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Exploring the user experience of three-dimensional virtual learning environments

Dong-Hee Shin[a]*, Frank Biocca[b] and Hyunseung Choo[c]

[a]*Department of Interaction Science, Sungkyunkwan University, 90327 International Hall, 53 Myeongnyun-dong 3-ga, Jongno-gu, Seoul 110-745, South Korea;* [b]*Syracuse University, Syracuse, New York, USA;* [c]*Department of Information and Computer Science, Sungkyunkwan University, Seoul, Korea*

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This study examines the users' experiences with three-dimensional (3D) virtual environments to investigate the areas of development as a learning application. For the investigation, the modified technology acceptance model (TAM) is used with constructs from expectation-confirmation theory (ECT). Users' responses to questions about cognitive perceptions and continuous use were collected and analysed with factors that were modified from TAM and ECT. Whilst the findings confirm the significant roles by users' cognitive perceptions, the findings also shed light on the possibility of 3D application serving as an enabler of learning tools. In the extended model, the moderating effects of confirmation/satisfaction and demographics of the relationships amongst the variables were found to be significant.

Keywords: immersion; presence; 3D; virtual environment; learning system

1. Introduction

A virtual environment is a genre of online community that takes the form of computer-based simulated environment, through which users can interact with one another (Bishop 2009). Recently, the term has become largely synonymous with interactive three-dimensional (3D) virtual environments, where the users take the form of avatars visible to others graphically. These avatars are usually depicted as textual, two-dimensional or three-dimensional graphical representations, although other forms are possible. Recently, 3D virtual environments have been readily adopted in instructional settings where students can learn, create, explore and gather information collaboratively and individually.

Many 3D virtual learning applications have been rapidly developing for a highly interactive, immersive, multi-modal and connected system. One of such applications today is 3D-enabled virtual learning environments (3DVLEs). Although there is widespread enthusiasm about 3D technologies, skeptics consider it to be a gimmick or, at best, an immature technology. Despite rising concerns over usability and marketability, 3D viability issues have been addressed in only a few research articles (Yoon *et al.* 2008). A 3D technology would presumably allow education professionals to transmit their lectures to geographically dispersed students (Kapp and O'Driscoll 2010). Although 3D technology would not be universally applicable for all educational contexts, it may prove particularly useful for distance learning applications, such as the ubiquitous campus (u-campus) and e-learning. Thus, a 3D technology may prove to be quite useful in learning applications, but acceptance will depend on how well the user interface supports particular educational contexts.

Applying 3D technologies in learning contexts, there remain unanswered questions as to how users feel about 3DVLEs, what are the user experiences of 3DVLEs in education and what will lead users to engage in 3DVLEs. It is essential to investigate how users perceive usability, how their continuance intentions are formed and what cognitive perceptions are fulfilled to determine possible uses of 3DVLEs in higher education. To address these questions, this study examines consumers' perceptions of 3DVLEs by applying the expectation-confirmation theory (ECT) and modified the technology acceptance model (TAM) to propose a new model that incorporates presence and immersion as enhancing constructs. With the theoretical framework, this study conducts an empirical assessment of the research model in the learning context.

This article is organised as follows: Section 2 provides a brief review on 3D learning and on the theoretical framework used to investigate 3D and users. Section 3 proposes the research model and develops the hypotheses that are tested in this study.

*Corresponding author. Email: dshin@skku.edu

Section 4 describes the research method. Section 5 provides the results of empirical tests, which are discussed in Section 6. Section 7 presents the conclusion and implications for practitioners and researchers. Finally, Section 8 describes the limitations of this study and the topics for future study.

2. Literature review: 3D virtual learning system

A virtual learning environment (VLE) is a system designed to support teaching and learning in an educational setting. A VLE will normally work over the Internet and provide a collection of tools such as those for assessment, communication, uploading of content, return of students' work, peer assessment, administration of student groups, collecting and organising student grades, questionnaires and tracking tools. The examples can include Second Life and Virtual Campus. VLEs are often used in schools and other educational establishments to make the learning experience more interactive. Although originally created for distance education, VLEs are now most often used to supplement traditional face-to-face classroom activities, commonly known as blended learning. These systems usually run on servers, to serve the course to students on multimedia and/or web pages.

Recently, VLEs have adopted 3D techniques, as 3D experiences have allowed for various levels of learning, from cognitive and affective, to skill- or competency-based learning. Studies have shown that 3D-enabled virtual applications offer very effective and engaging platforms for creating high-value learning exchanges, with the same sense of presence and collaboration as single-site events (Kapp and O'Driscoll 2010). Three-dimensional services provide an excellent platform for achieving performance results when designing for the needs of learners by enhancing engaging interactions. Learning with a 3D device can allow the enhanced interaction with content and other individuals in a unique way, because of the notion of advanced presence, or feeling like being really there. Given these potentials, 3D should be seen as a new learning delivery channel – a channel through which organisations can deploy facilitated experiential, simulated learning or group activities in a secure or semi-secure space. Not only does this capability address varying learning styles, interaction and outcomes, but it also offers significant business advantages in cost, time and the ability to reach broadly dispersed audiences efficiently and effectively (Kapp and O'Driscoll 2010).

Given the applicability of 3D in learning contexts, 3D technologies can be a good candidate for learning services. This study examines the effect of immersion and presence on user behaviour during a 3DVLE practice. It may be the case that, for new media users, a multi-dimensional construct does not explain their behaviour, whereas a simple construct does. Therefore, a cautious approach is required in the use of construct in user behaviour research.

3. User modelling of 3DVLE

Figure 1 presents the proposed 3DVLE acceptance/continuance model as a learning system. The research model postulates four constructs that determine satisfaction, which then influences continuance intention. The model is well suited to reflect the nature of 3D, because it addresses the evolutionary progression of 3D and usage dynamics towards a more fluid and agile digital environment. In applying this integrated model to a technology-driven environment, the classical TAM variables are posited as key drivers of 3D adoption, and the model integrates additional key drivers in consideration of the ECT. Placing these variables under the nomological structure of the

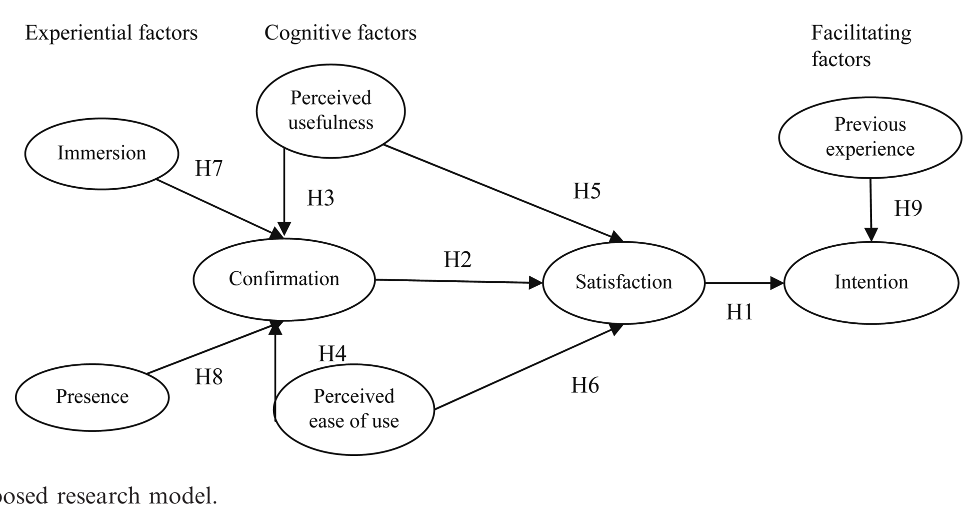

Figure 1. Proposed research model.

theories and precisely describing their interrelationships integrate them into a coherent and parsimonious research model.

3.1. Satisfaction and intention

According to the ECT, users' continuance intention is primarily determined by their satisfaction with prior information technology (IT) use. Following prior work (Bhattacherjee 2001, Chou and Chen 2009), satisfaction in this study is defined as a psychological or affect best related to and resulting from a cognitive appraisal of the expectation–performance discrepancy. Satisfaction also refers to an affect, captured as a positive (satisfied), indifferent or negative (dissatisfied) feeling. Affect (as attitude) has been theorised and validated in TAM-based research as a key factor of technology use (Davis 1989). In addition, empirical studies also show that IS continuance intention is positively affected by satisfaction (Bhattacherjee 2001, Lin *et al*. 2005). Applying the above arguments to 3DVLEs, the first hypothesis is proposed:

> H1. Users' satisfaction with the initial 3DVLE usage has a positive effect on their intention as a learning tool.

3.2. Confirmation and satisfaction

Bhattacherjee (2001) empirically validated that satisfaction is influenced by the users' confirmation level of technology services. Similarly, other studies, such as Hackbarth *et al*. (2003) and Tse and Wilton (1988), have consistently demonstrated the positive correlation between confirmation and satisfaction. In a number of other studies, it has been empirically established that confirmation has a causal link with satisfaction (Hayashi *et al*. 2004, Lin *et al*. 2005). Therefore, H2 is hypothesised as follows:

> H2. Confirmation, whilst using 3DVLEs, has a positive effect on satisfaction.

3.3. Confirmation and perceived usability

The TAM uses two interrelated beliefs, perceived usefulness (PU) and perceived ease of use (PEoU), as the basis for predicting end-user acceptance of technology. Given the widely accepted factors, PU and PEoU can be indicators of the 3DVLE usability. The definition of PU by Davis (1989) is that the degree to which a person believes that using a particular system will enhance his or her job performance. Bhattacherjee (2001) empirically validated that PU is influenced by the users' confirmation level in various technology services. The positive correlation between confirmation and PU has also been confirmed in learning contexts (Liu *et al*. 2009), VLEs (Hayashi *et al*. 2004) and in the use of a web portal (Lin *et al*. 2005). Hence, this leads to the following hypothesis:

> H3. The PU of 3DVLEs has a positive effect on confirmation.

PEoU refers to the degree to which a person believes that using a particular system will be free of effort (Davis 1989). Roca *et al*. (2006) showed that PEoU has a high correlation with confirmation. In the TAM studies, it has been shown that PEoU is a strong belief in the TAM context. Thus, H4 is hypothesised:

> H4. The PEoU of 3DVLEs has a positive effect on confirmation.

3.4. Perceived usability and satisfaction

The TAM studies have extensively found that there is a positive correlation between perceived usability and satisfaction. Hayashi *et al*. (2004) indicated that PU was positively correlated with satisfaction in three different online training environments. It is widely proven that user satisfaction is significantly impacted by PU and PEoU. In mobile commerce, Shin (2009) found that PU and PEoU were significant antecedents of consumer satisfaction. Bhattacherjee (2001) suggested that PU was a significant determinant of user satisfaction. In a study of the continued use of a website, Lin *et al*. (2005) reported a direct relationship between perceived playfulness and satisfaction. The following hypotheses are proposed:

> H5. PU whilst using 3DVLEs has a positive effect on satisfaction.

> H6. PEoU whilst using 3DVLEs has a positive effect on satisfaction.

3.5. Immersion and engaging experiences

Immersion is used to characterise a technology-enabled virtual reality environment (Teng 2010). Jennett *et al*. (2008) define immersion as sub-optimal experience that is concerned with the specific, psychological experience of engaging with certain activities like online games. This notion is clearly related to the widely researched concepts of flow, presence and cognitive absorption. In this study, the model investigates the effects of engaging experiences on confirmation by setting immersion, flow and presence as sub-optimal experiences. Immersion in this model includes the notion of flow.

Csikszentmihalyi (1977) defines flow as a 'shift into a common mode of experience' when people 'become absorbed in their activity' (p. 53). When people are 'in the flow', they 'shift into a common mode of experience when they become absorbed in their activity' (p. 72). In this light of definition, immersion and flow are conceptually similar, and, thus, flow can be included into immersion. Immersion is an experience in one moment in time, such as engagement, engrossment, flow and total immersion (Teng 2010).

H7. Immersion has a positive effect on confirmation of 3DVLEs.

The concept of presence has been investigated by several researchers in computer-mediated communication, and it refers to how much two people interacting through a technological media feel as if they were together (Lombard *et al.* 2000). In the research of human–computer interaction area, social presence has been defined as the extent to which a medium allows users to experience others as being psychologically present (Hassanein and Head 2007). The concept was originally defined as 'the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationship' (Short *et al.* 1976, p. 65). Although this definition is not clear and seems to imply the use of salience as traditionally defined in psychology, salience here is only that part of the information that is presented by the media. Though there are different definitions and perspectives on presence, this study sees presence different from immersion. Presence can be viewed as a state of mind, whereas immersion is an experience in time (Jennett *et al.* 2008). For example, although some games do not involve presence, they can still be immersive, leading to lost time and detachment from reality on the part of users. Presence is also possible without immersion, because one could imagine a person feeling present in a virtual environment, but not experience a lost sense of time. Thus, the concept of presence, which is different from immersion, can be applied to 3D learning.

H8. Presence has a positive effect on confirmation of 3DVLE learning.

3.6. *Intention and facilitating factor*

According to Liu *et al.* (2010), users' technology adoptions are influenced greatly by facilitating factors. In this study, previous experience is selected, as facilitating factors for the intention of evaluating two factors are closely related to learning services. In a learning environment, it is essential to consider a user's previous learning experience with technologies. Users may feel uncomfortable with computer-assisted learning if they lack experience in using a computer (Reed and Geissler 1995). Research has shown that previous technology-assisted learning experience can affect learners' perceptions of a new curriculum (Cereijo *et al.* 1999, Hartley and Bendixen 2001, Liu *et al.* 2010). Before participating in online learning, learners may perceive that a new system is easy to use if they have a detailed operating experience of the new IT (Shih *et al.* 2006) and, therefore, spend relatively little time exploring the new system. In this study, previous experience of computer-assisted learning or technology-enabled learning, such as web-based learning, e-learning or virtual learning system, is proposed as a factor influencing intention directly.

H9. Previous technology-assisted learning experience has a positive effect on continuance intention of 3DVLEs.

4. Study design

The methodology used in this study combines experimental design with a survey method. This special methodology was necessary, because a 3DVLE has not been widely introduced and is still at a developmental stage. Although there have been 3D virtual systems using Second Life, the system is not widely accepted in education sectors. Thus, it was essential to orient students about 3D learning before administering the survey questions.

First, a prototyped 3D learning system was constructed using 3D technologies (see Figure 2). The prototyped 3DVLE was created similar to the immersive system, which allows users to feel as if they are interacting with instructors in a real class environment. In the system, teachers' lectures were recorded, whilst they are giving lectures in offline classes. The class can be watched in real time in campus. In recording, a special 3D camera was used to grab a 3D image. A 3D camera was provided conditionally for educational purposes by industry. The recorded lectures were converted into 3D formats in 3DTV. The lectures were sent to the university web-courseware system, where the lectures were stored and retrieved. In retrieving the 3D lectures, students needed to access them from the designated labs where 3D displays were equipped. Students who missed the classes or who wanted to review the course content again retrieved the 3D content. The system was interactive, in that it allowed students to select some of the course modules and generates the series accordingly whenever possible.

Empirical data were gathered from a questionnaire survey of undergraduate students majoring in human–computer interaction, user interface and communications at several universities in Seoul, South Korea. Eight rounds of the survey were administered in the courses of the related majors in different locations and different universities. The reason of administering in different sites was to ensure internal reliability as well as external reliability. The results show that there is no

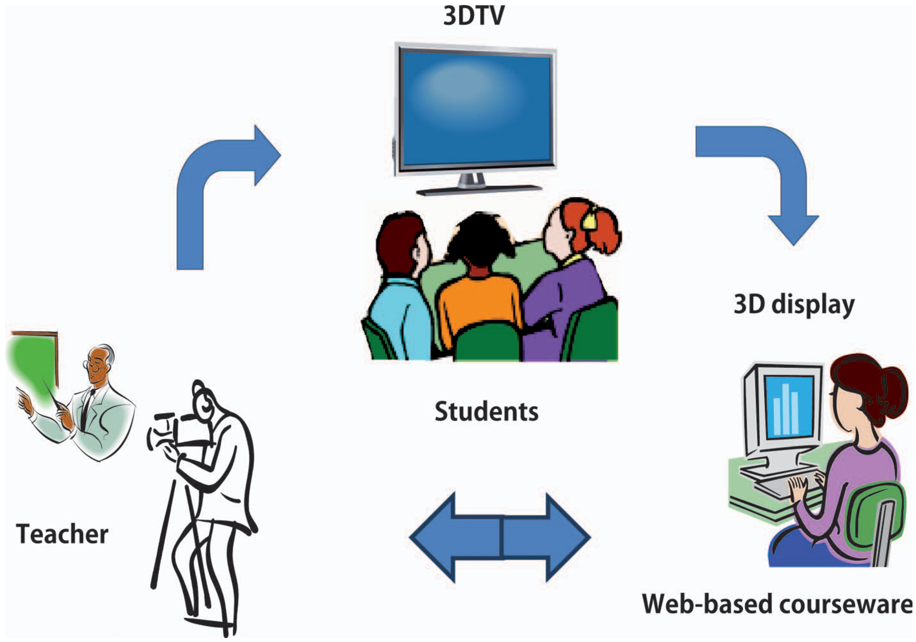

Figure 2. Prototyped 3D virtual learning system.

statistically significant difference across location, course, instructor and time.

The instrument development was implemented in the following three stages: (1) item creation, (2) scale development and (3) instrument testing. In the first stage, item creation, existing measurement items were reviewed for the study. For the second stage, scale development, a panel of experts reviewed the instrument to assess validity and to identify ambiguous items of the instruments created in the first step. All instruments were measured using multi-item scales. Each construct was measured by at least three observable indicators. The items were written in the form of statements or questions. Most measurements used a seven-point Likert rating scale system. For the instrument testing, during the last stage of instrument development, a pilot test was conducted before administering the survey for the field test. All measurement items are summarised in Appendix.

The survey sessions were held in computer-equipped labs, and participating instructors were asked to deliver one of their lectures through the 3D Virtual Learning Environments (3DVLEs). In the sessions, students were absent from physical class attendance and placed in different sites separate from instructors. After each session (1 h), students filled out survey questionnaires either online or on paper. Paper survey questionnaires were given to those who said they preferred them. The user interface of the learning system was controlled by virtual reality modelling language (VRML) technology, which allows interactive communication in 3D images. In designing the learning system, the Instructional Technology Design Center at the university assisted with the experiment, as they were themselves interested in a new pedagogical method using similar technologies. The experiment system can be displayed both real time and not real time. In case that students were watching a pre-recorded lecture, they were not able to interact with the lecturer. In the experiment, students had choices using either pre-recorded one or real-time streaming.

A total of 264 surveys were collected, but 40 surveys were excluded because of either incompleteness or apparent inconsistency. Although the surveys were administered in courses, the participation was voluntary. Although 40 out of 264 is a rather high rejection rate, we eliminated responses of careless response, sweepstake answers and insufficient efforts. We developed our own protocol to detect these kinds of careless responses. The survey was composed of 22 items; demographic questions were included on gender, age and the time of the online learning experience. Table 1 presents the sample demographics.

4.1. Measurement

The measures of behavioural intention to use, PU and PEoU were adapted from the previous studies related to the TAM model, mainly from a study by Davis (1989). The measures of immersion were selectively chosen from the long list noted by Jennett *et al.* (2008). To address flow and presence, this study used measures presented by Shin and Kim (2008). Presence items were also taken in part from Shin and Kim (2008), which were derived from Hassanein and Head (2007).

Table 1. Sample demographics of this study ($N = 224$).

Characteristics	Frequency	Percentage	Mean	SD
Age			25.67	3.21
Under 19	53	23.6		
20–30	153	68.3		
31–40	16	7.1		
41–50	2	0.8		
Gender				
Female	95	42.4		
Male	129	57.5		
User experience			13.9 months	4.37
1–3 months	19	8.4		
3–6 months	27	12.5		
6 months–1 year	39	17.4		
1–2 years	61	27.2		
2–3 years	38	16.9		
Over 3 years	40	17.8		

Note: Missing data are not counted in frequency.

The measures of continuance intention and satisfaction were adapted from Roca *et al.* (2006). The measures used to assess confirmation were taken from Lin *et al.* (2005). The final scales used in this study consisted of 30 items, three items per each factor. To improve the reliability and validity of this study, a panel of experts from academics and industries was formed to review each question and make necessary modifications.

4.2. *Data analysis*

A pretest was undertaken to examine test–retest reliability and construct reliability before conducting fieldwork. Thirty undergraduate students with knowledge/experiences of 3D application participated in the pretest within a two-week interval. After the pretest, a final sample was used for data analysis. Cronbach's α test was employed to identify poor item-to-total correlation measure items. After eliminating the items that failed in the test, retest or α-test phases, the remaining items were measured with Cronbach's α, the scores of which ranged between 0.84 and 0.93, suggesting satisfactory construct reliability (Table 2). The convergent and discriminant validity of the model were examined using the procedure suggested by Fornell and Larcker (1981). A confirmatory factor analysis was conducted to test the convergent validity of each construct; this analysis showed that most items had factor loadings higher than 0.7. For discriminate validity, a test of correlation amongst the factors was performed to measure the reciprocal relationship amongst them. Simple linear correlation (Pearson's r) was used to determine the extent to which the values of the variables were proportional to each other. The generally modest inter-correlations amongst the variables indicated no significant multi-collinearity problem. In addition, the square root of the average variance extracted (AVE) from the construct was much larger than the correlation shared between the construct and other constructs in the model. The test of the structural model was performed using the linear structural relations (LISREL) procedure. To assess how well the model represented the data, five goodness-of-fit indices were evaluated: the χ^2 test statistic, the goodness-of-fit index (GFI), the normed fit index (NFI), root mean square error of approximation (RMSEA) and the comparative fit index (CFI). The relative chi-square (χ^2/df) was 3.14, which was below the desired value of 5.0. All of the goodness-of-fit indices were all within the acceptance levels (Table 3). The internal consistency for the three scales was also strong, evidenced by a coefficient α of 0.79 for the scale indicating perceived presence, 0.90 for both perceived risk and intention, 0.84 for trust and 0.85 for perceived security. Given a satisfactory measurement model fit, the structural model was assessed.

5. Results

5.1. *Structural paths and hypothesis tests*

A structural equation modelling (SEM) approach was used in the data analysis, as it can simultaneously test the structural and measurement models. To test the structural relationships, the hypothesised causal paths were estimated and all the nine hypotheses were supported. The results are reported in Table 4 and Figure 3. The overall fit of the model is acceptable because the goodness-of-fit statistics are satisfactory. The results strongly support the proposed model. All the paths in the model were found to be statistically significant. Most importantly, the results highlight the key roles of immersion and presence perceived by users in determining confirmation (H7–H9), which, in turn, affects satisfaction (H2) through PU and PEoU (H5 and H6) and eventually influences intentions to adopt (H1). Confirmation is influenced by PU and PEoU, supporting H3 and H4, respectively. The testing results, in general, support the key role of experiential factors in establishing attitudes and intentions in 3DVLEs.

6. Discussion

6.1. *Findings*

This study examined the factors that affect users' attitude and intention to adopt 3DVLEs. In particular, the goal of the current study was to empirically measure the impact of psychological factors in influencing acceptance factors and establishing intention in a 3DVLE. To this end, this study extends the

Table 2. Convergent validity and internal consistency reliability.

Variables	Mean	SD	Cronbach's α	AVE	Composite reliability
Immersion	4.34	1.04	0.8489	0.764	0.97
Presence	4.12	0.93	0.7997	0.673	0.849
Confirmation	4.58	0.89	0.9003	0.784	0.915
PU	4.29	0.78	0.9020	0.717	0.903
PEoU	4.76	0.77	0.8489	0.719	0.910
Satisfaction	4.45	0.93	0.8511	0.624	0.916
Intention	4.46	0.93	0.9003	0.780	0.699

Note: AVE = summation of squared factor loadings/(summation of squared factor loadings)(summation of error variances) (Fornell and Larcker 1981).

Table 3. Fit indices for the measurement model and structural model.

Fit statistics	Measurement model	Structural model	Recommended value
χ^2 (df)	3.12	3.84	<5 (Bagozzi and Yi 1988)
p value	0.000	0.000	<0.05 (Bentler 1990)
AGFI	0.83	0.85	>0.8 (Joreskog and Sorbom 1996)
RMSEA	0.055	0.053	<0.06 (Joreskog and Sorbom 1996)
CFI	0.96	0.94	>0.90 (Bagozzi and Yi 1988)
NFI	0.92	0.93	>0.90 (Bentler 1990)
Incremental fit index	0.95	0.94	>0.90 (Bentler 1990)

Table 4. Summary of hypothesis tests.

Hypothesis	Path coefficient	t value	Support
H1: Satisfaction → Intention	0.51*	4.123	Yes
H2: Confirmation → Satisfaction	0.33**	2.323	Yes
H3: PU → Confirmation	0.30**	5.325	Yes
H4: PEoU → Confirmation	0.46*	4.934	Yes
H5: PU → Satisfaction	0.36**	4.525	Yes
H6: PEoU → Satisfaction	0.33**	3.525	Yes
H7: Immersion → Confirmation	0.69*	1.692	Yes
H8: Presence → Confirmation	0.53*	4.569	Yes
H9: Experience → Intention	0.24**	0.252	Yes

*$p < 0.001$
**$p < 0.05$.

ECT to explain the development of individuals' behavioural intentions in 3DVLEs. New constructs were employed, and the results offer insights into mechanism users' attitudes and intentions in a 3D learning paradigm, as well as into understanding implications for the development of effective 3DVLEs. The results provide substantial support for the research models. Overall, the results show that the models demonstrate a very good predictive power and explain behavioural intentions in 3DVLEs.

Consistent with the prior research of ECT, the results show that satisfaction and confirmation are significant predictors of intention. In the context of endogenous constructs, both confirmation and satisfaction had a significant effect on behavioural intention to use. Previous studies and industry reports have shown that usability is the most critical factor of 3D applications (Ozaktas and Onural 2010). This study confirms the importance of cognitive factors and further clarifies that cognitive factors can be greatly enhanced by experiential factors or subconscious constructs of immersion and presence. These findings raise a need for 3DVLEs to provide a stable user interface, as well as a quality user experience to customers. The perception of 3D usability by customers is one major factor for achieving market breakthrough of the system. Although the issue of usability has emerged as a major inhibitor of 3DVLE acceptance, research on this issue is quite rare to date, especially from the viewpoint of customers or users. The current study seeks to approach the issue from an empirical perspective to better understand the concept of 3DVLE usability. In this study, the users' confirmation and satisfaction have larger coefficients in value than the previous studies on IT use have indicated (Tse and Wilton 1988, Bhattacherjee 2001, Hackbarth *et al.* 2003, Hayashi *et al.* 2004, Lin *et al.* 2005, Roca *et al.* 2006). User confirmation and satisfaction are heavily influenced by psychological factors. It has been criticised that the most significant weakness of 3D system is the lack of content/service/application. What is more important than the content/service itself is the user experience when using them. That is, how users feel and what experience users get are essential factors in the acceptance of a 3DVLE. In this light, this study focused on the psychological effects of sub-optimal factors represented with presence and immersion.

As to immersion, the results show that the users perceived immersion as having strong impact on confirmation. In addition, the effect of presence on intention is stronger in a sense with a larger valued path coefficients than in the previous studies (Hayashi *et al*. 2004, Cyr *et al*. 2007, Hassanein and Head 2007). Although extensive studies have investigated the role of flow, presence and immersion in various contexts, not many studies have researched the three effects together in a systematic manner. Although these constructs may be conceptually similar concepts, they are worthy of further investigation to see how these constructs play operationally in 3DVLEs. As expected, all these constructs have shown high effects, and, more importantly, all the three constructs co-influence each other.

6.2. *An extended model*

Although the model shows good fit and most paths are shown to be valid, the users' intention explained 30% of the model's variance, indicating that there are more factors to be considered. In addition, the path of immersion (H7) demonstrated the highest effect in the model ($\beta = 0.69$, $t = 1.923$). The magnitude of effect (0.69) is unusually high and higher than that seen in the previous similar studies. Given all of these observations, it is reasonable to infer that there are some underlying effects behind immersion and possible other effects amongst these three constructs. Extended model includes flow construct as an antecedent of immersion, and the interaction effect between present and flow is examined.

Investigation revealed that there were clear interaction effects amongst them. The extended model (Figure 4) illustrates that immersion is a key factor,

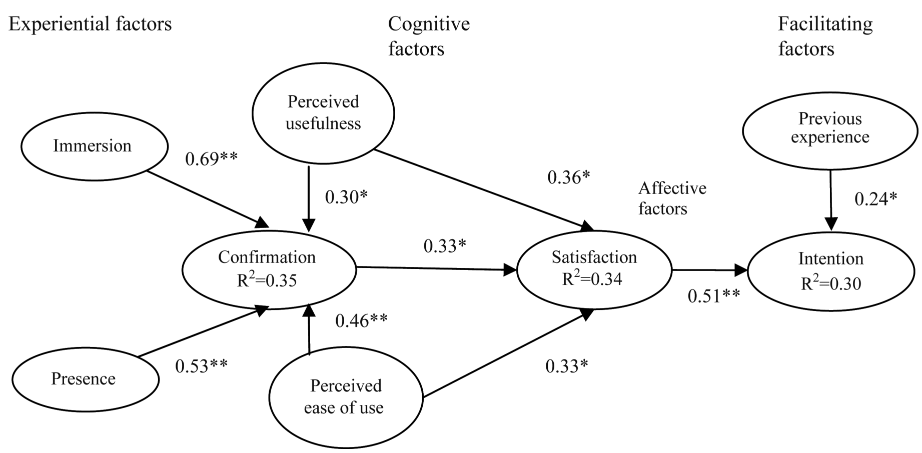

Figure 3. Results of initial model.

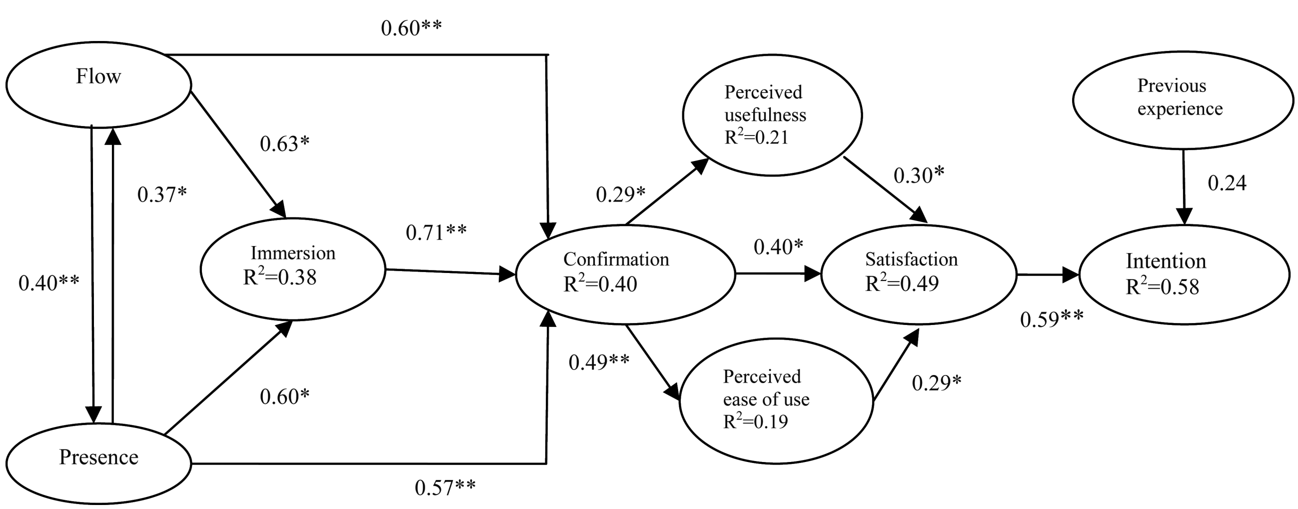

Figure 4. Extended model with immersion effect.

enhancing the other two factors. This finding is consistent with the immersion effect in education, indicating that the level of immersion is a critical factor in education contexts. This is even truer in 3DVLEs, where immersion is a key feature and plays a critical role in adoption.

As to flow and presence, the two were found to influence each other. Although the path from flow to presence is stronger than in the other direction ($\beta = 0.40 > 0.37$), each can be said to play enhancing roles for each other. With the addition of the interaction effects between flow and presence to the extended model, effects on immersion are notably increased ($0.58 \rightarrow 0.63$; $0.52 \rightarrow 0.60$). Previous studies have found the correlation between immersion and presence; the extended model advances the previous studies by showing the direction and effect size. It can be said that flow and presence are antecedents of immersion, which has been undiscovered in the human–computer interaction (HCI) research. Previously, immersion is considered as one of the elements of either flow or presence and has never been researched as a separate construct affected by flow and presence. As the key feature of a 3DVLE is immersion effect, it is notable to investigate immersion separate from flow and presence and to see how they are related. In this light, the extended model is a notable advancement, in that it sheds light on the way to measure immersion effect through flow and presence.

Although the effects of overall paths, particularly the ones of ECT relations and immersion, are increased, the effects of two paths were even decreased. The effect sizes of PU on satisfaction ($0.35 \rightarrow 0.30$) and PEoU on satisfaction ($0.32 \rightarrow 0.29$) were diminished. This implies that PU and PEoU account for a certain portion of satisfaction in the initial model. With the clarification of underlying paths, users' satisfaction is more influenced by confirmation. In other words, the portion used to be explained by PU and PEoU is now transferred to the path from confirmation and satisfaction ($0.30 \rightarrow 0.40$).

With the immersion effect in place, the fit of the model (overall fit indices) is improved, as well as each path of the model. In addition, the R^2 of confirmation, satisfaction and intention ($R^2 = 0.29 \rightarrow 0.40$; $R^2 = 0.34 \rightarrow 0.49$ and $R^2 = 0.32 \rightarrow 0.58$, respectively) are also greatly increased. From the extended model, it can be said that the users of 3DVLE may want to perceive clearer confirmation than they would in other digital devices. Users may want to have more apparent ease of use and usefulness than they would get from other typical digital learning pedagogy. Although users may be confirmed by presence and flow, the confirmation does not automatically lead users to believe in the usability of 3DVLEs. Instead, they may want to clearly realise what is useful when using 3DVLEs. Users also may want to perceive how easy it is to receive learning services from 3DVLEs. Immersion provides a venue for users to realise what is really useful and, thus, feel satisfied. Flow and presence lead users unconsciously to feel a stable confirmation and increased satisfaction, which, in turn, together affect intention. In sum, the extended model explicates the tree of eventual behavioural intention by adding immersion to the ECT model of confirmation–satisfaction–intention. This new link should be noted because previous studies have neglected the antecedents of confirmation. Although previous studies have focused on the ECT relation, this study found immersion as the antecedent of confirmation and further identified how immersion is affected by specific factors. The results here provide empirical support for the proposed model that immersion has a significant impact on users' confirmation, satisfaction and eventually intention. The results offer grounds to further develop immersion effect and shed light on the possibility to measure immersion effect quantitatively. Future studies may pursue this topic.

7. Implications for theory and practice: 3D as a platform for smart applications

The results of this study highlight several implications for academic researchers, as well as for the 3D industry. The empirical findings demonstrate that employing immersion and presence would be a worthwhile extension of the acceptance of 3DVLEs. As an educational tool, immersion effect is of importance in 3DVLEs. As antecedent variables, the roles of presence are significant in determining immersion. These findings are heuristic because one of the limitations of the technology acceptance literature is that it does not help us explain acceptance in ways that guide development, besides suggesting that system characteristics have an impact on the perceptions of ease of use and usefulness. Therefore, to explain user acceptance and use, it is essential to understand the antecedents and the underlying effects of the key variables of acceptance. Although traditional technology acceptance studies have extensively researched cognitive perception, subconscious factors remain a rarely researched area. Subconscious factors are even more critical to 3DVLEs, as immersion and presence are the key features of 3DVLEs. Numerous studies have considered such subconscious factors together with cognitive perceptions. The problem with this approach is that subconscious factors are at different levels from cognitive perception. As subconscious factors are difficult to conceptualise and often work differently depending on contexts, the factors should be researched with caution. The findings of this study have theoretical implications, clarifying subconscious factors and how they are interrelated to cognitive perceptions.

From this perspective, Hackbarth *et al.* (2003) argue that more emphasis should be given to confirmation and satisfaction, as both factors affect users' decision making towards the application of new technologies. Furthermore, many disciplines have shown that emotions are important components of many behaviours. Bhattacherjee (2001) has advocated the extension of the traditional acceptance model by integrating the ECT components of consumption experiences. His argument is particularly well applied to 3DVLEs, as confirmation and satisfaction are found to be prominently featured, together with subconscious factors, as well as cognitive factors.

An intriguing and heuristic contribution of this study is the recognition of a directional relationship between presence and immersion. Although presence is an embedded concept in the 3D literature, the similar concept of immersion has apparently been under-researched. It seems that the relationship is not apparent in the 3D context. Given the unique nature of 3DVLE interaction, the relationship with social presence and other factors should be clarified. On the basis of the findings of presence, this study conceptualises the roles of subconscious factors in the 3DVLE context.

Practical implications for the 3D industry can be drawn in terms of new services and applications of 3D. The finding that immersion directly and indirectly impacts behavioural intention through confirmation indicates that vendors should ensure that their device works and plays in accordance with users' expectations and emotions. In addition, the findings of this study imply that the potential of 3D user interfaces is not being fully realised in the learning context. On the basis of findings of the importance of customers' PEoU, vendors should devise an easier way to use 3D services. The high level of PEoU is in line with the other studies' findings that users may regard convenience, accessibility and enhanced functionality as the primary benefits of the learning system. Also, users may perceive traditional pedagogy as having an advantage in terms of ease and convenience of learning. Thus, for 3D to thrive as a learning tool, users should be provided with conveniently accessible enhanced functionality, as well as ease of use and an enjoyable learning experience. A 3DVLE has the potential to stimulate new forms of learning opportunities and will require vendors to think differently about how to accommodate the needs of users, as their preferences become more diverse and contextual. Viewing 3DVLEs through the lens of traditional educational services might cause vendors to miss important opportunities to improve learning performance.

8. Limitations and future studies

The results of this study should be interpreted and accepted with caution for several reasons. The first and most significant limitation is the use of a student sample. Although the target population of 3DVLEs may be young students, it is questionable to apply these findings to other populations, contexts and times. The participating students (pretests, pilot tests and surveys) were from courses related to new media and technologies; hence, they can be said to be more technology oriented and, thus, more likely to be early adopters more easily exploring new technical environment than the general populations.

A second limitation involves the test methodology. The respondents were tested in a laboratory environment, which could produce the Hawthorne effect, involving the respondents changing their behaviour to conform to the expectation of the researcher. As the respondents were students of the researcher, students might be conscientious about being evaluated by the professor. These limitations were somewhat inevitable, given the budget limitation of this study and considering the very early stage of development of 3DVLEs. It was not easy to take samples from the general populations, and it might be even more difficult to have the participants experience a 3DVLE in a real learning context.

A third limitation is that this study excluded individual differences as factors in the 3DVLE acceptance (e.g. demographics, user experience and personal innovativeness). Although this study did not consider demographics for parsimony, it may be essential to include individual variables, given a significant increase of variance of usage in many studies. As many studies (Hayashi *et al.* 2004, Teng 2010) included demographic differences in their research on presence and immersion, a closer investigation of individual differences and their direct and indirect effects on 3DVLE usage offers rich opportunities for future research. Demographic differences may play a considerable role in system learning, especially when learning achievement and performance are important factors, which were ignored in this study.

A fourth limitation regards the design of this study, in that the ECT-related variables are not exactly embedded in users' cognition (confirmation and satisfaction). Although the respondents in this study browsed the prototyped learning system before the surveys, it is not clear how the users really confirm the benefits of the system and how the users get real satisfaction from using it. These confirmation and satisfaction are the essential components of the ECT variables. In other words, as the respondents were not involved in actual learning, but, in experimental designs, it can be difficult to say whether users were aware of such cognitive perceptions as much as in an actual education environment.

Finally, some of the variables (i.e. experiential factors) are relatively new and have not been extensively researched in the previous studies. Although the variables have gone through pilot tests and expert reviews, they could be more carefully measured. As this study made an exploratory attempt to model user assurance through the new variables, future studies should follow up this finding, not only to confirm the validity of these variables, but also to further explore their relationships to other variables. As 3D converges with other instructional technologies, the concepts of interactivity and controllability will be newly highlighted. Interactivity and controllability will be the important factors in 3DVLEs. Research will focus on enhancing social presence through perceived interactivity and perceived controllability, and how to implement interactivity and controllability. In addition, future studies may further investigate the pervasive effects of subconscious factors on attitude, as well as its consequences. As the analysis in this study shows, the influences of subconscious factors are all-encompassing and embedded, and, thus, a comprehensive investigation is needed to clarify the effect in relation to new variables. More research is needed on the reliability and validity of the variables for research, through replication and cross-validation.

In all, more experiments are needed to corroborate the findings in this study. Despite several limitations, an important contribution of this study is the additional information on user behaviour metrics in a 3DVLE. In addition to the fact that, all of the scales used in the study showed high reliability, those of flow, presence and immersion also demonstrated high nomological validity. Therefore, future research can use these metrics with some assurance.

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Appendix

Constructs	Measure items	Source
Presence	PR1: There is a sense of human contact on 3DVLEs. PR2: There is a sense of sociability on 3DVLEs. PR3: There is a sense of human warmth on 3DVLEs.	Shin and Kim (2008), Hassanein and Head (2007)
Immersion	IM1: I was unaware of what was happening around me. IM2: I felt detached from the outside world. IM3: I felt as if I was in the classroom with a professor while 3D learning.	Jennett *et al*. (2008)
PU	PU1: I think 3DVLEs is useful to me. PU2: It would be convenient for me to have 3DVLEs. PU3: I think 3DVLEs can help me with many things.	Davis (1989), Yoon *et al*. (2008)
PEoU	PEoU1: I find learning via 3DVLEs easy. PEoU2: I find interaction through 3DVLEs clear and understandable. PEoU3: Overall, 3DVLE learning is easy for me.	Davis (1989)
Confirmation	CO1: My experience with using 3DVLEs was better than what I had expected. CO2: The product and service provided by 3DVLE was better than what I had expected. CO3: Overall, most of my expectations from using 3DVLE were confirmed.	Lin *et al*. (2005)
Satisfaction	SA1: I am satisfied with the overall experience of 3DVLEs. SA2: I have no problems/complaints in learning via 3DVLEs. SA3: Overall, I am pleased with 3DVLEs.	Roca *et al*. (2006)
Intention to use	IT1: I think I will use 3DVLEs in the future. IT2: I recommend others to use 3DVLEs. IT3: I intend to continue using 3DVLEs in the future.	Davis (1989), Roca *et al*. (2006)