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A Study on Design-oriented Demands of VR via ZMET-QFD Model for Industrial Design Education and Students' Learning

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The difficulty of Virtual Reality application in industrial design education and learning is VR engineers cannot comprehend what the important functions or elements are for students. In addition, a general-purpose VR usually confuses the students and provides neither good manipulation means nor useful toolkits. To solve these problems, the ZMET-QFD model presented in this paper, can translate the in-depth demands of VR into actual functions from the students' thoughts. With a ZMET-QFD model, twenty-one items are determined to be the functions for VR from the students' perspective. According to importance ranking, top ten items are: real-world parameters, physical database, multiple viewpoints, multiple-windows operation, ruler and unit display, environmental database, material database, multiple presentation models, graphical interface, and customized parameters. The findings of this study should lead to the creation of a concept of a designer-oriented virtual reality system that can truly help industrial design education and students' learning.

Keywords: industrial design, design education, virtual reality, computer-aid design, ZMET-QFD model

INTRODUCTION

A complete set of design-aided computer tools would be useful for the learning process of industrial design students, and would further inspire their imagination and creativity. Currently, general-purpose design-aid systems are quite popular, but

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specific-purpose packages, such as industrial design-aid systems, are relatively rare. As a result, students may feel demotivated and disappointed with their learning. Thus, acquiring an appropriate solution for industrial design students is essential.

Over the past few decades, virtual reality (VR) has been widely used in computer-aided learning, including in industrial design education (Barone & Lanzotti, 2001), because it has inherent benefits such as efficiency, safety, convenience, digitalization, and low cost (Gironimoa et al., 2006; Choi & Cheung, 2007). Further, VR is extensively utilized in the areas of culture conservation (Magnenat-Thalmann et al., 2007), human factors design (Maurel & Thalmann, 2000; Magnenat-Thalmann & Egges, 2006), e-learning (Jeff et al., 2008; Rueda et al., 2008), and surgery (Kim et al., 2008; Lee & Shin, 2009). These examples point to a growing number of research efforts that have come to the conclusion that utilization of VR in these various fields is invaluable.

Current VR functions and systems, however, were developed for different applications and are therefore not quite suitable to support the learning process of industrial design students, resulting in a shortage in product design presentation. This is primarily due to the fact that VR engineers cannot grasp the important functions or elements required in the learning process and, thus far, there has been relatively little research in the area. While considerable attention has been given to VR and industrial design (Barone & Lanzotti, 2001; Gironimoa et al., 2006; Choi & Cheung, 2007), to the best of our knowledge no literature on the issues of design students' demands in VR has emerged. Furthermore, the VR demands of industrial design students constitute a unique problem; therefore, using either questionnaires or interviews is not completely applicable.

In light of these concerns, this paper has three objectives: (1) proposal of a new model to overcome the research problems mentioned above; (2) analysis and comprehension of the ideal design-oriented VR system for industrial design students; and (3) generalization of the industrial students' VR demands from high involvement and represented population, and to determine the importance ranking of functions.

State of the literature

- General-purpose computer-aided systems are quite popular, but an industrial design-aided system, are relatively rare. The industrial design students may feel confused and disappointed with their learning.
- For industrial design students, using virtual reality (VR) in design education is useful for their learning processes of shape constructing, material usage, and product concept simulating or evaluating.
- Current VR functions and systems have been developed for different applications, and are thus not quite suitable for industrial design students on their learning process.

Contribution of this paper to the literature

- This study is one of the first attempts to analyze the demands of VR application for industrial design education and learning published by Taiwan science educators.
- This study presented a new model, combining the ZMET with the demands exploration of QFD, can translate the in-deep demands to the functions for every expert issue.
- The findings of this study should lead to the creation of a concept of a designer-oriented virtual reality system that can truly help the design education and students' learning.

BASIS OF THE ZMET-QFD MODEL

This paper proposes a combination of the Zaltman metaphor elicitation technique (ZMET) and quality function deployment (QFD) called the ZMET-QFD (Z-Q) model, which achieves the objectives outlined above. In the proposed model, ZMET is first used to investigate demands and opinions; then, QFD translates the demands into definite functions and the intensity of the demands is calculated. We envision that the outcomes of QFD can truly help VR engineers to understand how to construct suitable VR environments for industrial design students and to make industrial design learning more friendly and intelligent.

In this section, we explore the literature on the original concept and technique of the Z-Q model, which is composed of the revised personal involvement inventory (RPII), ZMET, and QFD. The ensuing sections discuss the relevant work in these areas.

Revised personal involvement inventory (RPII)

In the early stages of the development of involvement theory, Krugman (1965) stated that the involvement intensity of human beings is considered to be a personal difference that represents a kind of behavioral motive and demand, and also considered involvement to be a psychological condition of a human being's concern intensity or important intensity. Houston and Rothschild (1978) subsequently further proposed classification for involvement and divided it into three categories: (1) situational involvement, (2) enduring involvement, and (3) response involvement.

However, involvement intensity could not be calculated and measured at that time, and so it remained unmeasured until Zaichkowsky (1985) presented a personal involvement inventory (PII) approach that could help quantify involvement. The inventory comprised twenty questions with seven scales, with each question having one pair of opposite adjectives. A few years later, Zaichkowsky (1994) improved and simplified his research data via several practical case studies. The new approach was called the RPII, preserving the original high reliability and validity (Cronbach alpha > 0.9), and canceling some confusing adjectives in the new inventory. The new method for measuring involvement has a significant advantage in that functions more effectively by deleting the illogical or void questionnaires from participants who write arbitrarily or are not sufficiently focused.

Although RPII is generally utilized in the areas of advertisement and marketing, many researchers have used RPII in various regions to extract the available participants for further investigation. In our study, RPII was used to help find a representative sample of industrial design students, or selective participants, who meet the requirements for the research objective and have a high relevance. The RPII is illustrated in Table 1.

Zaltman metaphor elicitation technique (ZMET)

It is a known fact that more than 80% of human communications is neither text-based nor verbal (Philip, 2005). Thus, research methods such as investigations, interviews, and questionnaires are not suitable for an issue in which a participant's professional know-how, experience, and preference are particularly critical to the solution.

The ZMET metaphor elicitation technique proposed by Zaltman and Coulter (1995) is a good research method for exploring in-depth the true inner thoughts and needs of participants. It can be used to elicit a participant's idea regarding his/her personal viewpoint on a topic, then map concepts as mental models (Zaltman, 1997). This approach has been demonstrated to elicit vivid and detailed meanings in

Table 1. RPII- revised personal involvement inventory

1	Important	_:_:_:_:_:_:	Unimportant*
2	Boring	_:_:_:_:_:_:	Interesting
3	Relevant	_:_:_:_:_:_:	Irrelevant*
4	Exciting	_:_:_:_:_:_:	Unexciting*
5	Means nothing	_:_:_:_:_:_:	Means a lot to me
6	Appealing	_:_:_:_:_:_:	Unappealing*
7	Fascinating	_:_:_:_:_:_:	Mundane*
8	Worthless	_:_:_:_:_:_:	Valuable
9	Involving	_:_:_:_:_:_:	Uninvolving*
10	Not needed	_:_:_:_:_:_:	Needed

**indicates item is reverse scored*

the mental models of participants, some of which were deep and perhaps unconscious (Glenn & Jerry, 2002). Further, ZMET can be used in conjunction with a variety of behavioral and social research methods, including visual projection techniques, in-depth personal interviews, and a series of qualitative data-processing techniques (Lee et al., 2009). In addition, ZMET has been used to investigate the thinking of industrial designers, with much useful information being obtained (Liang et al., 2010).

ZMET's construction process can be separated into ten parts: (1) storytelling, (2) missing images, (3) sorting task, (4) construct elicitation, (5) most representative picture, (6) opposite image, (7) sensory images, (8) mental map, (9) summary image, and (10) consensus map. Researchers can use the constructs and their relationships to generate diagrams that represent the mental models that depict the interrelated concepts or constructs of the individual or sample group under study (Chen, 2010). Most of the constructs in the mental model include the desired values and goals. For different objectives and research areas, the process's content can be adjusted by researchers, and a new model can even be developed (Pieter, 2010). To the best of our knowledge, this is the first time the ZMET model is being applied to VR.

Quality function deployment (QFD)

QFD is a well-known technique that has been applied in many studies for demand research. The first complete concept of QFD was originated by Akao (1990), who proposed it as a systematic way to translate customer requirements (CRs) into engineering characteristics (ECs) via a matrix. QFD is helpful in solving the problem of demands in the design process. Akao's ECs are now globally acknowledged as design requirements (DRs) in the design area (Delice & Gungor, 2010), and the CRs are also called the voice of customers (VOC). In terms of its application in industry, QFD has been utilized by many companies, including General Motors (GM), Hewlett-Packard (HP), Motorola, and IBM, for various objectives—from new product idea generation to innovative product development (Cristiano et al., 2001). One important element of the QFD model is the relationship matrix or "House of Quality (HOQ)," which provides both a valuable resource for designers and a way to compile and convert customer feedback into information for researchers (Karsak, 2004). The HOQ matrix and sequence are illustrated in Figure 1.

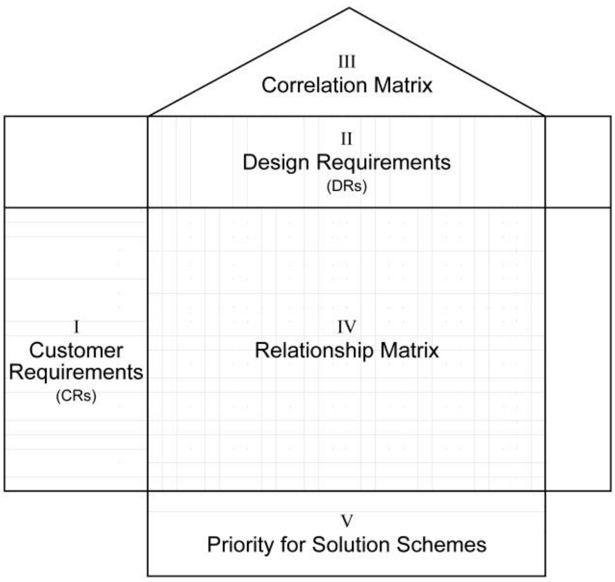

Figure 1. Original house of quality

Based on the HOQ, we know that CRs are in the left wing (Step I). Each of these requirements has an importance value elicited from the customer, usually via surveys, interviews, or focus groups (Cohen, 1995). Most recent studies, however, obtain the importance value through the analytic hierarchy process (AHP), which is more effective than other techniques (Ho, 2008; Okur et al., 2009). DRs are listed horizontally along the top of the relationship matrix (Step II), and every item that is suggested as a DR is according to the result of the CRs. The correlation matrix comprises the roof of the HOQ (Step III), and is composed of the relative strength between each DR item. In the middle site (Step IV), the relationship matrix describes the strength of the relationships between the DRs and CRs, and the impact of the DRs on provision of CRs is specified as different degrees. Previous studies typically adopted multiple degrees, such as "very strong," "strong," "moderate," "weak," and "none" (Buyukozkan & Feyzioglu, 2005; Lin et al., 2006), which have since been simplified to "strong," "weak," and "none" (Liu et al., 2009; Sun & Liu, 2010). This new and simple classification method allows the statistics to be clearer and more obvious.

An accurate understanding of CRs is a challenge in traditional QFD analysis (Sireli et al. 2007). As a result, various modifications have been proposed. For example, Matzler and Hinterhuber (1998) proposed a quantitative integration approach of Kano's Model and QFD that extends that approach into multiple product designs. Yan et al. (2005) proposed an improved conventional quality function deployment technique in which QFD is combined with the design knowledge hierarchy (DKH) and the restricted coulomb energy (RCE) neural network. On the basis of the principles of decision-based design (DBD), Hoyle and Chen (2009) proposed a new design tool, called product attribute function deployment (PAFD), which extends the qualitative matrix principles of QFD while utilizing the quantitative decision-making processes of DBD.

From the above review, it is clear that QFD is a good approach that can be integrated with other techniques for a variety of research purposes and objectives. A combination of ZMET with QFD should therefore be able to facilitate the acquisition of in-depth demands and the translation of those demands into functions. Consequently, finding a suitable way to explore the demands for QFD is a critical aspect of previous work. In our study, we used ZMET's features to support QFD at the first demands input step.

METHODOLOGY

Our study was designed to answer the following question: what are the real demands and functions of VR for industrial design education and the learning of students? For this primary objective, we employed a three-phase approach to gain an in-depth and complete understanding of the real VR demands and functions needed by industrial design students. The three phases were as follows: (1) Selection of representative participants through RPII. (2) Elicitation of demands and constructs using ZMET. (3) Translation of the demands into functions and importance ranking via QFD. For phase 3, we renamed VOC to voice of design students (VOD) because, in this study, the participants were not customers. Further, in this paper, we call the ZMET-QFD model the Z-Q model, as shown in Figure 2.

Participants

The participants in the study were randomly selected from a population of

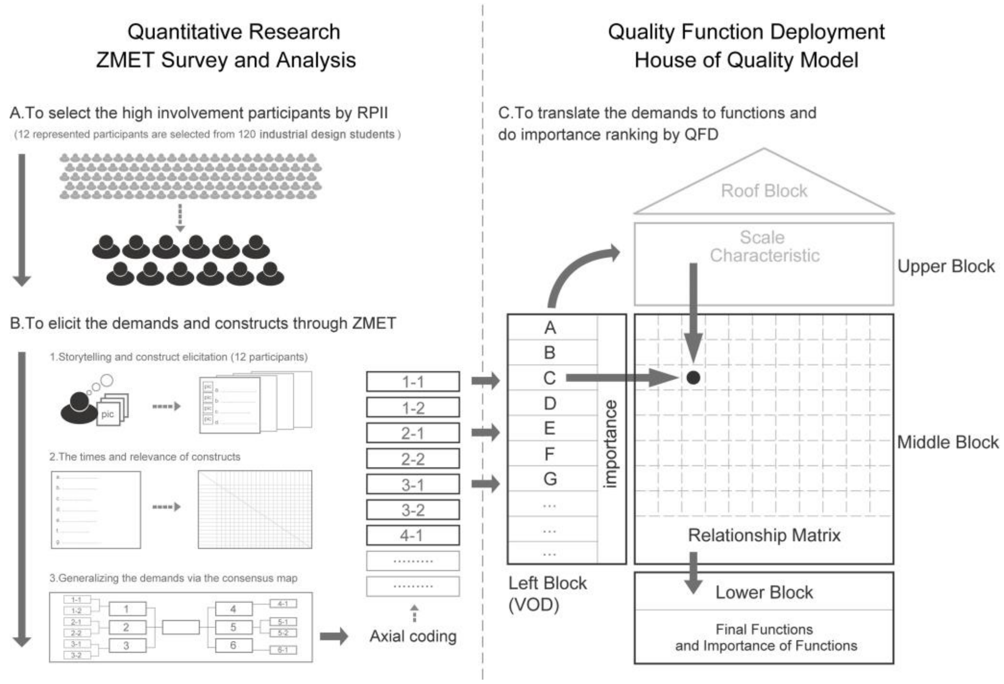

Figure 2. Framework of ZMET-QFD (Z-Q) model: development process for VR demands of industrial

industrial design students familiar with 3D and VR techniques. One hundred and twenty students participated in this experiment—sixty males and sixty females. To ensure statistical homogeneity of social backgrounds, all participants were from Taiwanese cities, specifically, Taipei, Tainan, and Kaohsiung. Their ages ranged from eighteen to twenty-two years old. All of the participants were volunteers, and there were no specific constraints in our experiment.

Phase-A: Selection of representative participants using RPII

Because ZMET is an approach for in-depth exploration, it is most suitable for experiments with fewer participants, normally between eight and twelve. Some studies used PII or RPII before execution of ZMET in order to encourage deep involvement by participants from the entire sample (Braun-Latour & Zaltman, 2006). As summarized from RPII, deep involvement by participants is represented by two characteristics: (1) they are more concerned about the research theme; and (2) they ordinarily pay more attention to the study. Apparently, such participants provide more original thoughts and better constructs than others.

RPII is composed of ten seven-scale items: (1) important-unimportant, (2) boring-interesting, (3) relevant-irrelevant, (4) exciting-unexciting, (5) meaningful-meaningless, (6) appealing-unappealing, (7) fascinating-tedious, (8) worthless-valuable, (9) involving-inadvertent, and (10) needful-needless. In this study, some of these items were reverse scored in order to prevent inattentive participants from influencing the collected data, thereby helping us to eliminate illogical answers from questionnaires. We set the theme for RPII as, "Doing shape constructing, product simulating, and product evaluating for industrial design learning in VR," and then invited the one hundred and twenty participants to fill out the questionnaire. The twelve participants with the highest involvement value were then chosen as the sample and asked to continue on to the next experiment.

Phase-B: Elicitation of demands and constructs through ZMET

ZMET is a standardized and systematic approach designed to elicit the in-depth or potential thinking of objective participants or the constructs of their minds (Zaltman & Schuck, 1998; Zaltman, 2003). Focusing on the aspect of thinking and the construct of industrial design students, we canceled some steps that were irrelevant to our objectives and integrated the original ten steps into three steps. The integrated procedure in this study was then distributed into (1) storytelling and construct elicitation, (2) times and relevance of constructs, and (3) generalization of demands via the consensus map.

Before completing the experiment with ZMET, the representative participants (N = 12) were asked to collect ten pictures that had an intense relationship with the research theme (VR for industrial design students learning). Collection of the pictures did not have any special constraints apart from the fact that they should be legal. After seven days, the participants were invited to the laboratory individually to complete the storytelling and were asked to bring the pictures they had collected. In this step, each participant told their story and explained their thoughts to the researcher (through those pictures). An audio recording and notes were taken throughout the session. The total time spent on this experiment was approximately ninety to one hundred and twenty minutes per participant. Finally, the recorded data were used to elicit various constructs over a period of two weeks.

In the next ZMET step, we organized a focus group with the participants to discuss each construct and to learn what the important constructs were. According to the principles of ZMET, a construct is deemed important if one-third or more of the participants ($CN \geqq (1/3)N$, N = 12) mentions it. Then, we placed these important constructs into a correlation matrix to obtain the correlated-strength of each of them. (Each important construct was to be connected together with a line in the next step of the consensus map, if one-quarter or more of the participants ($\geqq (1/4)N$) consider an intense correlation to exist between any two important constructs.)

Finally, we placed the important constructs specified and connections into a mind map to integrate all the information and data from the participants involved. The resulting mind map, which we call a consensus map, enables researchers to comprehend the participants' thought processes and logic regarding the research question. As a result, we were able to obtain the VR demands of the industrial design students from the constructs hierarchy of the consensus map. These demands were then utilized in the next phase.

Phase-C: Translation of the demands to functions and importance ranking using QFD

QFD is a practical approach for planning and problem solving in industrial design. This approach is also used extensively to explore the correlation between demands and functions. In this phase, we classified the HOQ model of the QFD into five main steps: (1) design students' demands, (2) functional requirements, (3) correlation matrix, (4) relationship matrix, and (5) importance ranking of functions. The HOQ model research team consisted of three academic staff members (two professors and a doctorate student) and a group of industrial designers (comprising a manager and two general staff), resulting in a total of six people.

As shown in Figure 2, first, we placed the consensus map result into the left block of the HOQ model to represent the demands of VR (Figure 2, left block). The AHP method was then used to determine the weight or importance level of each item on the scale. In the AHP process, the item's importance was calculated via comparison, based on the research team's discussion. The results from the AHP calculation revealed the systematic and logical importance of every item. Most importantly, this process is better than the traditional method of surveying and interviewing to enable valid distribution of weight (Liu et al., 2009).

Second, the upper block of the HOQ model consisted of the characteristics of the VR functions (Figure 2, upper block). These characteristics were developed based on the axial demands from the left block of the HOQ combined with professional opinions, which included the judgments of the research team and six VR engineers who were invited to participate in this step.

Third, the roof block of the HOQ model was used to determine the relative relationship among the characteristics of the functions on the scale (Figure 2, roof block). The intensity of the relationship was classified as strong, moderate, or weak, with a scale of 9, 3, and 1, respectively. This step was completed following discussions with the research team. Fourth, the middle block of the HOQ model was used to determine the relative relationship between the left block (demands of VR) and the upper block (functions for VR), acting as a key point for QFD. This step was also completed following discussions with the research team (Figure 2, middle block).

Finally, the lower block of the HOQ model was used to calculate the overall weight and relative importance of the functions. We then ranked the functions based on each item's importance value to learn what the valuable and suitable functions are for industrial design students (Figure 2, lower block).

RESULTS

Phase-A results

Among the one hundred and twenty participants, eighteen RPII results were deemed illogical through questionnaire reverse disposition, resulting in only one hundred and two participants' responses being deemed valid. Descriptive statistics

Table 2. Measurements of revised personal involvement inventory (N=102)

Number	Involvement index	Min	Max	M	SD
1	Important-Unimportant*	1.00	7.00	5.08	1.53
2	Boring-Interesting	2.00	7.00	5.22	1.43
3	Relevant-Irrelevant*	1.00	7.00	4.68	1.37
4	Exciting-Unexciting*	2.00	7.00	5.01	1.31
5	Meaningful- Meaningless	2.00	7.00	4.77	1.46
6	Appealing-Unappealing*	2.00	7.00	5.21	1.38
7	Fascinating-Tedious*	2.00	7.00	4.79	1.36
8	Worthless-Valuable	1.00	7.00	4.56	1.43
9	Involving- Inadvertent *	2.00	7.00	4.11	1.35
10	Needful-Needless	1.00	7.00	4.68	1.40

**indicates item is reverse scored*

Table 3. Twelve participants with highest involvement value

Involvement index	Participant code											
	A	B	C	D	E	F	G	H	I	J	K	L
1	7	7	7	7	7	7	7	7	6	7	7	7
2	6	7	6	7	6	7	7	5	7	6	6	5
3	7	6	7	7	7	7	6	7	5	6	6	6
4	7	7	7	6	6	5	5	6	7	5	4	5
5	7	7	7	6	7	7	7	7	6	7	7	7
6	7	7	7	6	6	7	6	6	7	6	6	6
7	7	7	4	7	7	6	6	6	7	6	5	4
8	7	7	7	7	6	6	7	7	6	6	7	7
9	7	5	7	6	6	6	6	5	6	6	6	7
10	7	7	7	7	7	6	7	7	6	7	7	7
Sum of measurements	69	67	66	66	65	64	64	63	63	62	61	61

of the RPII measurements are illustrated in Table 2.

Using the results of the involvement inventory ranking and the rule of ZMET (the number of participants should be multiples of 12), we chose twelve participants from the population of participants with the highest involvement. These participants were invited to participate in the next ZMET experiment. The results of the statistics are illustrated in Table 3.

Phase-B results

In the ZMET experiment, first, we acquired a set of data about the constructs and demands via storytelling and construct elicitation. Initially, there were forty unique constructs surfacing in the twelve participants. This total was reduced to twenty-eight important constructs highlighted by more than one-third of the participants (CN≧ (1/3)N, N = 12). Table 4 shows the construct items, the code of the participants, and the depiction times.

As shown in Figure 3, participant A provided twenty-five constructs, and

Table 4. Result of the construct elicitation and number of times

No	Construct item	Participants code	Times	No	Construct item	Participants code	Times
1	Visual interface	ABCDEFGIJKL	11*	21	Guideline	AG	2
2	Graphical interface	ABCDEFGIJKL	11*	22	Parametric of physical properties	ABCDEFK	7*
3	Humanized concept	ACFGJK	6*	23	Error tolerance	ABDFGHJKL	9*
4	Multiple tools	ACDFHIK	7*	24	Convenience of use	ABCDEFHL	8*
5	Easiness	ABCEFGHIL	10*	25	Multiple viewports and windows	AEFHIJKL	8*
6	Comprehension	ACFGHIJKL	3*	26	Environment database	BCDFHJL	7*
7	Design style	A	1	27	Material database	BCDFHJL	7*
8	High efficiency	ABCDEHK	7*	28	Product consistency	BGH	3
9	Low cost	ACEHL	5*	29	Adaptive range	BL	2
10	Time saving	ACDFHIL	7*	30	Real situation	BCDFGI	6*
11	Resources saving	ABCH	4*	31	Innovation	BEG	3
12	Reality	ABCDEFGHIKL	11*	32	Degree of real-time	BDH	3
13	Dynamic and animation	ABCDFGJL	8*	33	AR adoption	BDEFHIJ	7*
14	System standardization	ADFGIL	6*	34	Digital archives	BG	2
15	Graphical programming	ABDIKL	6*	35	Multiple interactions	CDEFGIJL	8*
16	Modularity	ABCDFL	6*	36	Collaborative design	C	1
17	Simulation of danger and difficulty	ABCEFHIJ	8*	37	Equipment reducing	EHIKL	5*
18	Interference exclusion	AJ	2	38	Comfortableness	E	1
19	Structure presentation	ABCDEFHJKL	10*	39	Interest	EGK	3
20	Accuracy	ACDEFGIJKL	10*	40	Light system	FJL	3

**indicates item is the important constructs (CN≧1/3N, N=12)*

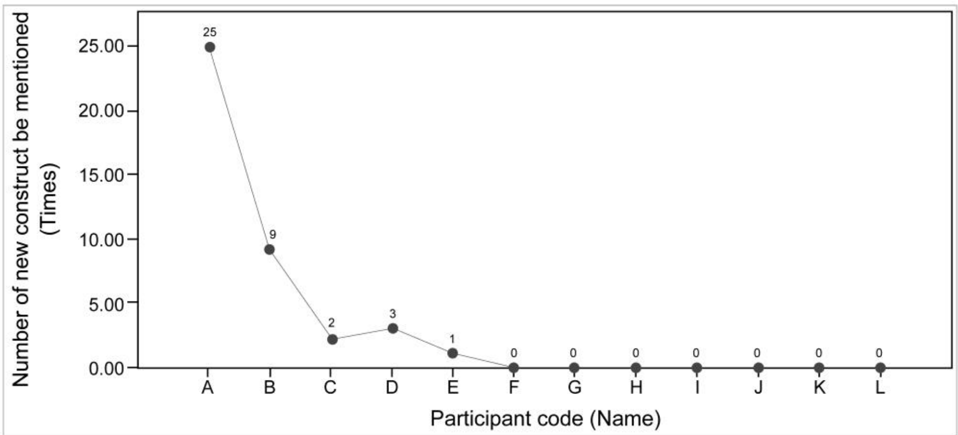

Figure 3. Result of times of new constructs are mentioned by participants A to L

participant B provided nine new constructs; the new constructs provided by participants F to L gradually decreased to zero. This situation of convergence is consistent with the principle of ZMET.

The construct relationship matrix was built by comparing the items listed on the vertical axis to those on the horizontal axis. The items were the twenty-eight important constructs obtained in the previous step and the comparison direction

	1. Visual interface	2. Graphical interface	3. Humanized concept	4. Multiple tools	5. Easiness	6. Comprehension	8. High efficiency	9. Low cost	10. Time saving	11. Resources saving	12. Reality	13. Dynamic and animation	14. System standardization	15. Graphical programming	16. Modularity	17. Simulation of danger and difficulty	19. Structure presentation	20. Accuracy	22. Parametric of physical properties	23. Error tolerance	24. Convenience of use	25. Multiple viewports and windows	26. Environment database	27. Material database	30. Real-life situation	33. AR adoption	35. Multiple interaction	37. Equipment reducing
1. Visual interface		12	6		10	9	8							5							7	4						
2. Graphical interface					9	12															9	1	2	1				
3. Humanized concept					10	7								2		1												
4. Multiple tools							8		2						1				5		6	1	5	5		4	7	
5. Easiness																												
6. Comprehension																												
8. High efficiency									6																			
9. Low cost																												
10. Time saving																												
11. Resources saving								1																				
12. Reality																												
13. Dynamic and animation											10					1	8					9	2	1	8			
14. System standardization					6	6		5	1	1											4							
15. Graphical programming			1		10	12	6														5	1	1	1				
16. Modularity				6	9	2	8		4				1								8		6	7				
17. Simulation of danger and difficulty					1	2			8		9	6						1							1			
19. Structure presentation						6				2	9							11						1	5			
20. Accuracy			1				1				10														5			
22. Parametric of physical properties					8		5		1		9		2					10			8			1	8			
23. Error tolerance			6		8		6		1	1								1			6							
24. Convenience of use																												
25. Multiple viewports and windows					8	9	11		12									1			12							
26. Environment database					6		10	1	9	1	12	2				2					10				12			
27. Material database					10		12	1	12		12	1				1					5				12			
30. Real-life situation																												
33. AR adoption						1					6										2							
35. Multiple interaction					8		3			1											6							
37. Equipment reducing			5		12		6														7							

Figure 4. Result of times of new constructs are mentioned by participants A to L (construct relationship matrix)

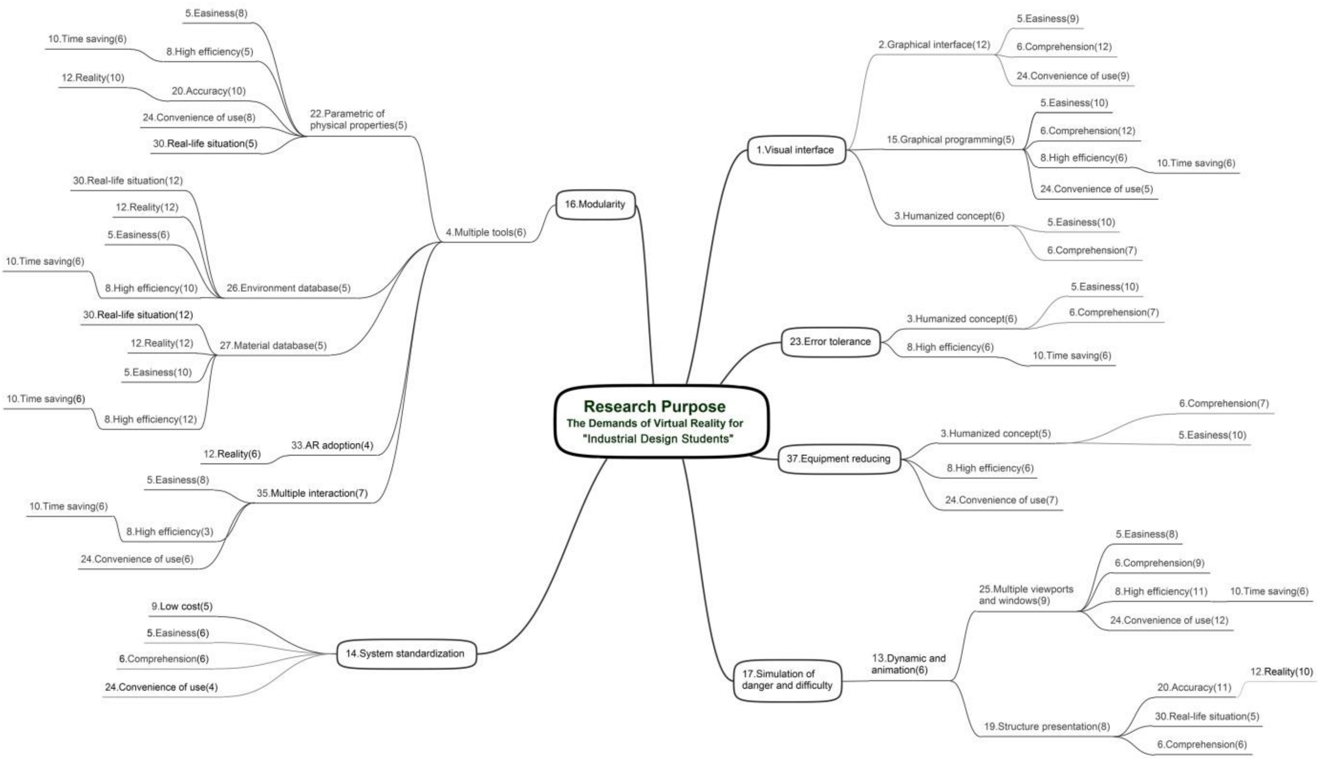

Figure 5. Result of consensus map

was the vertical axis to the horizontal axis. The number of times an item appeared in the matrix grid represented the number of participants who mentioned that there was a relationship between the two items being compared. Each pair of compared items was determined to have a relationship if at least one-quarter of the total number of participants agreed (CN≧ (1/4)N, N = 12). The resulting relationship matrix constructed is shown in Figure 4.

As shown in Figure 5, the consensus map was created in accordance with the results of the relationship matrix, which are also the results of ZMET. Each construct in the consensus map, called a "key construct," was established by connecting a line when a relationship existed between the items (CN≧ (1/4)N, N = 12). The map showed the participants' thinking processes, hierarchy, and direction. Consequently,

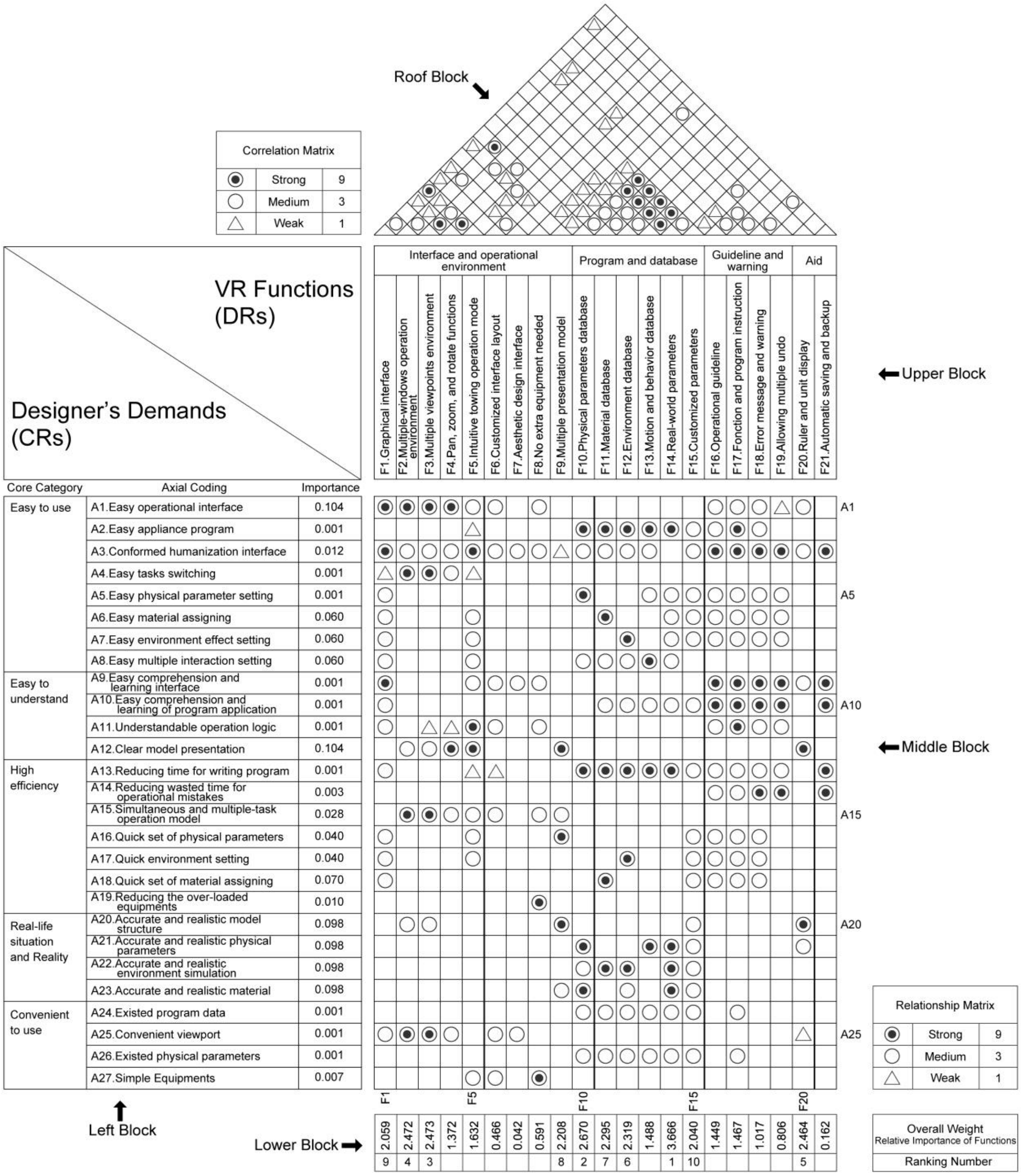

Figure 6. House of quality model for the industrial designers-oriented virtual reality

we could further understand the potential demands of these industrial design students and the logic behind their thoughts.

Phase-C results

In the left block of Figure 6, we divided the consensus map from ZMET demand constructs into five core categories totaling twenty-six items: easy to use, easy to understand, high efficiency, real-life situation and reality, and convenient to use. Each item was given an importance value determined by the research team via the AHP process. The data showed that the category "real-life situation and reality" had higher importance than the others. However, the category "easy to use" had more items than the others.

Second, the upper block had twenty-one functions, which were recognized to be problem solving as they satisfied each demand in the left block by the research team and the six VR engineers. These functions were classified into four groups: interface and operational environment, program and database, guideline and warning, and aid. Third, the experts discussed the roof block at the same time. The items in the same category had a higher strength than others.

Consequently, in the fourth and final steps, the middle and lower blocks were considered to be the important parts in the overall QFD process. According to the correlation of functions and the demand's importance, we perceived that the ten most important functional items for the students were as follows: (1) real-world parameters (3.666), (2) physical parameters database (2.670), (3) multiple viewpoints environment (2.473), (4) multiple-windows operation environment (2.472), (5) ruler and unit display (2.464), (6) environmental database (2.319), (7) material database (2.295), (8) multiple presentation model (2.208), (9) graphical interface (2.059), and (10) customized parameters (2.040). Consequently, we obtained twenty-one VR functions that were suitable and useful for the students, and simultaneously calculated the importance of the functions of all the VRs. The data and statistics obtained are shown in Figure 6.

The result of function determination, however, does not imply that other functions can be ignored or abandoned. All of the functions should be constructed, but the priority of the ten functions must be considered simultaneously.

CONCLUSION

In summary, this study constituted a preliminary research into the demands of industrial design students for product design learning processes in VR, and proposal of a new model in which ZMET is combined with the demands exploration of QFD. A major finding from this study is that the demands of VR functions for the students are not properly treated in the current VR system, which also reflects the aforementioned research problems.

The results indicate that the categories of the students' demands include visual interface, intuitional and simple operation, complete and parametric program database, guideline and warning, and design aid. This can be reasoned in various ways: first, students use their aesthetics and creativity on design concepts development in the learning process; consequently, the operation of a visual interface is probably similar to their manner of thinking. Second, many students are accustomed to image thinking; therefore, simple operations may allow them to work intuitively. Third, the majority of students are not program writing professionals; therefore, they may need a packaged program and database to reduce operational faults and to enhance efficiency. Fourth, guidelines and warnings should be required for wide applications in the VR system. Finally, aids, such as rulers and unit displays, are very important to students in their daily design work.

The present findings contribute to an understanding of the various factors acting in VR system development and suggest functions that facilitate learning by industrial design students. We presented an integrated model for demands to functions: ZMET-QFD (Z-Q). Therefore, the findings of this study should lead to the creation of a concept for a designer-oriented VR system that can truly aid in design education. Furthermore, this new system should reduce material waste, while improving the simulation and evaluation design process. On the basis of these research findings, we will continue to develop a designer-oriented VR system in the future.

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