Huang and Liaw 2018), which provide directions to further improve the VR scenes and content and enhance teaching and learning experience.

3.2 TAM of VR and engagement in VR-based learning

The TAM (Davis 1989) is a widely accepted theoretical model that is used to predict IT adoption in various contexts. It builds on a wide range of theoretical perspectives and studies, such as the theory of reasoned action (Ajzen and Fishbein 1980), self-efficacy theory (Bandura, 1983), and behavioural decision theory (Beach and Mitchell 1978). The TAM posits that two beliefs—perceived usefulness and perceived ease of use—are the fundamental determinants of use behaviours (Davis 1989; Davis et al. 1989). Based on Davis' (1989) study, the perceived usefulness of VR and its ease of use are defined as the extent to which a person believes that VR training will enhance his or her learning effectiveness and the extent to which that person believes that VR training will be free of effort.

In addition, the TAM and the TRA both postulate that the two beliefs influence actual behaviours via users' affective state and/or behavioural intention, and their attitudes towards the use of technology. According to these theoretical models, a person's affective state, or attitude towards a behaviour, is determined by his or her beliefs about the consequences of exhibiting the behaviour. Davis et al. (1986, p. 987) noted that 'positively valued outcomes often increase one's affect towards the means to achieving those outcomes'. Therefore, when a learner perceives that VR training can enhance learning effectiveness, the learner's affect towards VR training increases. The perceived

ease of use also has a positive influence on a learner's attitudes because of the enhanced self-efficacy and instrumentality. It is to be expected that when VR training is easier to interact with, learners' efficacy in adopting and operating the system will be greater.

From the perspective of the learning process, encouraging the use of technology is a means of motivating learners' commitment, involvement, and interaction with learning materials and hence enhancing the effectiveness of their learning. Learning engagement, specifically, the learners' cognitive and affective engagement (PytlikZillig et al. 2011), is important in the learning process (Fredricks et al. 2004; PytlikZillig et al. 2011), and it serves as the intermediate mechanism between the various ways of training and learning effectiveness. It represents a set of affective and cognitive states that encompass both positive and negative attitudes towards doing the work and the willingness to make the effort to comprehend complex ideas and master difficult skills (Fredricks et al. 2004). Learning engagement depicts affective and cognitive states, but is more relevant in the context of applying technology in learning. For example, Zhang et al. (2017) considered the distinct features of VR on visualisation, interaction, representational fidelity, and immediacy of control that could improve the effectiveness of VR-based learning. Similar studies were carried out by Jou and Wang (2013), Fussell and Truong (2021), and Song et al. (2021). Given the theoretical rationale of the TAM, learning engagement should be influenced by people's beliefs (i.e. perceived usefulness and perceived ease of use) about VR training.

When learners perceive that VR training helps them to acquire particular knowledge or skills (i.e. perceived VR usefulness) and that the learning process is effortless (i.e. perceived ease of use), they may be more likely to view the potential learning outcomes from VR training positively, and vice versa. According to the TRA (Ajzen and Fishbein 1980), the strength of behavioural belief and the evaluation of the potential outcomes determine the attitude towards the planned behaviour. Therefore, learners with high perceived VR usefulness or high perceived ease of use tend to have a positive attitude towards their learning efforts in VR training. This positive attitude will then motivate learners' intention to engage themselves in VR-based learning. Therefore, we can expect that the more learners perceive VR training as being useful to their learning and free of effort, the greater their engagement in learning will be. Accordingly, we propose the following hypotheses:

H1a The usefulness of VR that learners perceive has a positive relationship with engagement in VR-based learning.

H1b The ease of use that learners perceive has a positive relationship with engagement in VR-based learning.

Given the relationship between the perception of VR and learning engagement, in the next section, we will move on to discuss how does students' engagement in VR-based learning affect their learning effectiveness.

3.3 Learning engagement and effectiveness

Many studies have examined learning effectiveness in technology-mediated learning by analysing the influence of engagement on the underlying learning process (e.g. Chen et al. 2010; Russell et al. 2016; Soffer and Nachmias 2018; Guan et al. 2021; Huang et al. 2021). It has been concluded that when learners engage with learning, they spend more time thinking critically and reflectively about the knowledge they acquired and use more higher-order skills, such as problem-solving, collaboration, synthesis, and stimulation, when applying the knowledge (Duderstadt et al. 2002), resulting in greater learning effectiveness (Guan et al. 2021; Huang et al. 2021). In this study, to understand the important role of engagement in VR-based learning, we examined its effect on learning effectiveness, defined as the extent of the knowledge attained in VR training and measured by test results. According to the TRA (Ajzen and Fishbein 1980), stronger behavioural intentions lead to increased effort and a greater likelihood of performing the behaviour. Therefore, if learners are engaged in the VR training experience, the effectiveness of their learning can be expected to be better than that of those who are not engaged because they are more likely to perform the learned activities in the learning process. Accordingly, we propose the following hypothesis:

H2 Learners' engagement in VR-based learning has a positive relationship with learning effectiveness.

In considering the possibility of a joint relationship, H1 and H2 together set the stage for testing the indirect effects of engagement in VR-based learning on the relationship between the TAM of VR and learning effectiveness. Studies have examined the mediating role of learning engagement in the learning process (e.g. Blasco-Arcas et al. 2013; Hu and Hui 2012). Hu and Hui (2012) found that learning engagement mediates the effect of technology-mediated learning on perceived learning effectiveness. In examining the influence on learning performance of active collaborative learning with hyper-interactive teaching technology, Blasco-Arcas et al. (2013) noted the indirect effects of learning engagement. Similarly, the structural equation modelling (SEM) of Huang et al. (2021) also provided empirical support for the mediating role of cognitive engagement in the relationship between users' VR experience and their learning achievement. This indicates that engagement in learning is an important mediator in explaining the learning process of VR training. Therefore, we propose the following hypotheses:

H3a Learners' engagement in VR-based learning mediates the positive relationships between the perceived usefulness of VR and learning effectiveness.

H3b Learners' engagement in VR-based learning mediates the positive relationships between perceived ease of use of VR and learning effectiveness.

As mentioned in the introduction section, learners' personality affects their learning experience in VR (e.g. Kober and Neuper 2013; Widyanti and Hafizhah 2021). In this study, we further suggest that learners' openness to experience, a widely studied, learning-related personality in Big Five Inventory, may interact with learners' perception of VR and affect their learning engagement and effectiveness.

3.4 Moderation of openness to experience on the VR training process

Extending the TRA (Ajzen and Fishbein 1980; Fishbein, and Ajzen. 1975) and the TAM (Davis 1989), many studies have suggested that personality is an important attribute that affects people's acceptance and use of technology as well as their actual behaviour and performance (Bawack et al. 2021; Devaraj et al. 2008; Wedlock and Trahan 2019). A meta-analytical study also found that attitude and personality tend to moderate behavioural intention (Armitage and Conner 2001; Devaraj et al. 2008). Building on these studies, the moderating roles of personality traits were tested by examining the extent to which the TAM predictors resulted in learners' engagement and learning effectiveness in VR training.

Among the personality traits in the Big Five Inventory (Costa and McCrae 1992), people with greater openness to experience tend to adopt an open attitude and are more willing to try new and different things (Madrid and Patterson 2016). These people are more imaginative, broad-minded, curious, and unconventional, all of which are attributes associated with positive attitudes and motivation for learning (Devaraj et al. 2008; Madrid et al. 2014). Openness to experience has also been conceptualised as the tendency of an individual to favour innovation, exploration, and diversity over convention (Matz 2021; McCrae and Sutin 2009). A meta-analysis conducted by Barrick and Mount (1991) supported this view by identifying the relationship between openness to experience and training proficiency (i.e. learning effectiveness in training).

In this study, we propose that openness to experience plays an important role in reinforcing the effect of the TAM on learning engagement and thus learning effectiveness in VR training. In particular, the connection between a high level of acceptance of VR training and engagement, as well as learning effectiveness, is strengthened when individuals

are highly open to new experiences. Individuals with a high level of openness to experience are more willing to try new and different things, tending to seek out new and varied experiences and embracing change (Matz 2021; Puente-Díaz et al. 2022). Therefore, they are more self-motivated to engage in a new VR training experience based on their positive perception of its usefulness and ease of use, thus facilitating their learning effectiveness. In contrast, although those with a low level of openness to experience perceive VR training as useful and easy, they still have doubts and resist experiencing VR-based learning, leading to reduced engagement and thus weaker learning effectiveness. Accordingly, openness to experience serves as a critical reinforcer that strengthens individuals' learning engagement when they receive VR training. To test the conditional effect of openness to experience on the VR-based learning process, we specifically examined the moderating effect of openness to experience on the relationship between the TAM of VR and learning effectiveness as mediated by learning engagement:

H4a Learners' openness to experience moderates the mediating effect of engagement in VR-based learning on the relationship between learners' perceived usefulness of VR and learning effectiveness.

H4b Learners' openness to experience moderates the mediating effect of engagement in VR-based learning on the relationship between learners' perceived ease of use of VR and learning effectiveness.

The hypothesised model is summarised in Fig. 2.

4 Methodology

4.1 Research design

This study evaluated learners' openness to experience, as well as their perceived usefulness of, perceived ease of use of, and engagement in VR-based learning and the learning effectiveness of adopting VR for training. The study first developed and established a VR CAVE system with three interactive and immersive logistics and transport scenes for teaching and learning. The VR platform with simulation scenes included training on air cargo terminal operations, aircraft cargo loading and maritime port operations. The learning content of the three VR scenes in the training covered an air cargo container that is a ULD, passing through an air cargo terminal, moving from inbound to the terminal, through weighing and customs clearance, storage in material handling systems, transport in a dolly, to loading into an aircraft. Figure 3a shows how VR was used to illustrate the cargo load planning of ULD on the main deck of a 747-8F
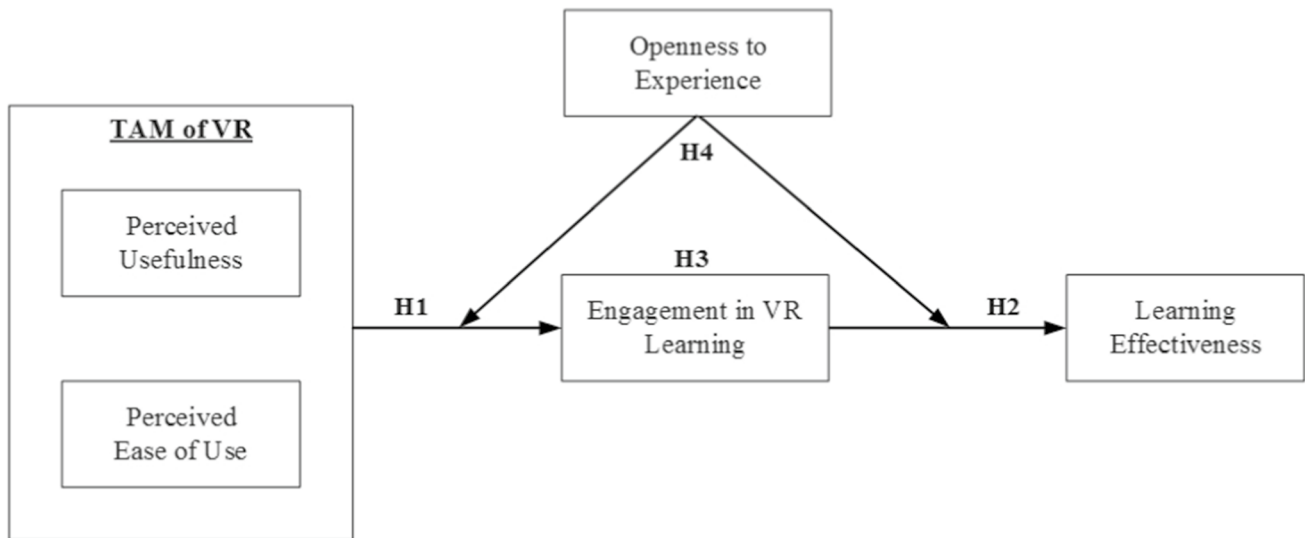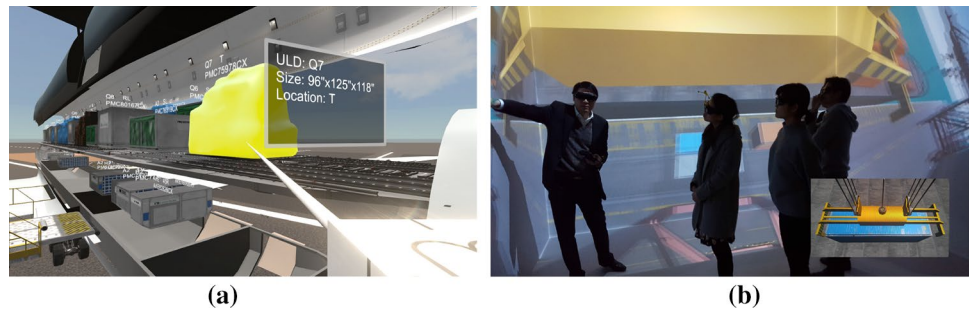
Fig. 2 Summary model of hypothesised relationships. (H = Hypothesis)

Fig. 3 Use of VR to explain and illustrate the functions of facilities in **a** air cargo terminal and **b** quay crane operations in a container terminal

(a)   **(b)**

airfreighter. The ULD and oversize cargo loading operations in an aircraft were then illustrated and explained. The training was then extended to port terminals, with users operating the container loading and discharge operations of a terminal quay crane in a simulated immersive environment (Fig. 3b). The principles of container stowage planning on the vessels were explained with the use of interactive VR scenes.

A pilot study was conducted to examine the model on the interaction of openness to IT experience and the perception of VR-based learning before a comprehensive survey was undertaken. To test the model, a survey was conducted. The sample of 175 respondents who participated in the VR training was divided between students (69%) and full-time practitioners (31%). 2% were younger than 18 years, 69% were between 18 and 25 years, 11% were between 26 and 35 years, 6% were between 36 and 45 years, 10% were between 46 and 60 years, and 2% were older than 60 years. The participants were asked to complete the survey after completing the learning experience on cargo terminals and aircraft operations using the VR platform.

The survey examined three key constructs—openness to IT experience (three items; $\alpha = 0.88$), perception of VR training (five items; $\alpha = 0.90$) and perceived learning effectiveness (three items; $\alpha = 0.94$)—and two demographic variables (i.e. age and occupation). Simple regression showed that both openness to IT experience ($\beta = 0.45$, $p < 0.01$) and perception of VR training ($\beta = 0.47$, $p < 0.01$) were positively associated with the perceived effectiveness of learning. However, their interactive effect on the perceived effectiveness of learning was not significant ($\beta = -0.02$, ns). It was concluded from the pilot study that the design of VR training was appropriate, but the measure of learning effectiveness and the perception of VR training needed improvement. For example, pre-training and post-training performance tests should be incorporated, including multiple-choice questions about the training content, to measure the participants' knowledge before VR training and the actual learning effectiveness after it. Furthermore, the general perception of VR training should be divided into two specific dimensions, namely the perceived usefulness of VR training and perceived ease of use, based upon the TAM (Davis 1989).

After reviewing the results of the pilot study, a comprehensive cross-sectional survey with 92 questions across six sections was compiled, with a measure of five constructs of

psychometric properties, focusing on undergraduate business students. The final sample in this study consisted of 321 undergraduate students at a self-financed university in Hong Kong. The mean age was 20.51 years (SD = 1.00). Most of the students were studying management, supply chain management, and business administration. Forty-nine per cent of the students were majoring in Management, 40.50% of them are studying Supply Chain Management, 6.85% of the students are studying business administration, including Marketing, Accounting, and Finance. The remaining students fall into other disciplines, such as Translation and Journalism. The sample was analysed after the participants completed a questionnaire about their demographic characteristics. The results are shown in Table 1.

The training with the VR platform was part of the curriculum in the students' modules. To assess their knowledge of the subject matter (i.e. supply chain and logistics), the participants were invited to complete a survey measuring their openness to experience (10 items) and a pre-training performance test (five questions) before taking the training with the VR platform. After the VR training, the participants were asked to complete the second part of the survey, which was designed to measure the TAM of VR (i.e. perceived usefulness of VR [four items], perceived ease of use [four items], engagement in VR-based learning [seven items], learning effectiveness [eight questions], and respondents' demographics, including gender, age, and major of study). The survey was conducted in English.

4.2 Research measures

Unless otherwise noted, a 7-point scale (1 = not at all, 7 = to a very great extent) was used in each of the questionnaires described below.

Openness to experience. Before the VR training, the participants were asked to assess their openness to experience with items adopted from John and Srivastava (1999).

The measure consisted of 10 items, such as 'I see myself as someone who is original and comes up with new ideas'. Cronbach's alpha for the measure was 0.81.

Perceived VR usefulness (PU) and perceived ease of VR use (PEU). Both PU and PEU consisted of four items, which were adapted from Davis (1989) and Davis et al. (1989) to reflect the VR training context. An example of a PU item was 'I find VR is useful in my study' (alpha = 0.93), and a PEU example was 'Interacting with VR does not require a lot of mental effort' (alpha = 0.88).

Engagement in VR-based learning. The participants were asked to report their commitment to, involvement with, participation in, and interaction with VR technology using a seven-item measure adapted from PytlikZillig et al. (2011) (e.g. 'VR technology helps me gain a deeper understanding of the concepts presented in class'; alpha = 0.85).

Learning effectiveness. The learning effectiveness of VR training was measured by eight multiple-choice questions about the content after the VR training. A sample question was 'What is the function of dollies in the air cargo terminal? A. To transport passengers to the rampside of the airport; B. To load, transport and unload ULD and cargo pallets; C. To temporarily store unit-load devices and cargo pallets; D. To supply electricity to the movable platform at the rampside of the airport; E. To transfer livestock to the aircraft'. The questions were all designed to assess the knowledge of supply chains, operations management, and logistics that the students had gained via immersion and interaction with the VR scenes. We marked the scores based on the number of correct answers, and the scores ranged from 0 to 8.

Control variables. All of the participants were invited to test their basic knowledge of the training content before starting the VR training. The participants' pre-training test performance, like the evaluation of the learning effectiveness of VR training, was assessed using five multiple-choice questions about the content. The score reflected the number of correct answers to the five questions (from 0 to 5). Other

Table 1 Demographic characteristics of the sample	Characteristics variables	Features	Sample distribution (%)	Number of respondents (*n*)
	Gender	Male	34.00	109
		Female	66.00	212
	Age	≤ 19	6.85	22
		20	55.76	179
		21	25.54	82
		≥ 22	11.83	38
	Major studies	Supply chain management	40.50	130
		Management	49.22	158
		Business administration	6.85	22
		Others	3.43	11

control variables were age and gender. Age was a continuous variable, whereas gender was dummy-coded (female = 0; male = 1).

5 Results

5.1 Descriptive statistics of study variables

Table 2 displays the means, standard deviations, internal consistency reliabilities, and bivariate correlations for the measures used in this study.

5.2 Hypotheses testing

Overall, the hypothesised model was a good fit for the data ($\chi^2(18) = 38.15$, $p < 0.01$, CFI = 0.98, NFI = 0.96, IFI = 0.98,

RMSEA = 0.05). Moreover, when the proposed moderation effects were removed, the overall fit deteriorated significantly ($\chi^2_{\text{diff}}(11) = 20.01$, $p < 0.05$, CFI = 0.95, NFI = 0.94, IFI = 0.95, RMSEA = 0.10). The individual hypotheses are now addressed (see Table 3 and Fig. 4).

H1, covering the direct effect of the TAM of VR on engagement in VR-based learning, was tested with SEM, with age and gender as covariates. The result of SEM showed that perceived usefulness of VR ($\beta = 0.56$, $p < 0.01$) and perceived ease of use ($\beta = 0.12$, $p < 0.05$) had a positive relationship with engagement in VR-based learning. Furthermore, in line with H2, engagement in VR-based learning showed a positive relationship with learning effectiveness ($\beta = 0.41$, $p < 0.01$); therefore, H1 and H2 were both supported.

Consistent with the criteria of Shrout and Bolger (2002), support for H1a, H1b and H2 leaves open the possibility that

Table 2 Descriptive statistics and correlations

Variables	M*	SD*	2	3	4	5	6	7	8	9
Perceived usefulness	5.03	1.00	(.93)							
Perceived ease of use	4.77	.97	.64**	(.88)						
Age	20.51	1.00	.05**	.04**	–					
Gender[a]	.70	.46	−.14**	−.17**	−.19**	–				
Pre-training test performance	3.45	1.21	.03**	.04**	.01**	−.03**	–			
Openness to experience	4.45	.79	.30**	.22**	.06**	−.19**	−.05*	(.81)		
Engagement in VR-based learning	5.06	.97	.65**	.48**	−.02**	−.08**	.05**	.18**	(.85)	
Learning effectiveness	5.43	2.00	.21**	.11**	−.14**	.05**	.21**	−.02**	.27**	–

$n = 321$ (listwise)

[a]Dichotomous variable (0 = Male, 1 = Female)

*$p < .05$, ** $p < .01$, two-tailed

Table 3 Structural equation findings for the hypothesised model (H1–H4)

Variables	Engagement in VR-based learning	Learning effectiveness
Control variables		
Age	−.05**(.04)	−.22**(.11)
Gender	.02**(.09)	.15**(.23)
Pre-training test performance	.02**(.03)	.33**(.08)
Key variables		
Perceived usefulness of VR (PU)	.56**(.06)	.28**(.16)
Perceived ease of use of VR (PEU)	.12**(.06)	−.10**(.14)
Openness to experience (OE)	−.02**(.05)	−.17**(.13)
Engagement (EN)		.41**(.14)
OE * PU	.05**(.06)	.36* (.18)
OE * PEU	−.11**(.07)	−.38* (.16)
OE * EN		−.38* (.17)

$n = 321$. Standardised estimates (based on grand-mean centring) are reported, with standard errors in parentheses
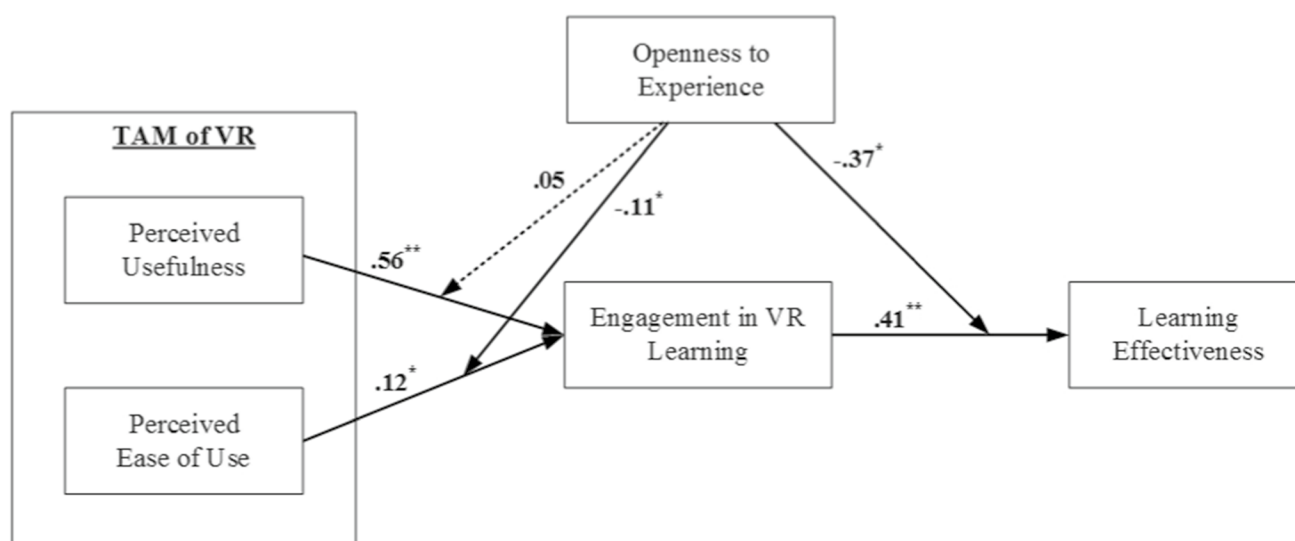
*$p < .05$, two-tailed. ** $p < .01$, two-tailed

Fig. 4 Standardised parameter estimates for the model

Table 4 Engagement in VR-based learning as a mediator of the TAM of VR-learning effectiveness relationships

Bootstrap estimate	TAM of VR[#]			
	Perceived usefulness		Perceived ease of use	
	β	SE	β	SE
Path analysis				
TAM of VR[#] –EN (a path)	.63**	.05	.47**	.05
EN–LE (b path)	.45**	.15	.52**	.13
Total effect (c path)	.41**	.11	.25**	.12
TAM of VR[#] –LE (c' path)	.13**	.15	.01**	.13
Bootstrapping				
Indirect effect	.28**	.10	.24**	.07
Bias Corrected 95% CI (Lower–Upper)	.10**	.51	.13**	.43
F	7.90**		7.73**	
R^2	.12**		.12**	
ΔR^2	.11**		.10**	

TAM of VR = technology acceptance model of virtual reality; EN = engagement in VR-based learning; LE: learning effectiveness; SE = standard error; CI = confidence interval based on 1000 bootstrap samples

Results for perceived usefulness of VR are in the left column, and in the right column for attitude to VR

*$p < .05$, two-tailed. **$p < .01$, two-tailed

engagement in learning mediates the relationship between the TAM of VR (i.e. perceived usefulness of VR and attitude towards VR) and the learning effectiveness of VR training. Table 4 shows the direct and indirect effects (Preacher and Hayes 2004, 2008). In line with H3a, engagement in VR-based learning mediated the relationship between the perceived usefulness of VR and learning effectiveness; the 95%

confidence interval (CI) (0.10 to 0.51) associated with the indirect effect ($\beta = 0.28$, $p < 0.01$) excluded zero. Furthermore, in support of H3b, engagement in VR-based learning mediated the relationship between the perceived ease of use and learning effectiveness; the 95% CI (0.13 to 0.43) associated with the indirect effect ($\beta = 0.24$, $p < 0.01$) excluded zero. Finally, engagement in VR-based learning accounted for 12.25% of the variance in the perceived usefulness of the VR-learning effectiveness relationship and 12.02% of the variance involving the perceived ease of use and learning effectiveness.

Finally, the moderated mediation models predicted in H4 were tested with the approach used by Preacher et al. (2007) (cf. Ng et al. 2008). We used PROCESS model 58, a macro for SPSS that conducts observed-variable moderated mediation analysis (Hayes 2018) to examine the model. This requires the magnitude of the moderated conditional indirect effect of the TAM of VR on learning effectiveness via engagement in VR-based learning to differ across high and low levels of the moderator (i.e. openness to experience). The SEM result showed that openness to experience moderated the positive relationship between the perceived ease of use and engagement in VR-based learning ($\beta = -0.11$, $p < 0.05$), but not the relationship between the perceived usefulness and engagement in VR-based learning ($\beta = 0.04$, *ns*). Therefore, H4b was examined, but not H4a.

For H4b, a moderated mediation effect was found when the interaction between openness to experience and perceived ease of use ($\beta = -0.15$, $p < 0.05$) and the interaction between openness to experience and engagement in VR-based learning ($\beta = -0.37$, $p < 0.01$) moderated the indirect effects of the perceived ease of use on learning effectiveness via engagement in VR-based learning ($\beta = 0.50$, $p < 0.01$)

(see the left-hand side of Table 5). The bottom half of Table 5 (left-hand side) shows that the indirect effect was statistically significant at the mean level (i.e. average openness to experience) and at one standard deviation above the mean (i.e. high openness to experience). This means that engagement in VR-based learning mediated the effects of the perceived ease of use on learning effectiveness when the participants' openness to experience was average to high. At one standard deviation below the mean level (i.e. low openness to experience), the indirect effect was not statistically significant, which means that engagement in VR-based learning did not mediate the effects of the perceived ease of use on learning effectiveness when the participants' openness to experience was low. It was concluded that learners with a moderate-to-high level of openness to experience who perceived VR as easy to use therefore showed greater engagement in VR-based learning than those with average to high openness to experience who perceived VR as being difficult to use. However, for learners with low openness to experience, engagement in VR-based learning did not mediate the effects of the perceived ease of use on learning effectiveness (see Fig. 5).

Furthermore, a moderated mediation effect was also found when the interaction of openness to experience with engagement in VR-based learning ($\beta = -0.37$, $p < 0.01$) moderated the indirect effect of the perceived usefulness of VR on learning effectiveness via engagement in VR-based learning ($\beta = 0.40$, $p < 0.01$) (see the right-hand side of Table 5). As shown in the bottom half of Table 5 (right-hand side), the indirect effect is statistically significant at the mean level (i.e. average openness to experience) and at one standard deviation above the mean (i.e. high openness to experience). This indicates that engagement in learning mediated the effects of the perceived usefulness of VR on learning effectiveness when the participants' openness to experience was average to high. At one standard deviation below the mean level (i.e. low openness to experience), the indirect effect was not statistically significant, which means that engagement in VR-based learning did not mediate the effects of the perceived usefulness of VR on learning effectiveness when the participants' openness to experience was low. It was concluded that learners with a moderate-to-high level of openness to experience who perceived VR as useful show greater engagement in VR-based learning than those with an average-to-high level of openness to experience who perceive VR as not useful. However, for learners with a low level of openness to experience, engagement in VR-based learning did not mediate the effects of the perceived usefulness of VR on learning effectiveness (see Fig. 5). Overall, H4b was supported, but H4a was not.

Table 5 Moderated mediated results for learning effectiveness across levels of openness to experience (for PEU of VR)

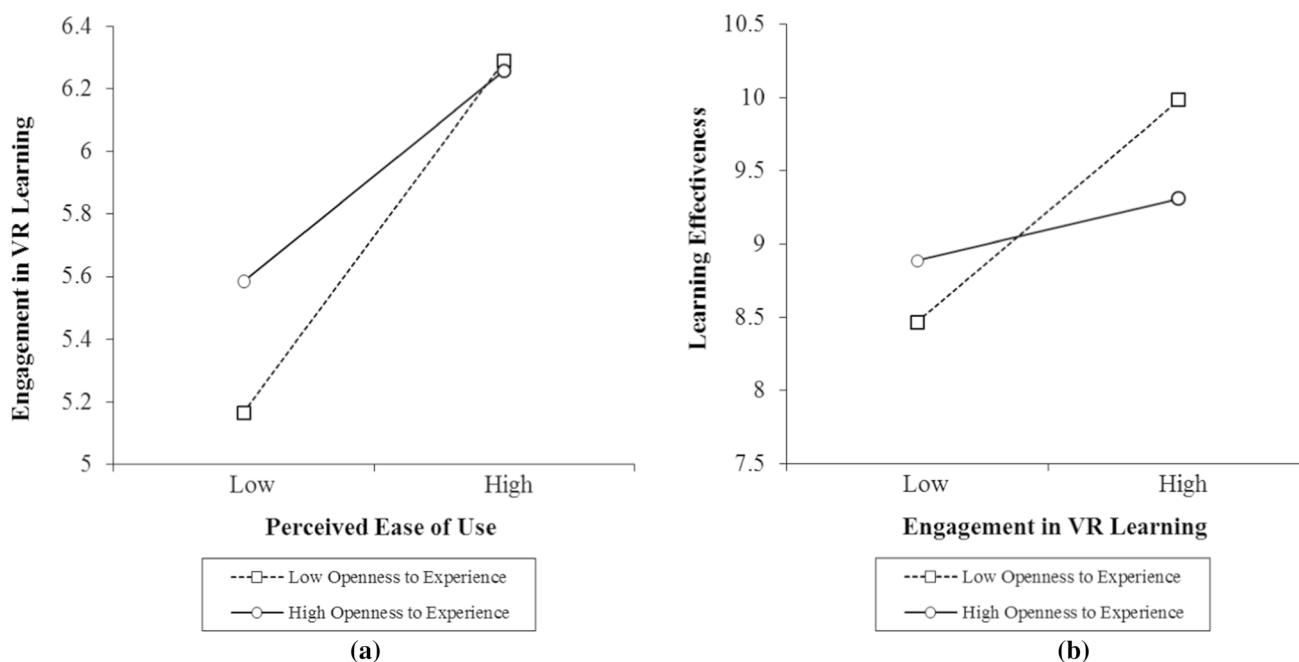|	Engagement in VR-based learning			Learning effectiveness		
	β	SE	t	β	SE	t
Control variables						
Age	−.03**	.05**	−.69**	−.23**	.11**	−2.13**
Gender	−.00**	.11**	−.06**	.05**	.25**	.22**
Pre-training Test Performance	.00**	.04**	.06**	.31**	.09**	3.32**
Key variables						
Perceived Ease of Use of VR (PEU)	.46**	.05**	8.74**	.00**	.13**	.04**
Openness to Experience (OE)	.12**	.07**	1.85**	.77**	.72**	2.45**
Moderation effects						
OE * PEU	−.15**	.06**	−2.50**			
OE * EN				−.37**	.14**	−2.63**
Mediation effects						
Engagement in VR-based learning (EN)				.50**	.13**	3.92**
ΔR^2	.02**			.02**		
R^2	.25**			.14**		
Moderator	Conditional Indirect effect	SE	Z	Conditional Indirect effect	SE	Z
−1 *SD* OE (−.75)	.57**	.07**	7.87**	.78**	.16**	4.92**
Mean OE (0)	.47**	.05**	8.81**	.52**	.13**	4.08**
+1 *SD* OE (.75)	.35**	.06**	5.46**	.23**	.17**	1.33**

*p < .05. **p < .01

Fig. 5 Moderation effects of openness to experience on **a** perceived ease of use-engagement in VR-based learning and **b** engagement in VR-based learning–learning effectiveness relationships

6 Discussion and implications

This study enriches the knowledge of what determines the learning effectiveness of VR training, especially in an educational setting. Our study presents a novel pedagogical conceptualisation of learning the management of complex operations, supply chains, and logistics using an immersive and interactive VR platform. Based on the TAM3 (Davis 1989; Venkatesh and Bala 2008), the findings advance our understanding of the adaptation process of VR training by first exploring the effects of an individual intrinsic factor.

(i.e. openness to IT experience) on the perceived usefulness and ease of use of VR training and thus the individual's attitude towards learning. Exploring these relationships also helps bridge the gap inherent in using theories of management psychology to explain the effectiveness of technology-based learning. As scholars have noted, theories about learning and psychology have rarely been considered in developing VR applications to enhance learning outcomes (Radianti et al. 2020). The literature on the Big Five personality traits has been incorporated into the TAM3 to regulate the level of engagement in learning and its consequent learning outcomes. Building on the TAM3, we specifically examined the moderating role played by a major individual trait in the mediation relationship and revealed that individuals with a greater willingness to accept new experiences are better able to adapt to new forms of learning, such as VR technology-mediated training. This finding is consistent with previous studies of the Big Five personality traits in the

management literature, in which openness to experience is crucial in determining an individual's learning effectiveness (Chow 2018; DeYoung et al. 2014; Kaufman et al. 2010).

The present study also examined the important role of the perceived usefulness of VR training in the learning process. According to the TAM3, the perception of the usefulness of technology mediates the relationship between individual differences and behavioural intention in learning. Furthermore, Calisir et al. (2014) and Venkatesh and Bala (2008) indicated that perceived usefulness is the strongest predictor of the behavioural intention to adopt a new learning practice. In this study, the perceived usefulness of VR training helped explain why people with a high level of openness to IT experience learned better than those with a low level of openness to IT experience. Thus, it was found that because people with a high level of openness to IT experience held a more positive view of VR training, they engaged more in the learning process of VR training, which in turn led to a more positive perception of learning, particularly in a specific subject matter.

The findings of this study have valuable implications for educators, corporate trainers, and managers about using VR training to develop human resources. First, to maximise the learning effectiveness of VR training, it is recommended that teachers and trainers prepare learners by ensuring they have an open mindset before the training event. Jackson et al. (2012a, b) demonstrated that openness to experience can be enhanced through cognitive training, such as instruction in inductive reasoning, crossword and Sudoku puzzles, and

coaching (Hui et al. 2013, 2019). Enhancing learners' openness to experience through these cognitive training would strengthen learners' engagement in learning which further leads to better knowledge acquisition and skills development in VR training. Second, educators, corporate trainers, and managers should brief trainees on the value and usefulness of VR training. They should explain how the content relates to their studies, to their work, and to attaining their goals, and how VR training can benefit their learning effectiveness when compared with traditional methods, especially in working environments that involve tough safety and security requirements or sophisticated operations procedures. A briefing can enhance the usefulness learners perceive in the VR training, thus heightening their engagement and the effectiveness of their learning.

7 Conclusion

The increasing use of VR technology and its applications in education obliges educators to understand the effectiveness of training using VR and the challenges to adopting VR systems, as well as the importance of user acceptance and attitudes towards new pedagogical teaching methods. In this study, we used the novel pedagogical development of VR immersive and interactive scenes to illustrate the cargo loading operations of aircraft, an air cargo terminal, and a port terminal. The results showed that individuals' intrinsic factors, including openness to IT experience, influenced their perceived usefulness of VR training and attitudes towards learning. With reference to the TAM3, by measuring learners' attitudes towards the use of VR in learning, we revealed that the participants who were open to new experiences in the use of IT scored higher in the usefulness they perceived in VR training and showed a more positive attitude towards learning. The findings were also consistent with the Big Five personality management theories, in which openness to experience is a crucial personal trait that determines an individual's learning effectiveness.

The findings of this study should be considered in light of several major limitations. Given our limited resources, the training content in the VR platform was developed containing several important scenes of cargo operations but did not reflect everything that can occur in a working environment. More examples of how to handle exceptions could be incorporated into the platform to help users understand and practise the required skills. Another limitation was that most of the respondents were young. Further studies could be carried out with a wider age range. In the survey, most of the data were collected at the same time and the cross-sectional design did not permit the examination of causality among the variables. Accordingly, future research could address the question of causality by examining personality,

perceptions, behaviours, and learning effectiveness in a longitudinal setting.

This study focused exclusively on one of the Big Five traits—openness to experience—and examined its effect on the learning effectiveness of VR training. Research has indicated that other Big Five traits are also related to learning (e.g. Katrimpouza et al. 2019; Tabatabaei et al. 2018). Further research could explore whether individual differences, such as other Big Five traits (i.e. conscientiousness, emotional stability, extraversion, and agreeableness) (Busato et al. 1998; Komarraju et al. 2011), moderate the learning effectiveness of VR training (Chang 2005; Haji et al. 2016). Future studies could examine the use of VR in learning how to act in complex problem-solving situations in cargo terminal and aircraft load planning operations. Furthermore, the literature has shown that situational factors, such as the complexity of the learning task and learners' expertise (Hui et al. 2013, 2019), may moderate learning effectiveness. Therefore, future research could also explore the effects of different situational factors on the learning effectiveness of VR training, as well as of individual differences. The complexity of VR-based learning could also be enhanced with the further grade of VR systems that could support collaborative and team learning.

Declarations

References

Abulrub AHG, Attridge AN, Williams MA (2011) Virtual reality in engineering education: the future of creative learning. In: 2011 IEEE global engineering education conference (EDUCON), pp 751–757

Aiken MP, Berry MJ (2015) Posttraumatic stress disorder: possibilities for olfaction and virtual reality exposure therapy. Virtual Real. https://doi.org/10.1007/s10055-015-0260-x

Ajzen I, Fishbein M (1980) Understanding attitudes and predicting social behavior. Prentice-Hall, Englewood Cliffs, NJ

Akbulut A, Catal C, Yildiz B (2018) On the effectiveness of virtual reality in the education of software engineering. Comput Appl Eng Educ 26(4):918–927

Alsop T (2022a) Augmented reality (AR), virtual reality (VR), and mixed reality (MR) market size worldwide in 2021 and 2028. Statista. https://www.statista.com/statistics/591181/global-augmented-virtual-reality-market-size/. Accessed 30 October 2022a

Alsop T (2022b) Investment in augmented and virtual reality (AR/VR) technology worldwide in 2024, by use case. Statista. https://www.statista.com/statistics/1098345/worldwide-ar-vr-investment-use-case/. Accessed 30 October 2022b

Armitage CJ, Conner M (2001) Efficacy of the theory of planned behaviour: a meta-analytic review. Br J Soc Psychol 40(4):471–499

Bandura A, Cervone D (1983) Self-evaluative and self-efficacy mechanisms governing the motivational effects of goal systems. J Pers Soc Psychol 45:1017–1028

Barrick MR, Mount MK (1991) The big five personality dimensions and job performance: a meta-analysis. Pers Psychol 44(1):1–26

Bawack RE, Wamba SF, Carillo KDA (2021) Exploring the role of personality, trust, and privacy in customer experience performance during voice shopping: evidence from SEM and fuzzy set qualitative comparative analysis. Int J Inform Manag. https://doi.org/10.1016/j.ijinfomgt.2021.102309

Beach LR, Mitchell TR (1978) A contingency model for the selection of decision strategies. Acad Manag Rev 3:439–449

Bertrand M, Bouchard S (2008) Applying the technology acceptance model to VR with people who are favorable to its use. J Cyber Ther Rehabil 1(2):200

Birrenbach T, Zbinden J, Papagiannakis G, Exadaktylos AK, Müller M, Hautz WE, Sauter TC (2021) Effectiveness and utility of virtual reality simulation as an educational tool for safe performance of COVID-19 diagnostics: prospective, randomized pilot trial. JMIR Serious Games 9(4):e29586

Blasco-Arcas L, Buil I, Hernández-Ortega B, Sese FJ (2013) Using clickers in class. The role of interactivity, active collaborative learning and engagement in learning performance. Comput Educ 62:102–110

Bourhim EM, Cherkaoui A (2020) Efficacy of virtual reality for studying people's pre-evacuation behavior under fire. Int J Hum Comput Stud 142:102484

Bracq MS, Michinov E, Jannin P (2019) Virtual reality simulation in nontechnical skills training for healthcare professionals: a systematic review. Simul Healthc 14(3):188–194

Brooks FP (1999) What's real about virtual reality? IEEE Comput Gr Appl 19(6):16–27

Burmester A, Burmester F, Reiners T (2008) Virtual environment for immersive learning of container logistics. In: EdMedia+ Innovate learning. Association for the advancement of computing in education (AACE), pp 5843–5852

Busato VV, Prins FJ, Elshout JJ, Hamaker C (1998) The relation between learning styles, the big five personality traits and achievement motivation in higher education. Personal Individ Differ 26(1):129–140

Calisir F, Altin Gumussoy C, Bayraktaroglu AE, Karaali D (2014) Predicting the intention to use a web-based learning system: perceived content quality, anxiety, perceived system quality, image, and the technology acceptance model. Hum Factors Ergon Manuf Serv Ind 24(5):515–531

Chang SE (2005) Computer anxiety and perception of task complexity in learning programming-related skills. Comput Hum Behav 21(5):713–728

Chang CW, Heo J, Yeh SC, Han HY, Li M (2018a) The effects of immersion and interactivity on college students' acceptance of a novel VR-supported educational technology for mental rotation. IEEE Access 6:66590–66599

Chang SC, Hsu TC, Chen YN, Jong MSY (2018b) The effects of spherical video-based virtual reality implementation on students' natural science learning effectiveness. Interactive learning environments, pp 1–15

Chen PSD, Lambert AD, Guidry KR (2010) Engaging online learners: the impact of web-based learning technology on college student engagement. Comput Educ 54(4):1222–1232

Chen LW, Tsai JP, Kao YC, Wu YX (2019) Investigating the learning performances between sequence and context-based teaching designs for virtual reality (VR)-based machine tool operation training. Comput Appl Eng Educ 27(5):1043–1063

Chirieleison Jr A, Chirieleison Sr T, 2004. U.S. Patent No. 6,744,436. Washington, DC: U.S. Patent and trademark office, 2004

Chow IHS (2018) The mechanism underlying the empowering leadership-creativity relationship. Leadersh Org Dev J 39(2):202–217

Chow M, Herold DK, Choo TM, Chan K (2012) Extending the technology acceptance model to explore the intention to use second life for enhancing healthcare education. Comput Educ 59(4):1136–1144

Costa PT, Jr McCrae RR (1992) Revised NEO personality inventory and NEO five-factor inventory: professional manual. Odessa, FL: psychological assessment resources

Cruz-Neira C, Sandin DJ, DeFanti TA, Kenyon RV, Hart JC (1992) The cave: audio visual experience automatic virtual environment. Commun ACM 35(6):64–73

Czernuszenko M, Pape D, Sandin D, DeFanti T, Dawe GL, Brown MD (1997) The immersadesk and infinity wall projection-based virtual reality displays. ACM SIGGRAPH Comput Gr 31(2):46–49

Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q 13(3):319–340

Davis FD, Bagozzi RP, Warshaw PR (1989) User acceptance of computer technology: a comparison of two theoretical models. Manag Sci 35(8):982–1003

Davis FD (1986) A technology acceptance model for empirically testing new end-user information systems: theory and results. Doctoral dissertation, MIT Sloan school of management, Cambridge, MA

Demiralp C, Jackson CD, Karelitz DB, Zhang S, Laidlaw DH (2006) Cave and fishtank virtual-reality displays: a qualitative and quantitative comparison. IEEE Trans Visual Comput Gr 12(3):323–330

Devaraj S, Easley RF, Crant JM (2008) Research note—how does personality matter? Relating the five-factor model to technology acceptance and use. Inf Syst Res 19(1):93–105

DeYoung CG, Lena CQ, Jordan BP, Jeremy RG (2014) Openness to experience, intellect, and cognitive ability. J Pers Assess 96(1):46–52

Ding D, Brinkman WP, Neerincx MA (2020) Simulated thoughts in virtual reality for negotiation training enhance self-efficacy and knowledge. Int J Hum Comput Stud 139:102400

Duderstadt JJ, Atkins DE, Van Houweling DE, Van Houweling D (2002) Higher education in the digital age: technology issues and strategies for American colleges and universities. Greenwood Publishing Group, USA

Durodolu OO (2016) Technology acceptance model as a predictor of using information systems to acquire information literacy skills. Library philosophy and practice

Fishbein M, Ajzen I (1975) Belief, attitude, intention and behavior: an introduction to theory and research. Addison-Wesley, Reading, MA

Fredricks JA, Blumenfeld PC, Paris AH (2004) School engagement: potential of the concept, state of the evidence. Rev Educ Res 74:59–109. https://doi.org/10.3102/00346543074001059

Fussell SG, Truong D (2021) Using virtual reality for dynamic learning: an extended technology acceptance model. Virtual Real. https://doi.org/10.1007/s10055-021-00554-x

Gao L, Wan B, Liu G, Xie G, Huang J, Meng G (2021) Investigating the effectiveness of virtual reality for culture learning. Int J Hum-Comput Interact 37(18):1771–1781

Guan JQ, Wang LH, Chen Q, Jin K, Hwang GJ (2021) Effects of a virtual reality-based pottery making approach on junior high school students' creativity and learning engagement. Interact Learn Environ. https://doi.org/10.1080/10494820.2021.1871631

Guo Z, Zhou D, Chen J, Geng J, Lv C, Zeng S (2018) Using virtual reality to support the product's maintainability design: immersive maintainability verification and evaluation system. Comput Ind 101:41–50

Haji FA, Cheung JJ, Woods N, Regehr G, Ribaupierre S, Dubrowski A (2016) Thrive or overload? The effect of task complexity on novices' simulation-based learning. Med Educ 50(9):955–968

Hamilton D, McKechnie J, Edgerton E, Wilson C (2021) Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design. J Comput Educ 8(1):1–32

Han HC (2015) Teaching visual learning through virtual world: why do we need a virtual world for art education? Art Educ 68(6):22–27

Hayes AF (2018) Introduction to mediation, moderation, and conditional process analysis: a regression-based approach, 2nd edn. Guilford Publications, New York

Heilig M (1962). Sensorama simulator, United States patent and trade office, Virginia, USA, US-3,050,870, 1962

Hilfert T, König M (2016) Low-cost virtual reality environment for engineering and construction. Vis Eng. https://doi.org/10.1186/s40327-015-0031-5

Horowitz K, Sega VR (2004) Great idea or wishful thinking. In: Sega-16 Forum, 28/12/2004

Hu PJH, Hui W (2012) Examining the role of learning engagement in technology-mediated learning and its effects on learning effectiveness and satisfaction. Decis Support Syst 53(4):782–792

Huang HM, Rauch U, Liaw SS (2010) Investigating learners' attitudes toward virtual reality learning environments: based on a constructivist approach. Comput Educ 55(3):1171–1182

Huang W, Roscoe RD, Johnson-Glenberg MC, Craig SD (2021) Motivation, engagement, and performance across multiple virtual reality sessions and levels of immersion. J Comput Assist Learn 37(3):745–758

Huang YC, Han SR (2014). An immersive virtual reality museum via second life. In: International conference on human-computer interaction, Springer international publishing, 2014, June, pp 579–584

Huang HM, Liaw SS (2018) An analysis of learners' intentions toward virtual reality learning based on constructivist and technology acceptance approaches. International review of research in open and distributed learning, 19(1)

Hui RTY, Sue-Chan C, Wood RE (2013) The contrasting effects of coaching style on task performance: the mediating roles of subjective task complexity and self-set goal. Hum Resour Dev Q 24(4):429–458

Hui RTY, Sue-Chan C, Wood RE (2019) Performing versus adapting: how leader's coaching style matters in Hong Kong. Int J Hum Resour Manag. https://doi.org/10.1080/09585192.2019.1569547

Izard SG, Juanes JA, Peñalvo FJG, Estella JMG, Ledesma MJS, Ruisoto P (2018) Virtual reality as an educational and training tool for medicine. J Med Syst 42(3):50

Jackson JJ, Hill PL, Payne BR, Roberts BW, Stine-Morrow EA (2012a) Can an old dog learn (and want to experience) new tricks? Cognitive training increases openness to experience in older adults. Psychol Aging 27(2):286–292

Jena RK (2016) Investigating the interrelation between attitudes, learning readiness, and learning styles under virtual learning environment: a study among Indian students. Behav Inform Technol 35(11):946–957

John O P, Srivastava S (1999) The big-five trait taxonomy: history, measurement, and theoretical perspectives. In: Pervin LA, John OP, Handbook of personality, New York: Guilford, pp 102–38

Jou M, Wang J (2013) Investigation of effects of virtual reality environments on learning performance of technical skills. Comput Hum Behav 29(2):433–438

Kalantari M, Rauschnabel P (2018) Exploring the early adopters of augmented reality smart glasses: the case of microsoft HoloLens. In: Augmented reality and virtual reality, Springer, Cham, pp 229–245

Kapoor K, Singh A (2022) Veterinary anatomy teaching from real to virtual reality: an unprecedented shift during COVID-19 in socially distant era. Anat Histol Embryol 51(2):163–169

Katrimpouza A, Tselios N, Kasimati MC (2019) Twitter adoption, students' perceptions, big five personality traits and learning outcome: lessons learned from 3 case studies. Innov Educ Teach Int 56(1):25–35

Kaufman SB, DeYoung CG, Gray JR, Jim´enez L, Brown J, Mackintosh NJ (2010) Implicit learning as an ability. Cognition 116(2010):321–340

Kaufmann H, Schmalstieg D (2006) Designing immersive virtual reality for geometry education. In: IEEE virtual reality conference (VR 2006). IEEE, pp 51–58

Kober SE, Neuper C (2013) Personality and presence in virtual reality: does their relationship depend on the used presence measure? Int J Hum-Comput Interact 29(1):13–25

Komarraju M, Karau SJ, Schmeck RR, Avdic A (2011) The big five personality traits, learning styles, and academic achievement. Personal Individ Differ 51(4):472–477

Krueger MW, Gionfriddo T, Hinrichsen K (1985) VIDEOPLACE—an artificial reality In: ACM SIGCHI Bull. 16(4): 35–40

Lanier J (1989) Plenary address on virtual reality. Proceedings of UISE: the annual ACM SIGGRAPH symposium on user interface software and technology

Lau H, Chan L, Wong R (2007) A virtual container terminal simulator for the design of terminal operation. Int J Interact Des Manuf 1(2):107–113

Lau HYK, Chan LKY, Wong RHK (2009) A VR-based visualization framework for effective information perception and cognition. Human-Computer Systems Interaction: Backgrounds and Applications, pp 313–332

Lee EL, Wong KW, Fung CC (2009) Learning effectiveness in a desktop virtual reality-based learning environment

Lee EAL, Wong KW, Fung CC (2010) Learning with virtual reality: its effects on students with different learning styles. In: Transactions on edutainment IV. Springer, Berlin, Heidelberg, pp 79–90

Li S, Huang Y, Tri VS, Elvek J, Wan S, Kjallstrom J, Lejerskar D (2014) Interactive theatre-sized dome design for edutainment and immersive training. In: Proceedings of the 2014 virtual reality international conference. ACM, p 8

Limniou M, Roberts D, Papadopoulos N (2008) Full immersive virtual environment CAVE TM in chemistry education. Comput Educ 51(2):584–593

Lohre R, Wang JC, Lewandrowski KU, Goel DP (2020) Virtual reality in spinal endoscopy: a paradigm shift in education to support spine surgeons. J Spine Surg 6(Suppl 1):S208

Luckey P (2013) Building a sensor for low latency virtual reality—Oculus Rift-virtual reality headset for 3d gaming, 2013

Luo H, Li G, Feng Q, Yang Y, Zuo M (2021) Virtual reality in K-12 and higher education: a systematic review of the literature from 2000 to 2019. J Comput Assist Learn 37(3):887–901

Lyons FA (2016) U.S. Patent no. D751,072. Washington, DC: U.S. patent and trademark office, 2016

Madrid HP, Patterson MG (2016) Creativity at work as a joint function between openness to experience, need for cognition and organizational fairness. Learn Individ Differ 51:409–416

Madrid HP, Patterson MG, Birdi KS, Leiva PI, Kausel EE (2014) The role of weekly high-activated positive mood, context, and personality in innovative work behavior: a multilevel and interactional model. J Organ Behav 35(2):234–256

Martin J, Bohuslava J (2018) Augmented reality as an instrument for teaching industrial automation. In: 2018 Cybernetics and Informatics (KandI). IEEE, pp 1–5

Massei M, Tremori A, Poggi S, Nicoletti L (2013) HLA-based real time distributed simulation of a marine port for training purposes. Int J Simul Process Modell 8(1):42–51

Matsas E, Vosniakos GC, Batras D (2018) Prototyping proactive and adaptive techniques for human-robot collaboration in manufacturing using virtual reality. Robot Comput-Integr Manuf 50:168–180

Matz SC (2021) Personal echo chambers: openness-to-experience is linked to higher levels of psychological interest diversity in large-scale behavioral data. J Pers Soc Psychol 121(6):1284–1300

McCrae RR, Sutin AR (2009) Openness to experience. In: Leary MR, Hoyle RH (eds) Handbook of individual differences in social behavior. The Guilford Press, pp 257–273

Müller D, Bruns FW, Erbe HH, Robben B, Yoo YH (2007) Mixed reality learning spaces for collaborative experimentation: a challenge for engineering education and training. Int J Online Eng 3(4):15–19

Murphy M (2016) Google cardboard, oculus rift or microsoft hololens: which firm is trademarking the most VR inventions? Techworld

Ng KY, Ang S, Chan KY (2008) Personality and leader effectiveness: a moderated mediation model of leadership self-efficacy, job demands, and job autonomy. J Appl Psychol 93(4):733–743

North MM, North SM (2016) A comparative study of sense of presence of traditional virtual reality and immersive environments. Australas J Inform Syst https://doi.org/10.3127/ajis.v20i0.1168

Ott M, Freina L (2015) A literature review on immersive virtual reality in education: state of the art and perspectives. In: Conference proceedings of eLearning and Software for Education (eLSE). Universitatea Nationala de Aparare Carol I. L, vol 01, pp 133–14

Parker E, Saker M (2020) Art museums and the incorporation of virtual reality: examining the impact of VR on spatial and social norms. Convergence 26(5–6):1159–1173

Petrov C (2019) 35 Virtual reality statistics that will rock the market in 2019. Techjury. https://techjury.net/stats-about/virtual-reality/#gref. Accessed 14 November 2019

Preacher KJ, Hayes AF (2004) SPSS and SAS procedures for estimating indirect effects in simple mediation models. Behav Res Methods Instrum Comp 36:717–731

Preacher KJ, Hayes AF (2008) Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. Behav Res Methods 40:879–891

Preacher KJ, Rucker DD, Hayes AF (2007) Addressing moderated mediation hypotheses: theory, methods, and prescriptions. Multivar Behav Res 42(1):185–227

Puente-Díaz R, Cavazos-Arroyo J, Puerta-Sierra L, Vargas-Barrera F (2022) The contribution openness to experience and its two aspects to the explanation of idea generation, evaluation and selection: a metacognitive perspective. Personal Individ Differ 185:111240

PytlikZillig LM, Horn CA, Bruning R, Bell S, Liu X, Siwatu KO, Bodvarsson MC, Kim D, Carlson D (2011) Face-to-face versus computer-mediated discussion of teaching cases: impacts on pre-service teachers' engagement, critical analyses, and self-efficacy. Contemp Educ Psychol 36(4):302–312

Radianti J, Majchrzak TA, Fromm J, Wohlgenannt I (2020) A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda. Comput Educ 147:103778

Rasimah CMY, Ahmad A, Zaman HB (2011) Evaluation of user acceptance of mixed reality technology. Australas J Educ Technol 27(8)

Reznek MA, Rawn CL, Krummel TM (2002) Evaluation of the educational effectiveness of a virtual reality intravenous insertion simulator. Acad Emerg Med 9(11):1319–1325

Rovira A, Slater M (2017) Reinforcement learning as a tool to make people move to a specific location in immersive virtual reality. Int J Hum Comp Stud 98:89–94

Russell JE, Van Horne S, Ward AS, Bettis EA III, Sipola M, Colombo M, Rocheford MK (2016) Large lecture transformation: adopting evidence-based practices to increase student engagement and performance in an introductory science course. J Geosci Edu 64(1):37–51

Sampaio AZ, Martins OP (2014) The application of virtual reality technology in the construction of bridge: the cantilever and incremental launching methods. Autom Constr 37(2014):58–67

Shrout PE, Bolger N (2002) Mediation in experimental and nonexperimental studies: new procedures and recommendations. Psychol Methods 7(4):422

Soffer T, Nachmias R (2018) Effectiveness of learning in online academic courses compared with face-to-face courses in higher education. J Comput Assist Learn 34(5):534–543

Soliman M, Pesyridis A, Dalaymani-Zad D, Gronfula M, Kourmpetis M (2021) The application of virtual reality in engineering education. Appl Sci 11(6):2879

Song H, Kim T, Kim J, Ahn D, Kang Y (2021) Effectiveness of VR crane training with head-mounted display: double mediation of presence and perceived usefulness. Autom Constr. https://doi.org/10.1016/j.autcon.2020.103506

Sterling R (2008) JVC D-ILA high resolution, high contrast projectors and applications. In: Proceedings of the 2008 workshop on immersive projection technologies/emerging display technologies. ACM, p 10

Tabatabaei SS, Vaziri E, Towhidi A (2018) Structural analysis of the effects of personality factors on academic achievement: mediation of coping strategies and college learning effectiveness. Educ Psychol 13(46):49–75

Tarr MJ, Warren WH (2002) Virtual reality in behavioral neuroscience and beyond. Nat Neurosci 5(2002):1089–1092

Time (2016) The 25 best inventions of 2016. Time Tech. http://time.com/4572079/best- inventions-2016/. Accessed 16 October 2018

Trentsios P, Wolf M, Gerhard D (2020) Comparing virtual reality SDK potentials for engineering education. In: International conference on remote engineering and virtual instrumentation, Springer, Cham, pp 375–392

Vasileva S, Petrova T (2019) Virtual reality development and the socialization of Bulgarian cultural heritage. J Int Coop Develop 2(1):34–39

Venkatesh V, Bala H (2008) Technology acceptance model 3 and a research agenda on interventions. Decis Sci 39(2):273–315

Wang P, Wu P, Wang J, Chi HL, Wang X (2018) A critical review of the use of virtual reality in construction engineering education and training. Int J Environ Res Public Health 15(6):1204

Wedlock BC, Trahan MP (2019) Revisiting the unified theory of acceptance and the use of technology (UTAUT) model and scale: an empirical evolution of educational technology. Res Issues Contemp Educ 4(1):6–20

Widyanti A, Hafizhah HN (2021) The influence of personality, sound, and content difficulty on virtual reality sickness. Virtual Real. https://doi.org/10.1007/s10055-021-00525-2

Won J, Choi Y, Kim YS (2021) A study on the effective education in metaverse platform: case of South Korea. J Posit Psychol Wellbeing 5(3):578–586

Wong EYC, Mo DY, So S (2020) Closed-loop digital twin system for air cargo load planning operations. Int J Comput Integr Manuf. https://doi.org/10.1080/0951192X.2020.1775299

Xi N, Chen J, Gama F, Riar M, Hamari J (2022) The challenges of entering the metaverse: an experiment on the effect of extended reality on workload. Inform Syst Front. https://doi.org/10.1007/s10796-022-10244-x

Xu M, Niyato D, Kang J, Xiong Z, Miao C, Kim DI (2021) Wireless edge-empowered metaverse: a learning-based incentive mechanism for virtual reality. arXiv preprint arXiv:2111.03776

Zhang X, Jiang S, Ordóñez de Pablos P, Lytras MD, Sun Y (2017) How virtual reality affects perceived learning effectiveness: a task–technology fit perspective. Behav Inform Technol 36(5):548–556

Zhang M, Shu L, Luo X, Yuan M, Zheng X (2022) Virtual reality technology in construction safety training: extended technology acceptance model. Autom Constr. https://doi.org/10.1016/j.autcon.2021.104113

Zimmermann P (2008) Virtual reality aided design. A survey of the use of VR in automotive industry. Product engineering, pp 277–296