



Using the Technology Acceptance Model to Investigate the Effect of Self-Efficacy on Gesture Control in Virtual Reality

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Abstract: The growth in distance learning during the COVID-19 pandemic has made the incorporation of touchless control into virtual reality (VR) worth investigating. This study used a head-mounted VR device for a virtual art gallery software program (GOXR) and adopted the technology acceptance model (TAM) to analyze how well senior high school students in New Taipei City accept gesture control in VR, thereby investigating the effect of self-efficacy on technology acceptance. This study used the TAM as the foundation to perform a questionnaire survey among the aforementioned students. This study distributed 272 questionnaires and collected 271 valid responses; thus, the response rate was 99%. The conclusions of this study are as follows. First, students' acceptance of gesture control in VR did not differ significantly in relation to sex or experience of using VR headsets. Second, perceived usefulness, perceived ease of use, attitude toward use, and intention to use had significant positive correlations with each other. Third, self-efficacy did not have a significant moderating effect on the relationship between perceived usefulness and attitude toward use or the relationship between perceived ease of use and attitude toward use.

Keywords: Gesture control; Self-efficacy; Technology acceptance model (TAM); Virtual art gallery; Virtual reality (VR).

Introduction

VR technologies rely on head-mounted devices to display three-dimensional images [1]. Most head-mounted displays have a wireless controller with sticks that users use to control the virtual environment. During the COVID-19 pandemic, users were wary and afraid of conventional controllers because of the contagiousness of the coronavirus. Consequently, touchless controllers began attracting the attention of users. Although the hand tracking function was originally an experimental feature, software firms have placed increasing emphasis on it, and different applications [2-4] that support the hand tracking function began to appear in the market. Gesture control has thus become a novel topic in the postpandemic era.

As the number of electronic products in the market is increasing, control methods are becoming more

complicated [5], and human-machine interface designs are receiving increasing attention. Intuitive control methods are replacing conventional control methods. For example, Android cameras allow users to take selfies by using certain hand gestures. Gaming industries have integrated Kinect into games so that games can detect the body movements of users and respond accordingly. Leap motion sensors, which facilitate signal input through palm and finger movements, are being integrated into unmanned aerial vehicles for parcel delivery [6]. Intuitive human-machine interactions that are easy to learn have become one of the key needs of users [7].

This study performed a questionnaire survey and used the technology acceptance model (TAM) to investigate the effect of self-efficacy on gesture control in virtual reality. This study analyzed the questionnaire data, proposed conclusions, and formulated suggestions for the future development of teaching materials that



integrate VR and hand gestures. VR resembles the real world, and users can use wearable devices to enter a completely virtual setting. The development of various VR devices [8] and novel interaction methods [9] has enabled VR to achieve major breakthroughs in the domains of technology and education [10,11].

The authors of the present study observed in teaching settings that incorporating VR into learning can help students with a low learning interest to develop learning motivation. The pandemic highlighted the value of integrating touchless control and VR to create remote interactions. Therefore, this study aimed to understand the needs and thoughts of users for gesture control and the effect of self-efficacy on the learning of gesture control. This paper aims to investigate how self-efficacy affects the technology acceptance of gesture control in virtual reality. We used a virtual art gallery software program (GOXR) [12] and collected user feedback on the experience. We also explored how they perceived and used gestures to interact with the virtual environment. Three questions guide our study: (1) How to implement a virtual art gallery that appeals to high school students? (2) How to design gestures that are intuitive and easy for high school students to control in the virtual art gallery? (3) How does self-efficacy influence the technology acceptance model of gesture control in virtual reality?

The rapid revolution of technology [13] has prompted the technology industry to pursue intuitive, simple, and multifunctional human-machine interactive interfaces [14]. However, the continual improvement of software and hardware equipment and personal factors affect the acceptance of new human-machine interactive interfaces by individuals and their frequency of using such interfaces [15,16]. Therefore, this study used technological systems as the foundation to explore the subjective perspective of users regarding the use of hand gestures to control interactions in VR. In addition, this study investigated the moderating effect of self-efficacy on the relationships between perceived ease of use, perceived usefulness, and attitude toward use to understand whether different levels of self-efficacy have different effects on attitude toward use.

Related Research

Chia-Chun Tsai received Master degree from National Kaohsiung Normal University in 2023, and Bachelor degree from National Kaohsiung Normal University in 2018. Her research interests include technology education.

Yen-Lun Chen received B.S. and M.S. degrees from Department of Electrical Engineering at National Taiwan University, and Ph.D. degree from Department of Electrical and Computer Engineering at the Ohio State University. Her research interests include machine learning, pattern recognition, computer vision, and multimedia signal processing.

Technology Acceptance Model

The psychologist Bandura [17] used social learning theory to propose the term “self-efficacy,” which refers to the belief of individuals in their ability to achieve the objective of tasks. Many studies [18] have mentioned that learners with a higher self-efficacy have a higher learning motivation and learning outcome and a more positive learning attitude when they learn a language or math. However, the effect of self-efficacy on users who operate human-machine interfaces is uncertain. In the TAM, the perceived ease of use and perceived usefulness of gesture control in VR are also unknown. Because current studies lack data related to the effect of self-efficacy on gesture control in VR, the present study used the TAM to explore this effect. This study used the virtual art gallery software developed by the New Taipei City Government as an example to understand the thoughts and expectations of users for VR design and gesture control.

The TAM was proposed by the American scholar Fred D. Davis [19]. The TAM combines the theory of reasoned action (TRA) and the theory of planned behavior (TPB). Davis proposed the TAM to predict and explain the technology acceptance of individuals. The TAM ignores the subjective norm of the TRA and the normative belief of the TPB and encompasses two cognitive beliefs, namely perceived usefulness and perceived ease of use. Perceived usefulness refers to the extent to which users believe that the usage of a specific system would improve their work performance, whereas perceived ease of use refers to how easy users believe a specific system is to use.

Users have a more positive attitude toward using a system if they have a higher level of perceived usefulness and if they have a higher level of perceived ease of use. External variables were introduced into the TAM after repeated revisions to it. External variables refer to factors such as individual characteristics, backgrounds and experiences, and organizational or job characteristics. Davis [20] argued that external variables affect the internal variables of users, namely their perceived usefulness and perceived ease of use, both of which influence the attitude toward use. In addition, Davis mentioned that perceived ease of use affects perceived usefulness, which in turn directly influences intention to use. The TAM is most commonly used to investigate the extent to which users accept new information technology, and it includes five dimensions, namely external variables, perceived usefulness, perceived ease of use, attitude toward use, and intention to use. In addition to the aforementioned five dimensions, predicted future usage can be added as an additional dimension.



VR Development Tool

The Meta Quest 2 VR system, which is a head-mounted VR display, was used in the conducted experiment. This VR system provides users a highly immersive experience, offers a visual effect with 20 pixels for each degree in the field of view, and includes a liquid-crystal display with a resolution of 1832 × 1920 pixels for each eye. The system has 6 GB of RAM and is integrated with the rapid Qualcomm Snapdragon XR2 platform for considerably improving the smoothness of the virtual images. The system supports Oculus Touch handheld controllers, and users can use these controllers or hand tracking technology to control objects in VR. Different hand gestures correspond to different actions in the VR system so that users can intuitively engage in VR.

The setting of the experiment was a virtual gallery constructed by the National Palace Museum on GOXR. GOXR is a virtual interactive exhibition platform that allows brands, businesses, and content creators to develop their own three-dimensional spaces. Users can use devices such as phones, tablets, and VR head-mounted devices to enter the virtual exhibition and engage in real-time interactions with other users. The exhibition of historical treasures from the museum, built on the GOXR platform, offers immersive guided tours, interactive exhibit browsing, and real-time multi-person interaction. This platform was chosen because of its comprehensive interactive design and support for Meta Quest 2 gesture control, which aligns with the needs of this research exploring VR gesture control. Students wore the Meta Quest 2 head-mounted display and used hand gestures to visit the virtual art gallery and interact with virtual characters in the art gallery. They also zoomed in and out of the Meat-Shaped Stone, which is a historical treasure in Taiwan, by using their hands and turned and appreciated this stone to enjoy a different exhibition experience.

Research Design and Implementation

Research Framework and Procedures

This study conducted a literature review [22] to formulate variables related to the TAM and used self-efficacy as a moderating variable to develop the basic research framework.

- (1) External Variables: The external variables in this study were sex, educational attainment (current grade), prior experience of using VR headset, prior experience of using the GOXR virtual art gallery software, and prior experience of using hand gestures for interactions in VR.
- (2) Independent Variables, Moderating Variable, and

Dependent Variable: This study used the TAM as the foundation to investigate how perceived usefulness and perceived ease of use correlated with attitude toward use and intention to use. This study also examined the moderating effect of self-efficacy on the relationships between perceived usefulness, perceived ease of use, and attitude toward use.

- Independent Variables: perceived usefulness and perceived ease of use in the TAM
- Moderating Variable: self-efficacy in the TAM
- Dependent Variable: attitudes towards use

Research Hypotheses

H1 to H6 are all based on the TAM and self-efficacy theory, and combined with previous research on VR interaction, it is inferred that perceived ease of use and perceived usefulness may affect the willingness to use the device, while self-efficacy may have a moderating effect. The following hypotheses are proposed:

- H1: Perceived ease of use and perceived usefulness have a significant positive correlation.
- H2: Perceived usefulness and attitude toward use have a significant positive correlation.
- H3: Perceived ease of use and attitude toward use have a significant positive correlation.
- H4: Attitude toward use and intention to use have a significant positive correlation.
- H5: Self-efficacy strengthens the positive correlation between perceived usefulness and attitude toward use.
- H6: Self-efficacy strengthens the positive correlation between perceived ease of use and attitude toward use.

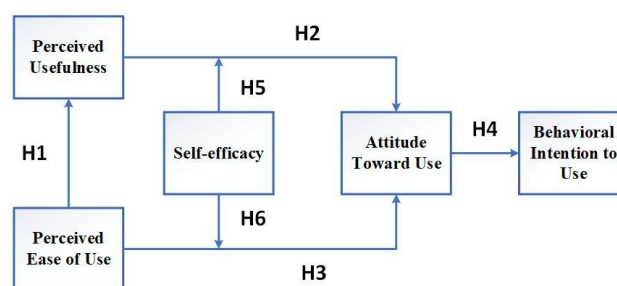


Figure 1. Diagram of research hypotheses established according to the framework of technology acceptance model.

Participants

The purpose of this study was to employ the TAM to explore the feedback of senior high school students from Taiwan regarding the usage of gesture control in VR and the effect of self-efficacy in the TAM. The participants in this study were students enrolled in New Taipei City's senior high schools in 2022; thus, this study



was a regional study. Statistical theories were used to set the confidence level and margin of error as 95% and 6%, respectively, and the sample size was approximately 270.

Questionnaire Design and Pretest

The questionnaire items used in this study were designed based on TAM and self-efficacy theory with expert validity. The questionnaire consisted of six sections. The first section was a basic information survey. The second section pertained to perceived ease of use for gesture control in VR. The third section was related to perceived usefulness for gesture control in VR. The fourth section was related to the self-efficacy of the participant. The fifth section concerned attitude toward use for gesture control in VR. The sixth section was related to intention to use for gesture control in VR.

Questionnaire Design

The basic information section employed self-reported items. Items in other five sections were rated on a 5-point Likert scale ranging from 1 to 5 for strongly disagree, disagree, neutral, agree, and strongly agree, respectively. The scores provided in second to sixth sections reflected the perceived ease of use, perceived usefulness, self-efficacy, attitude toward use, and intention to use of the participant for gesture control in VR. The questionnaire (see appendix) includes questions from a self-efficacy scale, demonstrating that the scale effectively reflects users' confidence and ability in virtual reality gesture manipulation, which aligns with the research objectives.

Validity Test

We engaged experts of questionnaire design to review the questionnaire content, ensuring it aligns with specialized knowledge in relevant fields [23]. Experts and scholars were requested to check the questionnaire items for relevance and then correct them. The experts also reviewed the overall questionnaire structure, response method, and phrasing and provided suggestions regarding each of these aspects so that the revised questionnaire was more comprehensive. The items of the questionnaire were revised on the basis of the suggestions. The revised questionnaire was then used in a pretest to investigate the effect of self-efficacy on gesture control in VR.

Questionnaire Pretest

This study conducted a pretest to assess the reliability of the adopted questionnaire, ensuring the pilot study itself was reliable. The pretest participants

were 33 students of New Taipei Municipal Hsin Tien Senior High School. The instructor first demonstrated the steps and provided textual and illustrative explanations to ensure students understood how to perform these gestures. The following is the course implementation and questionnaire process:

- Instructor Demonstration: Researchers wear VR headsets, use gestures to control the virtual exhibition hall GOXR, and display demonstration content on the screen.
- Student Operation: Students take turns wearing VR headsets and interacting with the virtual exhibition hall using gestures.
- Questionnaire Administration: Students complete the questionnaire and can ask questions about any of the questions.

Researchers introduced the use of VR, and then demonstrated the use of gestures in the virtual art gallery software, and presented interactive images on the digital screen in the class. Then, students wore VR headsets and entered the GOXR software, performing two dynamic gesture operations: "point and pinch" and "point and retract". These gestures are the most commonly used interaction methods on the platform and were selected because they are simple and easy to learn, thereby reducing cognitive load and ensuring the validity of the research results. Subsequently, they completed the questionnaire. The participants could ask any question related to the questionnaire to the teacher who assisted and instructed them. A total of 33 valid responses were obtained in the pretest, and the results were input into SPSS 28.0 for reliability analysis and factor analysis [24].

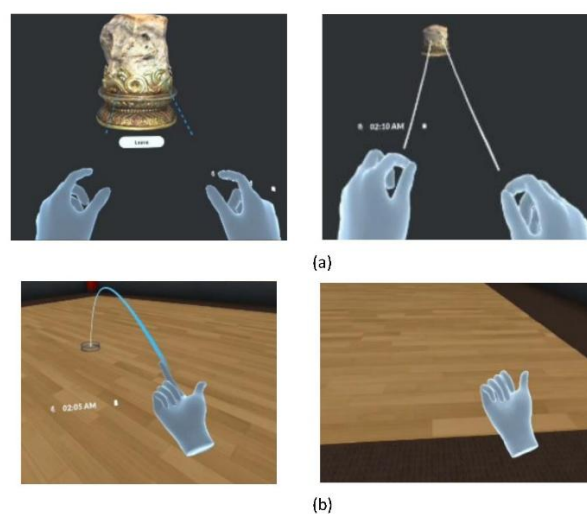


Figure 2. Gesture functions and operation methods: (a) point and pinch to select an object and (b) point and retract to move location.

Factor analysis

Before factor analysis, this study employed the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett’s test of sphericity to determine whether factor analysis was appropriate for the data. The KMO measure indicates the variation that might be attributable to latent factors; 0.5 is used as the KMO measure threshold, and a value smaller than 0.5 indicates that the results of factor analysis are unsuitable for the analysis of the current data. Bartlett’s test of sphericity also indicates whether data are suitable for factor analysis. If the p value is lower than the significance level ($p < 0.001$), the data are suitable for factor analysis. This study adopted principal component analysis to perform factor analysis and used maximum variance for orthogonal rotation. Questionnaire items with a factor loading of less than 0.50 or items with ambiguous factors were deleted.

Reliability analysis

After this study performed factor analysis to determine the validity of the pretest questionnaire, it calculated the Cronbach’s α value to obtain the internal consistency and reliability of the questionnaire. The Cronbach’s α was calculated for each subscale and the overall scale; a larger Cronbach’s α indicated a higher consistency between the items and a higher reliability of the questionnaire [25]. The results of the reliability analysis are presented in Table 1. The Cronbach’s α of each subscale was 0.797–0.960, and the Cronbach’s α of the overall scale was 0.973; these results indicate that the adopted questionnaire had high consistency and stability.

Table 1. Reliability analysis of the questionnaire in the pretest

Subscale	Number α of items	Cronbach's α	Cronbach's overall scale
Perceived ease of use	6	0.922	0.973
Perceived usefulness	7	0.922	
Self-efficacy	4	0.797	
Attitude toward use	5	0.960	
Intention to use	5	0.956	

Item analysis

A newly developed scale should be subject to an item analysis to determine whether the scale can distinguish a high-scoring group from a low-scoring group. Item analysis [26] involves conducting an independent

samples t-test to determine whether the total scores of a high-scoring group and low-scoring group have a significant difference. If the difference is significant and the critical ratio is higher than 3, the total scores of the two groups are sufficiently different, indicating excellent discriminatory power of the scale [27]. This study deleted one questionnaire item, namely the first item under the dimension “intention to use,” after factor analysis and reliability analysis. This item was deleted because it had a standard deviation of 0 for its high- and low-scoring groups, which precluded the calculation of t value. All the other items exhibited a significant difference between the two groups and thus were retained.

Results and Analysis

Following the 33 pre-test questionnaires described in the previous section to refine the research tools, this section describes the distribution of the 272 formal questionnaires after the course was implemented, and the analysis presented reflects the results collected. Students completed the exhibition browsing and interactive operations, such as zooming in, zooming out, and rotating exhibits. Gesture recognition accuracy is determined by system feedback records. If a gesture successfully triggers a specified function (such as zooming in on an exhibit), it is considered a successful recognition. The study used IBM SPSS 28.0 to analyze the results of the survey to investigate the effect of self-efficacy on gesture control in VR.

Table 2. Distribution of the participants among the schools

School name	School type	School location	Num ^a	Num ^b
New Taipei Municipal Shuang Xi High School	Junior–senior high school	Rural	64	63
New Taipei Municipal Shu Lin High School	Junior–senior high school	Urban	20	20
New Taipei Municipal Lin Kou Senior High School	General senior high school	Urban	82	82
New Taipei Municipal Hsin Tien Senior High School	General senior high school	Urban	106	106
Total			272	271

a: Number of questionnaires distributed.

b: Number of questionnaires returned.



Table 3. Demographics of the participants

Category	Variables	Number	Percentage
Sex	Male	143	52.77%
	Female	128	47.23%
Grade	10	132	48.71%
	11	109	40.22%
	12	30	11.07%
First time to use a VR headset?	Yes	142	52.39%
	No	129	47.61%
First time to use the Virtual Gallery software (GOXR)?	Yes	242	89.30%
	No	29	10.70%
First time using gestures to interact in a VR scene?	Yes	235	86.72%
	No	36	13.28%

Table 4. Participants of different sex (M/F)

Variable	S	#	Average	SD	t	p
Perceived ease of use	M	134	23.39	4.80	1.525	.128
	F	125	22.53	4.23		
Perceived usefulness	M	134	27.70	5.40	0.888	.375
	F	125	27.13	4.96		
Self-efficacy	M	134	14.83	3.53	0.745	.457
	F	125	14.52	3.27		
Attitude toward use	M	134	20.17	4.06	0.508	.612
	F	125	19.93	3.61		
Intention to use	M	134	19.88	4.06	0.608	.544
	F	125	19.58	3.98		

Table 5. Experience of using VR headsets

Variable	F ^c	#	Average	SD	t	p
Perceived ease of use	Y	133	22.70	4.71	-1.024	.307
	N	126	23.28	4.36		
Perceived usefulness	Y	133	27.19	5.16	-0.779	.437
	N	126	27.69	5.22		
Self-efficacy	Y	133	14.57	3.58	-0.543	.588
	N	126	14.80	3.22		
Attitude toward use	Y	133	19.94	4.07	-0.524	.601
	N	126	20.19	3.60		
Intention to use	Y	133	19.63	4.05	-0.451	.652
	N	126	19.86	4.00		

c: First time using a VR headset.

Basic Information of the Participants

Schools Selected for the Questionnaire Survey: Purposive sampling was adopted in this study, and the 31 senior high schools in New Taipei City were divided into junior–senior high schools and general senior high schools. This study selected one rural junior–senior high school (New Taipei Municipal Shuang Xi High School) and one urban junior–senior high school (New Taipei Municipal Shu Lin High School). Next, this study selected two senior high schools that were subsidized by New Taipei City to promote emerging technology, namely New Taipei Municipal Hsin Tien Senior High School and New Taipei Municipal Lin Kou Senior High School.

A total of 272 electronic questionnaires were distributed in the four aforementioned schools, and 272 responses were obtained. After excluding one incomplete response, this study finalized its valid sample to 271 responses; thus, the return rate was 99%. The number of participants from each school is presented in Table 2.

Using the TAM to Investigate the Relationships Between the Variables

The effects of two variables, namely sex and experience of using VR headsets, on the factors in the TAM were investigated. The results of this investigation are described in the following text.

- Effect of Sex in the TAM: A t-test was performed to determine whether sex affected the factors in the TAM. The results indicated that perceived ease of use, perceived usefulness, self-efficacy, attitude toward use, and intention did not differ significantly between male and female students. Thus, sex did not have any significant effect in the TAM.
- Effect of Experience of Using VR Headsets in the TAM: A t-test was performed to determine whether prior experience of using VR headsets affected the factors in the TAM. The results indicated that perceived ease of use, perceived usefulness, self-efficacy, attitude toward use, and intention to use did not differ significantly between students who had and did not have prior experience of using VR headsets.
- Relationships Between the Variables in the TAM: The Pearson product-moment correlation was used to test the correlations between perceived usefulness, perceived ease of use, attitude toward use, and intention to use. The results presented in Table 6 indicate that all four variables had significant positive correlations with each other ($p < 0.01$). Thus, with regard to the acceptance of gesture control in VR, perceived usefulness, perceived ease of use,

attitude toward use, and intention to use have significant correlations with each other.

Table 6. Pearson correlation coefficients between variables in the TAM

	Perceived ease of use	Perceived usefulness	Attitude toward use	ItU
Perceived ease of use	—			
Perceived usefulness	0.821**	—		
Attitude toward use	0.750**	0.838**	—	
Intention to use (ItU)	0.728**	0.839**	0.858**	—

** : p<0.01

Table 7. Moderating effect of self-efficacy (W) on the relationship between perceived usefulness (X) and attitude towards use (Y)

R	R-sq	MSE	F	p
0.8521	0.7262	4.0927	225.3895	0.0000

Model	coeff.	t	p
constant	1.0052	0.3451	0.7303
X	0.5711	5.4908	0.0000
W	0.3235	1.4997	0.1349
X*W	-0.0033	-0.4568	0.6482

Interaction	R2-chng	F	p
X*W	0.0002	0.2086	0.6482

Table 8. Moderating effect of self-efficacy (W) on the relationship between perceived ease of use (X) and attitude towards use (Y)

R	R-sq	MSE	F	p
0.7669	0.5881	6.1562	121.3509	0.0000

Model	coeff.	t	p
constant	7.4744	2.2237	0.0270
X	0.3863	2.5935	0.0100
W	0.0660	0.2642	0.7918
X*W	0.0079	0.7813	0.4354

Interaction	R2-chng	F	p
X*W	0.0010	0.6104	0.4354

Using the TAM to Investigate the Effect of Self-Efficacy on Each Variable

SPSS and Hayes Process Macro v4.2 were used to test the moderating effect of self-efficacy (moderating variable W)

on the relationship between perceived usefulness (independent variable X) and attitude toward use (dependent variable Y). The results in Table 7 and Figure 3 indicated that self-efficacy did not have a significant moderating effect (p<0.01) on this relationship.

Moreover, regression analysis was conducted to understand the effect of self-efficacy (moderating variable W) on the acceptance of gesture control in VR. In this study, we used multiple regression analysis instead of structural equation modeling (SEM) because our primary focus was to test the specific effects of interaction gestures and the moderating role of self-efficacy. Regression analysis provides a clearer and more robust interpretation of these specific paths, especially when testing for interaction effects. The results in Table 8 and Figure 4 indicated that self-efficacy did not have a significant moderating effect on the relationships between perceived ease of use (independent variable X) and attitude toward use (dependent variable Y).

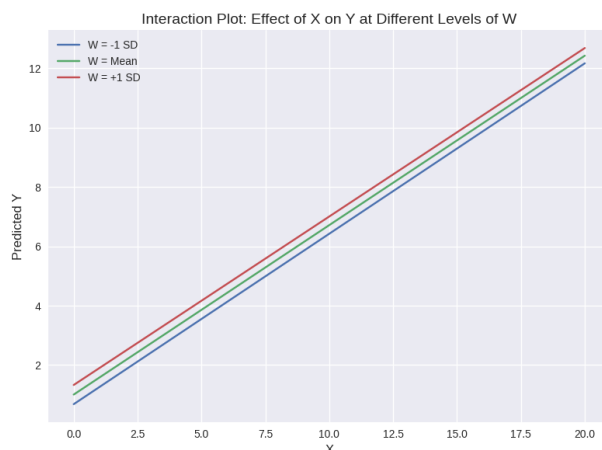


Figure 3. Interaction Plot: The effect of perceived usefulness (X) on attitudes toward use (Y) under different levels of self-efficacy (W).



Figure 4. Interaction Plot: The effect of perceived ease of use (X) on attitudes toward use (Y) under different levels of self-efficacy (W).

Conclusion

The main purpose of this study was to use the TAM to analyze whether the background variables of senior high school students in New Taipei City had significant effects on their acceptance of gesture control in VR. This study also explored the relationships between the variables in the TAM in the context of gesture control in VR. Finally, this study investigated whether self-efficacy had a positive effect on the relationships of perceived usefulness and perceived ease of use with attitude toward use.

A questionnaire survey was performed, and 271 valid responses were collected. The collected questionnaire data were subsequently used to test the research hypotheses. The following conclusions were obtained in this study with respect to user acceptance of gesture control in VR systems:

- Perceived ease of use and perceived usefulness have a significant positive correlation.
- Perceived usefulness and attitude toward use have a significant positive correlation.
- Perceived ease of use and attitude toward use have a significant positive correlation.
- Attitude toward use and intention to use have a significant positive correlation.
- Self-efficacy does not strengthen the positive correlation between perceived usefulness and attitude toward use.
- Self-efficacy does not strengthen the positive correlation between perceived ease of use and attitude toward use.

This study offers insights for the enhancement of instructional design and user experience in educational settings. By understanding the impact of self-efficacy on the use of gesture-based interfaces, educators can develop more intuitive learning environments that align with the natural interactions of students. This research provides three key theoretical insights. First, it broadens the scope of TAM by testing it in a fully immersive VR environment, moving beyond traditional web and mobile studies. Second, it integrates VR-specific interactions, specifically interaction gestures, into the model. This bridge between technology acceptance and human-computer interaction helps explain how physical movement influences user perceptions. Finally, by identifying the moderating role of self-efficacy, the study highlights that user acceptance is not uniform; instead, it is shaped by individual confidence and capabilities, offering a more detailed view of why different users adopt VR technology differently.

This study found that the moderating effect of self-efficacy was not significant, reflecting that the high

intuitiveness and immersion of virtual reality systems lower the operational threshold. Because virtual reality interactions typically employ a "natural mapping" design, even users with low self-confidence can complete tasks intuitively, thus weakening the role of individual psychological traits (such as self-efficacy). This suggests that in technologically supported environments, the influence of traditional psychological traits on behavior may be offset. Future research could examine whether self-efficacy re-emphasizes complex or non-intuitive tasks and extend to dynamic operations (such as rotation and grasping) to test the generalizability of findings.

To further refine these findings, it is essential to address the study's limitations in subsequent research. The initial study's participant pool was narrow, predominantly young and educated, which may not reflect the broader population's experiences. One limitation of this study is the use of regression-based path testing rather than a full SEM approach. While this was appropriate for our sample size ($N = 271$) and focus on moderation, future research could use larger samples and SEM to further validate the overall structural fit of the extended TAM. Additionally, the research focused on immediate behavioral intentions, omitting the consideration of long-term engagement and practical application in everyday learning contexts. To mitigate common method bias (CMB), this study employed anonymization, avoided terms associated with social expectations, and utilized a cross-sectional design. Furthermore, the correlation matrix revealed the absence of extremely highly correlated variables, thus reducing concerns about single-source bias. However, the cross-sectional design and self-reported data may still be affected by CMB; future research could utilize longitudinal or multi-source data to validate the stability of the results. Moreover, influential variables such as personality, motivation, and feedback were not examined in relation to self-efficacy and VR gesture control. Future studies should, therefore, aim to include a more diverse and extensive sample, assess the enduring impact of self-efficacy over time, and explore the various factors that could facilitate or impede the integration of gesture-based controls into educational frameworks.

The researchers found in their experiment that self-efficacy can enhance interest in learning gestures, but it is not necessarily related to perceived ease of use or perceived usefulness. Future research is recommended to analyze and experimentally study the impact of self-efficacy on learning attitudes. This approach will not only validate the research but also enhance the adoption and effectiveness of gesture-controlled interfaces in learning environments.



Appendix

TAM-Based Questionnaire for Investigating the Effect of Self-Efficacy on Gesture Control in VR

※Except for the open-ended items and multiple-choice items, all other items were answered using a 5-point Likert scale ranging from 1 for strongly disagree to 5 for strongly agree.※

Basic information

- Sex: Male Female
- Grade:
Elementary school (Year 1 or 2 Year 3 or 4 Year 5 or 6)
Junior high school (Year 7 Year 8 Year 9)
Senior high school (Year 10 Year 11 Year 12)
- Is this your first time using a VR headset: Yes No, I have used the _____ VR headset.
- Is this your first time using a virtual art gallery software program: Yes No, I have used it on my phone or computer.
- Is this your first time using hand gestures to interact in VR: Yes No, I have used hand gestures to interact in VR in the past.

Perceived ease of use

- I think using gesture control to perform actions in the virtual art gallery was easy.
- I can easily learn to perform actions through gesture control in the virtual art gallery.
- I think navigating through gesture control in the virtual art gallery was easy.
- I think selecting objects through gesture control in the virtual art gallery was easy.
- I could use gesture control to visit the virtual art gallery easily without the assistance of a controller.
- My learning of gesture control was smooth.

Perceived usefulness

- Gesture control allowed me to achieve my objective of visiting the virtual art gallery faster.
- Gesture control facilitated the process of visiting the virtual art gallery.
- Gesture control helped me to easily interact with artworks in the virtual art gallery.
- I think using gesture control for performing actions in VR is a useful approach.
- I think gesture control is more convenient than a mouse or keyboard.
- I think gesture control helps visitors to immerse themselves in the virtual art gallery more easily.
- I think gesture control helped me to perform actions more intuitively.

Self-efficacy

- When I used gesture control, I did not need the assistance of others.
- Even if I had never used gesture control in VR before, I still believed that I could do an excellent job.
- When I encountered problems in the gesture control, I solved the problems myself and did not require assistance from others.
- I believed that I could use gesture control to visit the virtual art gallery successfully.

Attitude toward use

- I enjoyed using gesture control to perform actions in the virtual art gallery.
- Using gesture control to visit the virtual art gallery was a pleasant experience to me.
- I believed that using gesture control to perform actions in the virtual art gallery was something worth trying.
- I enjoyed using gesture control to interact with artworks in the virtual art gallery.
- I am happy to use more diverse hand gestures to visit virtual art galleries.

Intention to use

- I am willing to continue using gesture control to interact in the virtual art gallery in the future.
- I am willing to recommend others to use gesture control to interact in the virtual art gallery.
- I am willing to frequently use gesture control to interact in the virtual art gallery.
- I am willing to use more hand gestures to perform actions in the virtual art gallery.
- I prefer using hand gestures over controllers when I interact in the virtual art gallery.

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