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A COMPARATIVE STUDY OF THE PHYSICAL MODEL AND VIRTUAL MODEL IN INDUSTRIAL DESIGN

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ABSTRACT

This paper describes a multi-sensory virtual reality application in industrial design. We demonstrate how model making aid students in solving an industrial design task, using the method of verbal protocol analysis. Survey research come from 12 students in arts, engineering and industrial design disciplines, we find that both physical and virtual model during an open-ended design task helped students generate and evaluate ideas, better visualize their ideas, and helped them discover differences between physical model and the virtual model which is used to guide design behavior. The result shows that virtual model making is more efficient than the physical model, and using virtual model system could enhance creative thinking and help students become more aware of their own design ideas. Experiment results demonstrate that the adopted method can increase students' effective haptics and can be widely used in computer-aided industrial design field.

Keywords: *Physical model, Virtual model, Verbal protocol analysis (VPA), Industrial design*

1. INTRODUCTION

There is growing interest in applying ANN to power system, considerable efforts have been placed on the applications of ANNs to power systems. Several interesting applications of ANNs to power system problems [1]-[5], indicate that ANNs have great potential in power system on-line and off-line applications. One noteworthy feature of an ANN is that it can solve a complicated problem very efficiently for the knowledge about the problem is distributed in the neurons and the connection weights of links between neurons, and information are processed in parallel.

Researchers have made impressive improvements in immersive multimedia applications for computer-based education during the previous several decades. Previous studies in the design process have utilized verbal accounts, written communications, sketches, and drawings, there is less research investigate whether physical and virtual model making can contribute to a better understanding of the industrial design process [1]. Koray, Ozlem investigated the effectiveness of the problem which is based on learning and supported by interactive computer simulations [2]. These studies have also shown that immersive computer-based learning enhances students' ability of absorbing complex information [3]. Many abstract concepts in physics, geometry, chemistry, astronomy and biology can be better understood through multisensory interactions, such as vision, audition and haptics, by comparing with traditional textbooks. Especially haptics, which provides hands-on experience to students, not only makes learning more interesting and interactive but also improves the efficiency for learning.

We designed a project to investigate whether physical or virtual model making activity can contribute to students' understanding of the industrial design process. Through the method of Verbal Protocol Analysis, the results were collected from 12 students from arts, engineering and industrial design during the process of a model making design task.

Modeling methods based on strict physical disciplines need much time to deform objects, which are not suitable for interactive applications [4]. Furthermore, making a physical model helps students implement their imagination into real products, and offers them the opportunity to investigate the differences between real behavior and the conceptual model which is used to check that behavior [5].

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2. BACKGROUD

2.1 Theoretical Background

In exploring the processes which is associated with making sense of our experiences, Atman and Turns developed a 4-stage, circular model of experiential learning [6]:

1) Concrete experience: direct, practical experience.

2) Observation and reflection: discussion and identification of unexpected difficulties arising from those experiences.

3) Forming abstract concepts: critical thinking and analysis of what was observed.

4) Active experimentation: testing the analysis in new situations.

The theory suggests that learning often begins with a person who is carrying out a particular action in a particular setting, reflecting on the effects of that action, attempting to understand those effects, and then modifying actions to accommodate new ideas.

Industrial designers do not simply think step by step through conventional design process but instead iterate through cycles of proposal, conceiving and modification. Smith and Tjandra offer a review of several different models of iteration and compare them to their own experimental results [7]. They found that while no existing model accounted for all of their observations, features from each of the models most closely matched their observations. The student groups began with a short period of non-iterative design during which the students shared goals and perceptions on what were the most important design considerations [8].

We try to research the role of iteration in design through studies of students from different majors attending to individual and group tasks.

2.2 Physical Model

During model making process, students are encouraged to reflect on their actions and the results of those actions in order to validate their solution or formulate a better one. We intended to investigate the possible benefits of including a model making activity for students of arts, engineering and industrial design during a design task. The practice of hand-on physical model has been extensively used in the industrial design sector with two main purposes:

1) Representing the conceptual idea of the new product.

2) Evaluating the idea and the styling features of the new product, and assessing it.

The production of physical models and their modifications require long time and are expensive. Therefore, hand-on physical model is effective on one side, but not efficient and convenient on the other side. Physical clay model usually includes the following steps:

1) Make model prototype using foam plastic.

2) Smear sludge and rough scraping model.

3) Produce model template, and paste the reference line, see Fig.1.

4) Produce model with scraper, measuring template and other professional equipments.

5) Fix their work until the satisfying model is achieved.

6) Scan the result model into computer aided manufacturing equipments with 3D scanner.

Figure 1 Physical Clay Model

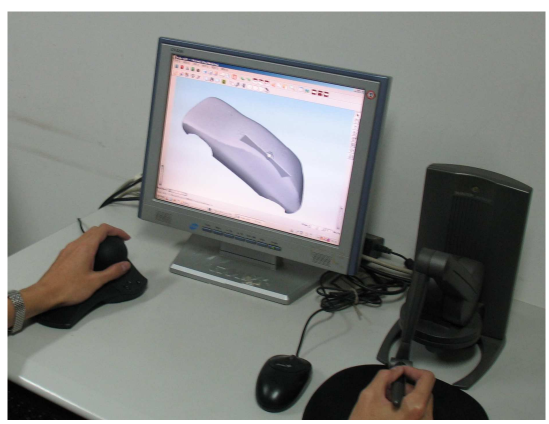

Figure 2 Virtual Model System Scenes

2.3 Virtual Model

3D free-form modeling techniques are more important approach to solve the problems by

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regarding the objects as clay which can be deformed freely. If students can deal with objects in the same way as real clay works, handling of free-form objects becomes very easy and user-friendly. So, students who are ignorant of knowledge of geometry also can build up a solid model using instructed geometrical operations, and do not need much knowledge such as mathematical theories and flexibilities of spatial recognition. We present the scene of an intuitive interface for virtual clay modeling with our free-form modeling system (see Figure 2). When sculpting tool touches virtual model, students can operate the tools on the virtual model. They can touch the virtual model with an appropriate force, which is according to the amount of penetrate depth.

3. METHODOLOGY

Because we cannot view cognitive processes, one way to know what people are thinking during a design task, is to simply ask them. We wanted to investigate the cognitive processes of within-subjects students during an open-ended industrial design task.

3.1 Subjects

In addition, being at different stages in their educational career, participants had varying levels of design experience. We collected students from arts, engineering and design discipline. Six freshmen and six seniors were contacted and asked to participate, for a total of twelve students. The freshman and the senior group both consisted of two industrial design, two mechanical engineering and two visual communication students. The average freshmen age of the subject participants was 18.5 and the average senior age was 22.6 years. However, some students may have had elective courses that included varying levels of design experience. So the range of design experience varied considerably within this student sample. It was a sample of convenience as the students were all known by another two co-authors. There were eight males and four females, from diverse disciplines and academic years.

3.2 Design Task

Robson and Crellin employed verbal protocol analysis in interface design [10].We use the verbal protocol method in the processes of design and modeling. Transcription, segmenting, and coding of the text from the audio tapes allows us to describe student design and modeling behavior. The steps were briefly described as following:

1) Transcription: Each subject's verbal protocol was transcribed from the audio tape.

2) Segmenting: Break the verbal text into segments that can be coded with a predefined coding scheme.

3) Coding: Design and modeling steps were chosen to describe each student's design and modeling process.

3.3 Procedure

Table 1 shows the measures used for the current study, in relation to the measures used for the previous studies. In summary, the following independent variables were explored:

1) Solution Quality (SQ): quality-of-solution score. Two professors and three industrial designers initially developed a scoring rubric for all of the model solutions. They evaluated each suggested alternative to rank them based on their abilities to meet design criteria.

Design Time Spent (DTS): total amount of time spent in design activity except time spent talking to the instructor.

2) Time Spent in Gathering Information and Discussion Steps (TSGIDS): combination of time spent in problem definition and time spent in gathering information.

3) Time Spent in Concept Design (TSCD): amount of time spent on individual design activities.

4) Time Spent in Decision (TSD): combination of decision and communication.

Modeling Time Spent (MTS): combination of generating ideas, modeling, feasibility analysis and evaluation.

5) Time Spent in Physical Model (TSPM)

6) Time Spent in Virtual Model (TSVM)

7) Time Spent in Evaluation for Physical Model (TSEPM)

8) Time Spent in Evaluation for Virtual Model (TSEVM)

Transition Efficiency (TE):

9) Number of Transitions (NT): number of transitions made between design steps.

10) Transition Rate (TR): number of transitions between design steps per minute.

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4. DISCUSSION

This research project was designed to investigate whether a hands-on physical model and virtual model making activity can benefit students during an industrial design task.

4.1 Design Spent Time Vs. Modeling Spent Time

In this section we characterize the processes for the physical and the virtual model using the measures and discuss the measures that correlated with quality of solution. We will also discuss comparisons made between these two modeling methods and present physical and virtual differences. Finally, the findings for differences in design process according to design task are introduced.

Figure 3 shows how the students of four groups (two physical model groups and two virtual model groups) distributed their time among the steps of the design and modeling process.

Table 1 The Measures Of Physical Model And Virtual Model Making

Measures	Physical Model Group1(P-M G1)	Physical Model Group2(P-M G2)	Virtual Model Group3(V-M G3)	Virtual Model Group4(V-M G4)
Solution Quality (SQ)	87	80	91	86
Design Time Spent (DTS)				
TSGIDS	30	26	35	20
TSCD	35	25	35	27
TSD	45	37	20	18
Modeling Time Spent (MTS)				
TSPM	80	70		
TSVM			35	32
TSEPM	25	32		
TSEVM			15	13
Transition Efficiency (TE)				
NT	6	8	3	4
TR	0.3	0.4	0.7	0.8

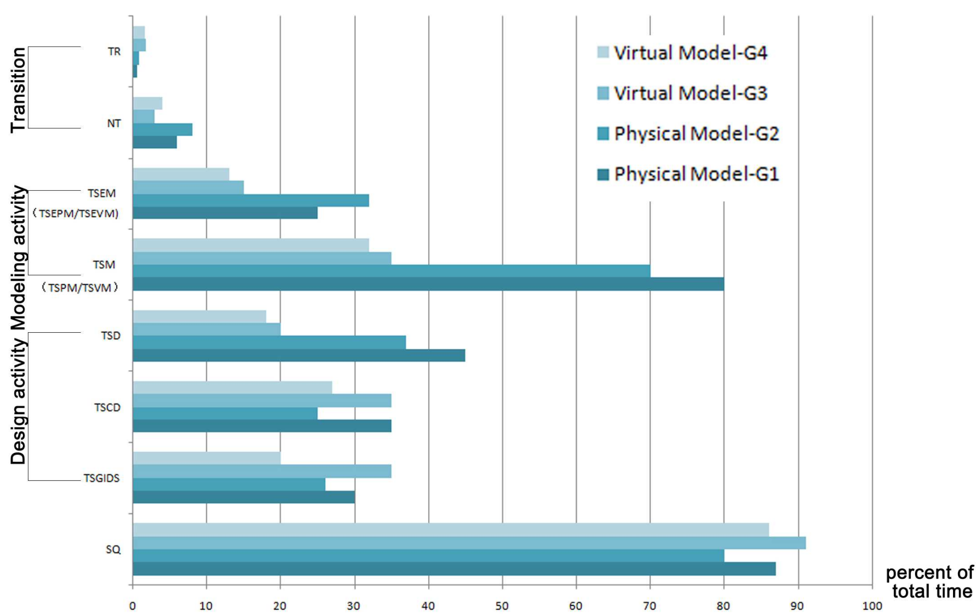

Figure 3 Percent Of Time Spent In Design And Modeling Activity For Physical And Virtual Model Groups

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To further analyze the design and modeling process of each group, we looked at the time they began gathering information, the time they began designing, the time they began modeling, the percent of time spent gathering information, the percent of time spent designing, the percent of time spent model making, and the total task time (Table 2). We wanted to investigate whether or not there was any relationship between the amount of time designing and the amount of time model making. P-M G1 spent 51.16% of their total task time gathering information and conception, but it spent 110 minutes. While V-M G3 only spent 90 minutes that represented 64.29% of their total task time. Furthermore, V-M G3 got the highest score (91) of the model solution quality, while the percent of the modeling time they spent (35.71%) was least, only spent five minutes more than V-M G4 that spent least time in model making. Only P-M G2 spent more time in model making (102 min.) than in designing time (88 min.), but they got the lowest score (80) in the four groups.

Table 2 Design And Modeling Time Variables

Group name	Gather inf. & Design (min.)	Design time (%)	Modeling (min.)	Modeling time (%)	Total time (min.)	Solution Quality
P-M G1	110 (0.312)	51.16	105 (0.348)	48.84	215	87
P-M G2	88 (0.249)	46.32	102 (0.338)	53.68	190	80
V-M G3	90 (0.255)	64.29	50 (0.165)	35.71	140	91
V-M G4	65 (0.184)	59.09	45 (1.149)	40.91	110	86

As can be seen in Table 2, the total time in the stage of design and modeling had not inevitable relationship with score of solution quality. P-M G1 got 87 SQ and spent the most time (215 min.), while G4 only spent close to half of the time of P-M G1, also got 86 SQ. Analyzing PM and VM respectively, we would find that the group which spent more time in gathering information and designing got higher score. For example, Group 1 and Group 2 both made physical model, and spent almost the same time in stage of modeling (102 min. vs. 105 min.). The time spent in gathering information and designing decided the final score of SQ. P-M G1 spent more time (110 min.) and then got the higher SQ as a matter of course. Similarly V-M G3 and V-M G4 can be availably explained.

4.2 Physical Model Spent Time Vs. Virtual Model Spent Time

As can be seen in Table 3, when students began modeling varied considerably. Does the method which students modeling will affect the total amount of time they spent on the task? Obviously, it does. Although P-M G1 and V-M G4 got the close SQ (87 vs. 86), V-M G4 only spent half of time of P-M G1. V-M group completed the modeling task in less than 34 minutes; the P-M group completed the modeling task for more than 75 minutes. P-M group spent almost 20 minutes to complete the model prototype; it was completed just three to four minutes in V-M group. The precision and modeling speed both depended on the students' proficiency of material characteristics and software. Experiments show that, students operate the software system more easily than physical model. V-M group spend average 33.5 minutes to complete the virtual model, P-M group complete the physical model for 75 minutes. As for the evaluation phase, the operator's experience of seeing and touching is crucial for physical model, while in the virtual system, a specialized detection module can evaluate whether the surface is smooth or not. The great advantage of virtual model is conversion of computer data. Data conversion output of virtual model only needs 1 minute, while the physical models need special scan equipments and reverse engineering.

4.3 Overall Findings Based On Questionnaires

Questionnaires are designed to investigate the problem of physical and virtual model making process. In the end of the test, Survey shows:

To the question which is more helpful to their innovation in the stage of idea generation, 8 students answer that virtual model making method is more efficient, 4 students prefer the real hand-on model just because they find it is easier to represent their ideas. 9 students regard the virtual model making system operate more easily than the hand-on method.

All 12 students consider that the computerized method is comparatively more efficient in the stage of evaluation than the traditional ways. That demonstrates the virtual model would very approach the real performance of the hand-on physical model.

When comes to the question which method can reduce the materials, all students consider the

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computerized model had obvious advantages in economic performance.

During the process of design task, some of the students in groups surprised when they knew they would be making a model. Some students mentioned that they did not see any building materials in virtual environment so did not expect to build. Some brought up the fact that making a model for their senior project generally took weeks, so it did not occur to them that they would make a model for this short design task. Obviously, model making prove beneficial for many students; the trend of making model in virtual environment is hopefully starting to change.

Table 3 Physical Model Spent Time Vs. Virtual Model Spent Time

	P-M Group1	P-M Group2	P-M Avg.		V-M Group3	V-M Group4	V-M Avg.
Time spent in Physical model making (min.) (%)	80	70	75	Time spent in Virtual model making (min.) (%)	35	32	33.5
Model prototype	20 (25)	19 (27.14)	19.5 (26)	Size data input (*x*,*y*,*z*)	2 (5.71)	3 (9.38)	2.5 (7.46)
Smear clay	15 (18.75)	12 (17.14)	13.5 (18)	Box prototype	1 (2.86)	1 (3.13)	1 (2.99)
Template & Reference line	14 (17.5)	13 (18.57)	13.5 (18)	Template generation	12 (34.29)	10 (31.3)	11 (32.84)
Refined scraping model	26 (32.5)	23 (32.86)	24.5 (32.67)	Modeling in virtual system	17 (48.57)	15 (46.87)	16 (47.76)
Evaluation (Artificial)	5 (6.25)	3 (4.29)	4 (5.33)	Evaluation (Intelligent)	2 (5.71)	2 (6.25)	2 (5.97)
Scan data				Data transition	1 (2.86)	1 (3.13)	1(2.99)

5. CONCLUSION

Baed on the analysis of students' verbal protocol during the physical and virtual model making task, it appears that physical and virtual model both have the potential to help students generate, visualize, and evaluate design ideas, as well as expose flaws in preliminary sketches and ideas. By tracking the time students spent in various design, physical and virtual model modeling activities, we find that, virtual model is more effective than physical model in the aspect of time spending, evaluation, data conversion. The results of comparative research between physical model and virtual model shows that operating the virtual model helps students understand better and have more fun in model making than traditional physical model. The application can be used in many design and assistant class-teaching fields, such as 3C products model making, vehicle clay model making.

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