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Investigating the Effect of Virtual Reality Application on Teaching Assistance for Machine Tools Operation Education

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Abstract—**With the assistance of developed virtual CNC machine tools, industry and school can alleviate the educating and training constraints on CNC practice courses. However, whether the design product (virtual machine tool) is consistent with student's expectation is also worthwhile to study. Therefore, in this paper, we investigated the effect of VR on the student's intention to learn the designed VR machine tool in CNC practice course based on affordance theory. The proposed theoretical model was empirically evaluated by using survey data collected from 170 students concerning their perceptions of affordance for a designed VR machine tool. The research result might provide a reference for academy and industry to design an improved VR system to satisfy student's expectation**.

Keywords: Virtual Reality (VR) , machine tool, affordance theory, visibility, compatibility.

I. INTRODUCTION

The VR has attracted more attentions for industry and education. The teaching and learning in CNC practice course need many expensive machine tools. But current teaching environment cannot afford enough equipment and safe learning environment for students. This will result in the difficulties to achieve the learning performance and affect the student's capability for further learning and job. Moreover, even the equipment is sufficient, if the student incautiously operates the real machine, he will get injured or destroy the machine. Therefore, the adoption of virtual machine tool to assist the CNC practice course is imperative. Though the VR machine tool has many advantages to assist the learning, it still has some constraints in comparison with a real machine tool. **Norman [1]** argued that if the system image of the product (or system) does not make the design model (designer's conceptual model) clear and consistent **(Fig. 1)**, then the user will end up with the wrong mental model (user's model). Many scholars have argued that the customer's perceived affordance is very important for product's market success. The affordance will influence the user's intention to adopt the product. Therefore, the objective of this paper is to investigate the effect of VR on the student's intention to learn for the designed VR machine tool in the CNC practice course based on affordance theory.

From the economic point of view, VR can decrease the training cost of using real machine operation practices **[2].** Furthermore, it can also enhance both the learning interest and teaching effectiveness for students **[3]**. **Steuer [4]** considered that VR has three important elements - media richness, interactivity and telepresence. In this paper, we adopted non-immersive VR so the telepresence element of VR is not in the research scope. The two elements, media richness and interactivity, are the research key points in this paper.

The noun "affordance" was first introduced by **Gibson [5,6]** and it was used to interpret the actionable properties between the world and an actor (a person or animal). Gibson defined the affordances of the environment as "what it offers the animal, what it provides or furnishes, either for good or ill" from ecological psychology view. **Hartson [7]** defined and used four complementary types of affordance in the context of interaction design and evaluation. In order to explain why ICT acceptance and use is still limited, **Zhang [8]** believed that the ultimate goal of designing an ICT for human use is to achieve high motivational affordance so that users would be attracted to it, really want to use it, and cannot live without it.

From the above-mentioned literature of affordances and related research, we find that affordances have become an indispensible factor to investigate the effectiveness and usability of product design. However, there are various perspectives on affordances based on the different discussion contexts. So it is necessary to make an arrangement in order to discriminate the affordance terminologies, and further apply them on ICT artifacts design or on explanation for the user acceptance of ICT artifacts.

II. RESEARCH METHOD

A. Research Model

The primary objectives of this research are to investigate (1) the effect of two VR characteristics, media richness and interactivity, on the perceived affordance for visibility and compatibility, and to investigate (2) the effect of two mediate variables, visibility and compatibility, on the intention to learn for the VR machine tool. **Fig. 2** illustrates the research model, and the operational definition of each construct is shown in **Table I**.

B. Questionnaire Design

Measurement variables were adapted from the literature. All items are in the team context and measured on a

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5-point Likert scale, with anchors ranging from 1 (strongly disagree) to 5 (strongly agree). Intention to learn is considered as a measure of the degree to which the students want to intention to learn **Coyle and Thorson [9]**. The measure consists of 3 items. The characteristics of virtual reality are media richness and interactivity. The 7 items on the perceived virtual reality characteristics was adopted from **Jiang & Benbasat [10]**. Perceived affordance for visibility and compatibility measure the students' perceptions of the ability of a medium to convey relevant visible information that can assist them in understanding the capability and functions of CNC machine tools and the extent to which students believe their virtual test experiences are consistent with their existing styles, habits, and past experiences in physical CNC teaching environments. The items were developed by **Moore & Benbasat [11]** and **Jiang & Benbasat [10]**.

III. Data Collection And Analysis

A. Data Collection

175 subjects were recruited from Far East University(FEU) and National Kaohsiung University of Applied Science (KUAS). They were also told that they would be consulted on their experiences upon their completion of the study. Prior to filling the questionnaire, the teacher introduces how to operate the VR machine tool and then let the students to test and experience themselves to the VR platform **(Fig. 3)**. These above procedures were repeated for the two products.

The survey yielded a total of 170 complete and valid responses for data analysis. **Table II** lists the demographic information. Among the respondents included 13 women and 157 men. The majority of participants belonged to the young adult segment and they were undergraduate students. Survey packages included two cover letters and two questionnaires over limited demographics, Virtual reality characteristic variables, affordance variables, and intention to learn were sent to identified students willing to participate.

B. Data Analysis

PLS (partial least squares) Graph 3.0 software was used to evaluate the measurement and structural models. Using ordinary least squares as its estimation technique, PLS performs an iterative set of factor analyses and applies a bootstrap approach to estimate the significance of the paths. The validation of the measurement model includes item reliability, convergent validity, and discriminant validity tests. Factor loadings, shown in **Table III**, should be higher than 0.7 to demonstrate high reliability. All loadings reflect this condition. Convergent validity can be examined by item-total correlation (ITC) shown in **Table III**, composite reliability (CR) also shown in **Table III**, and the average variance extracted (AVE) by the constructs as shown in **Table IV**.

To demonstrate convergent validity, ITC should not be lower than 0.3 **[12]** and composite reliability should be higher than 0.7 **[13]**. Moreover, if the square root of the AVE is less than 0.71, it means that the variance captured by the construct is less than the measurement effect and the validity of a single construct is questionable. To have required discriminant validity, the correlation between constructs (**Table VII**) should be lower than 0.80 and the square root of AVE should be higher than inter-construct correlation coefficients **[14,15]**. As can be seen in **Tables III and IV,** all of these conditions are met. **Figure 4** shows the analysis results of the structural model. All results are as expected except the negative relationship between relationship conflict and balance of member contribution is not significant at $p < 0.05$.

IV. Discussion

From **Fig. 4**, we can find that interactivity has very strong positive influence on perceived affordance for compatibility but the effect of media richness is insignificant; both media richness and interactivity has significant positive influences on perceived affordance for visibility; and perceived affordance for visibility has strong positive influence on intention to learn but the effect of perceived affordance for compatibility is insignificant. As a result, it provides further empirical evidence on the generalization of the prior studies to the VR frame. The CNC teaching institutions should continue to use virtual reality technique to improve teaching outcomes. However, it is necessary to further realize some important factors such as perceived affordance for visibility influencing the intention to learn of students, even the intention to adopt for possible users.

V. Conclusions

In this paper, we have investigated the effect of virtual reality application on teaching assistance for machine tools operation education. Most of prior studies of virtual reality on education focused on development of system or tool (technical aspects) but seldom spent efforts to investigate the user's cognition towards the designed system. This will result in a gulf between the designer and user and the software system can't achieve its original design goal on education or market. By way of the user's evaluation, the research result in this paper could feedback to the designers and notify them which factors is more important based on users' attitudes and intentions so as to develop a successful software system for CNC operation training and teaching. This paper has also proposed a new theoretical model to investigate the relations of characteristics of VR, perceived functional affordances, and the intentions to learn. The research result in this paper might also provide a reference for academy and industry to design and improve related or similar VR systems in future.

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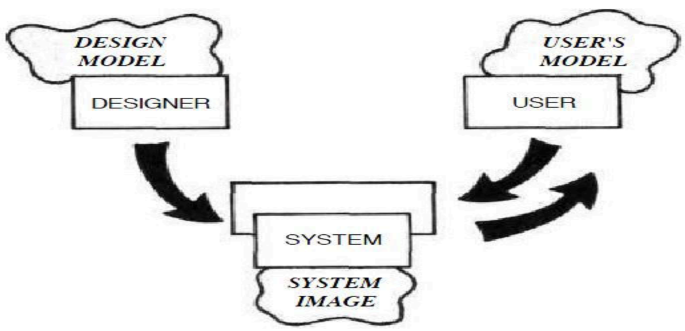


Fig. 1 Relations between design model, system image and user's model (Norman, 1990) [1]

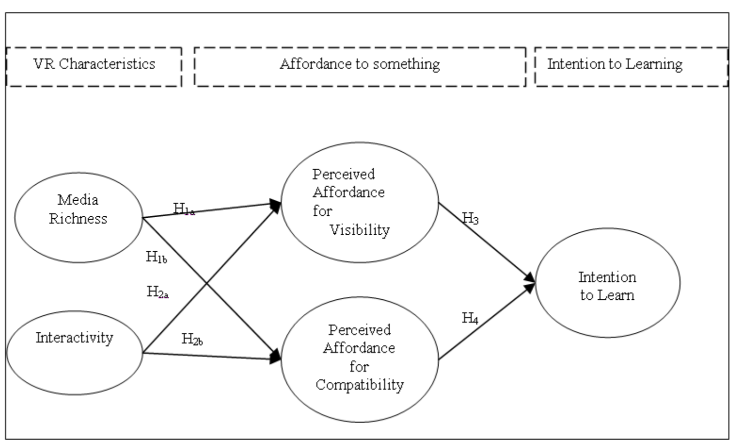


Fig. 2. Research Model

Table I. Operational Definition of Constructs in Research Model

Construct	Operational Definition	Ref. Source
Media Richness	*levels of representational quality and volume of content in a mediated environment.*	Jiang & Benbasat (2007)
Interactivity	*the degree to which users can manipulate the form and content of a mediated environment in real time*	Jiang & Benbasat (2007)
Perceived Affordance for Visibility	*students' perceptions of the ability of a medium to convey relevant visible information that can assist them in understanding the capability and functions of CNC machine tools*	Jiang and Benbasat (2007)
Perceived Affordance for Compatibility	*the extent to which students believe their virtual test experiences are consistent with their existing styles, habits, and past experiences in physical CNC teaching environments*	Moore & Benbasat, 1991; Jiang & Benbasat, 2007
Intentions to Learn	the likelihood that students will use and learn on this medium	Coyle and Thorson (2001)

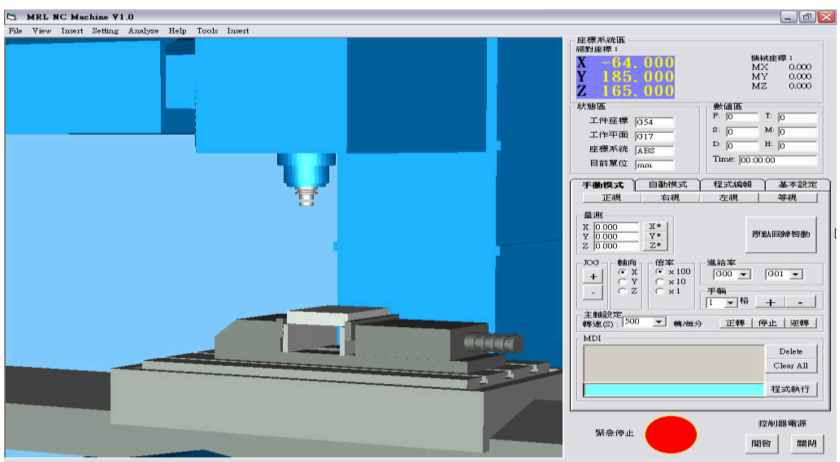


Fig. 3. Snapshots of the teacher's demonstration with a developed virtual machine tool

Table II. Demographic Characteristics of Respondents (participants n = 170)

Gender	Frequency	Percentage
Male	157	92.35%
Female	13	7.65%
School		
FEU	81	47.65%
KUAS	89	52.35%
Department		
Mechanical	116	68.23%
Computer Application	52	30.59%
Mold	2	1.18%
Degree		
Bachelor 2	127	74.72%
Bachelor 3	40	23.53%
Bachelor 4	3	1.76%

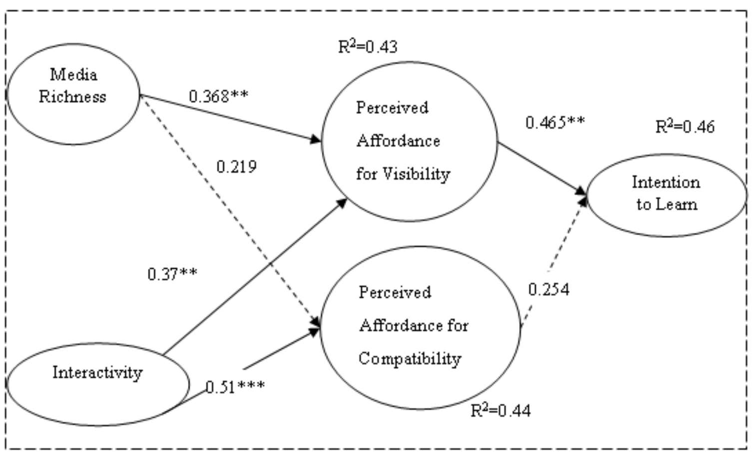
TABLE III. Factor Loadings and Item-Total Correlation

Constructs	Loadings	ITC
Media Richness **(CR=0.91)**		
1. The virtual machine tool is animated.	0.86*	0.65
2. The virtual machine tool is lively.	0.88*	0.63
3. I can acquire the capability and functions of the virtual machine tool from different sensory channels.	0.78*	0.47
4. the virtual machine tool is exciting to my senses.	0.86*	0.59
Interactivity **(CR=0.91)**		
1. I am able to interact with this virtual machine tool.	0.88*	0.61
2. This virtual machine tool can respond to my input on real time.	0.88*	0.60
3. I feel that I can interact with this virtual machine tool	0.88*	0.62
Perceived Affordance for Visibility **(CR=0.90)**		
1. This is helpful for me to realize the capability and functions of the CNC machine tool.	0.90*	0.68
2. This interface is helpful in familiarizing me with the CMC controller.	0.89*	0.70
3. This interface is helpful for me to understand the functions of the CNC machine tool.	0.83*	0.55
Perceived Affordance for Compatibility **(CR=0.91)**		
1. The virtual machine tool is compatible with how I observe in physical machine tool.	0.86*	0.57
2. The virtual machine tool fits well with the way I like to learn in physical machine tool.	0.90*	0.72
3. Familiarizing myself with the virtual machine tool is similar to my leaning style in physical machine tool.	0.88*	0.63
Intention to Learning (CR=0.93)		
1. If I need to learn the operation of CNC controller, I would like to use this virtual machine tool.	0.93*	0.73
2. If I need to learn the setting of tool parameters in CNC controller, I would like to use this virtual machine tool.	0.92*	0.70
3. If I need to learn the setting of origin of workpiece in CNC machine, I would like to use this virtual machine tool.	0.88*	0.60

Table IV. Descriptive Statistics of the Constructs

Construct	Mean	SD	M3	M4	Correlations and AVE				
					V1	V2	A_1	A_2	IL
Media Richness(V1)	3.78	0.65	0.75	2.96	**0.71**				
Interactivity (V2)	3.64	0.71	0.22	0.96	0.59	**0.77**			
Perceived Affordance for Visibility (A_1)	3.80	0.69	0.53	1.61	0.58	0.58	**0.76**		
Perceived Affordance for Compatibility (A_2)	3.64	0.72	0.25	1.12	0.52	0.64	0.74	**0.77**	
Intention to Learn (IL)	3.75	0.80	0.92	1.77	0.40	0.35	0.65	0.60	**0.82**

Notes: The **bold** diagonal line of the correlation matrix is the square root of AVE; M3: Skewness; M4: Kurtosis



*** $p<0.001$; ** $p<0.01$; * $p<0.05$.

Fig. 4 Resulting Structural Model