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Article

Perceptual Learning for Promoting Design Thinking in Space Design Education

Daisuke Nagatomo

Department of Design, National Taiwan Normal University, Taipei 106, Taiwan; dn@ntnu.edu.tw

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Abstract: The application of real-time visualization and virtual reality (VR) technology was examined to promote students' design thinking in space design education. Learning space design, such as architecture and interior design, takes a series of iterations of training to nurture their imagination of how to translate their idea into a physical format. While design thinking refers to ideating, prototyping, testing, and implementing, educational methods for space design linearly provide students with an opportunity by employing this procedure. Traditionally, academic tools for space design education have been drawing, model making, and, recently, computer rendering. However, these methods differ from prototyping in design thinking regarding physical experience. It lacks the problem-finding, and cannot articulate the feedback system. Thus, this study was carried out to implement perceptual learning and training by data processing via acquired visual experience. With real-time visualization and VR technologies, spatial design prototypes were developed virtually. After the perceptual learning, the result evaluation was carried out with a qualitative analysis of the participants and a quantitative analysis of pre-course and after-course questionnaires. Afterward, the teaching experience of perceptual learning and findings were discussed.

Keywords: Design thinking, Perceptual learning, Real-time visualization, Virtual reality, Design education

1. Introduction

A frequently discussed topic is how people learn and how educators support students' learning attitudes in design curricula (Clair, 2015). However, course design influences the interaction between teaching and learning stakeholders. Thus, significant effort is required to develop effective professional development curricula (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). The design studio is a primary pedagogical method in design education where a professional situation is reproduced in an academic context (Ioannou, 2018). Design studios' roots trace back to the 19th century when Ecole des Beaux-Arts introduced their architectural education. Since then, the design studio has followed the traditional format of master-apprentice relations and repetition exercises (Ciravoğlu, 2014). However, there are disadvantages to the design studio system such as students' lack of confidence in decision-making for their project and constantly waiting for affirmation from the instructor (Ciravoğlu, 2014). The design studio conducts face-to-face discussions between students and instructors. Therefore, other students rarely exchange and discuss matters in their direction (Ioannou, 2018). Due to the rapidly changing social systems, these disadvantages appear more critical in the design education system since the 21st-century skill requirement urges students to obtain communication, problem-solving, and critical thinking skills during their education (Bellanca, 2010). Therefore, we investigated how to promote students' problem-solving and critical thinking skills while developing their design projects by using real-time visualization and virtual reality (VR) technologies.

2. Design Education and Design Thinking

2.1. Issues in Design Studio

The design process generally includes steps of considering the problem and challenges. Therefore, the trained designer uses design thinking and a complex cognitive process to create design outcomes as the solutions (Bequette & Bequette, 2012). The design pedagogy is interwoven in the standards related to cognitive aspects of problem-solving, creativity, innovation, and understanding concepts through an interdisciplinary means for training students to cultivate such skills (ZANDE, 2010). While the design studio needs to implement these aspects of the design process, researchers pointed out issues of the pedagogical method, such as lacking focus on rational problem-solving and coping with the changing nature of the world or the changing context of design practice (Bashier, 2014). Furthermore, the current design studio cannot provide adequate design thinking education due to the non-articulated design process.

2.2. Design Dynamics

Design is a creative, disciplined, and decision-oriented inquiry in iterative cycles of social systems in a changing world. Banathy mentioned that design manifested dynamic interaction between feedback and feedforward, reflection and creation, and divergence and convergence (Banathy, 2013). Figure 1 shows the dynamics of the interplay of divergence and convergence. These dynamics happen in exploring and imagining the design. Furthermore, the loop of divergence and convergence is critical for evaluating the design options and making design decisions. The interaction is never one-directional but recursive and mutually affecting. Feedback and feedforward are always ongoing and two-pronged operations (Banathy, 2013). In this mechanism, it is crucial to develop the loop system of the feedback system in the design process.

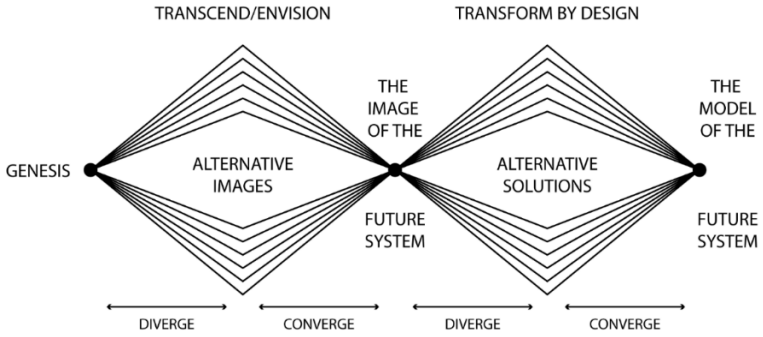

Fig. 1. Dynamics of divergence and convergence by Banathy (re-illustrated by the author).

2.3. Design Thinking

Design thinking is an analytic and creative process that engages a person to experiment, create and prototype a model, gather feedback, and redesign. It positively influences 21st-century education across disciplines due to creative thinking in generating solutions for problems (Razzouk & Shute, 2012). However, several difficulties are identified in the course of design thinking as follows (Chan & Nagatomo, 2022).

- Instruction requires professional knowledge and adaptive problem-solving guidance, which burdens the instructor by preparing unforeseen questions.
- Evaluating results requires an objective understanding of learning and instruction, which demands a clear framework and procedure.
- Design thinking reflects the complex process of inquiry and learning, which involves performing in a systematic context and decision-making.

Prototyping becomes crucial in the design thinking approach to overcome these difficulties. Prototyping enables exploration of different aspects of the problem, helps build a more complete and in-depth picture of the problem, and elicits new understanding and requirements (Newman et al., 2015).

3. Perceptual Learning and Digital Technologies

Perceptual learning was initiated to argue how humans learn via perception. There are different understandings of this term as human perception is what we learn to see depth or human learning is in whole or part a matter of perception. Experience accumulates when traces of the past somehow exist in our perception of the present and becomes our knowledge (Gibson, 1969). Perceptual learning is also defined as improvements in performance on visual tasks following practice or experience with stimuli related to those tasks (Deveau & Seitz, 2014). In mathematics, perceptual learning interventions facilitate the discovery of structure and recognition of patterns (Bufford, Mettler, Geller, & Kellman, 2014). In summary, perceptual learning refers to data processing via visual perception and the accumulation of knowledge. We use perceptual learning to stimulate design thinking in space design education.

Virtual reality (VR) is a term for a computer-simulated environment first introduced in 1989 by Jaron Lamier. VR induces the experience of presence (sense of being there) in a computer-generated world (Riva et al., 2007). VR technology has the potential to assist students with learning/training. However, the innovative application of VR in the educational setting is still under-explored and not fully known (Chang, Yeh, Li, & Yao, 2019). Furthermore, the VR experience simulates complex real-life situations and contexts to measure human behavior's emotional state (Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015). These

investigations in VR technology suggests that perceptual experience from the virtual environment can be as close as those of the real world. Thus, we employed VR technology to simultaneously stimulate students' perceptual experience for accumulating spatial design feedback and measure the effectiveness of the design thinking loop while developing their projects via a questionnaire survey.

3.1. Research Method

To demonstrate perceptual learning in space design education and measure the effectiveness of promoting design thinking, we employed the course guide of Interior Design I of the Department of Design, National Taiwan Normal University (NTNU). Interior Design I is an elective course for NTNU students, not limited to the Department of Design students. In addition, NTNU offers the interior design certificate to campus-wide undergraduate students. Therefore, in this study, we collected students' intentions of taking this class and their skills and knowledge levels of interior design before the class. Since Interior Design I is an introductory design class in interior design, it is crucial to understand students' skill level for the assignment and implement VR experience. Therefore, participants were asked to complete the pre-course questionnaire to understand their knowledge level and motivation toward the class.

3.2. Pre-course Questionnaire

A total of 30 students participated in the questionnaire survey relating to their motivation for the class, knowledge level, previous experience of interior design, and how challenging it is to learn interior design (Table 1). The survey result showed that 23 students enrolled in the interior design certificate program, while 30 showed interest in learning interior design. Regarding students' knowledge level, 80% of students claimed intermediate, while 13.3% of students were well acknowledged. In addition, they showed strong interest in improving their design skills to expand their knowledge in interior design and designing sophisticated interior spaces. The majority of students (86.7%) thought the essential skill for the interior designer was design skill. In addition, the students believed the best way to design interior space was to build while designing (36.7%) and build 3D models (33.3%). Finally, 76.7% of students thought it was not easy to learn interior design, yet it was achievable. In summary, the student's learning experience in interior design was not high. However, they were willing to take on the challenge of learning.

3.3. Assignment 'Personal Space'

Since the course was an introductory interior design class for students, the assignment was relatively straightforward for students to be creative. Moreover, the space needed to be accessible for the students to design. Therefore, "Personal Space" was chosen as the assignment. Students were asked to design their personal space to do their daily routine or somewhere they wished to be. There was no restriction to space conditions such as location, material, or function besides the maximum volume of a 2.5-m cube. As the first step of this assignment, the instructor gave a related lecture about human proportion and scale. Afterward, students were asked to measure their figures in detail to work on their personal space. The final requirement for this assignment was the figure measurements, hand-drawing, and 1 to 10-scale physical model (Fig. 2).

Fig. 2. Personal space assignment and presentation.

Table 1. Pre-course questionnaire survey result (participants N = 30).

Question: Motivation for this class (Multiple choice)	Answer	Percentage
I want to know about Interior Design	30	100.0%
I am interested in interior design	25	83.3%
I enroll in the interior design certificate program	23	76.7%
I am wondering how the interior design class is	20	66.7%
I want to be an interior designer in the future	15	50.0%
Question: The knowledge level of interior design	**Answer**	**Percentage**
Intermediate	24	80.0%
Little	4	13.3%
None	1	3.3%
Very well	1	3.3%
Question: Have you ever attended interior design related class?	**Answer**	**Percentage**
I have attended an interior design class	13	43.3%
I attended a lecture by an interior designer	13	43.3%
I have never attended any class or lecture	10	33.3%
Question: Is learning interior design difficult?	**Answer**	**Percentage**
It is not easy, but achievable	23	76.7%
It is hard, but I can try	7	23.3%
Question: What is our interest in interior design study? (Multiple choice)	**Answer**	**Percentage**
To improve my design skills	30	100.0%
To extend my knowledge of interior design	30	100.0%
How to design good interior space	30	100.0%
To improve my computer software skills	26	86.7%
To improve my physical model skills	21	70.0%
To improve my drawing skills	20	66.7%
How to prepare for finding a job in interior design	20	66.7%
How to be an interior designer in the future	18	60.0%
Question: What is the essential skill for interior designers?	**Answer**	**Percentage**
Design skill	26	86.7%
Business skill	2	6.7%
Model making skill	1	3.3%
Communication skill	1	3.3%
Question: What is the best way to design interior space?	**Answer**	**Percentage**
Build while designing	11	36.7%
Build a 3d computer model	10	33.3%
Draw sketch	5	16.7%
Make model	4	13.3%

3.4. VR Experiment for Perceptual Learning

After all the students completed the Personal Space presentation, they started designing with their computer modeling software. However, several students lacked the digital skills to build a 3D model. Thus, the class provided one extra week to work on their 3D models with the instructor's support (Fig. 3). Making the 3D model at the end of the design process required students to imagine their space with hand drawing and model making rather than computer modeling. Afterward, the student's digital model was connected to the VR device via Real-Time Visualization software. Through the software, students could experience their design and

receive feedback on their design intention (Fig. 4). However, there were the disadvantages of the software is the hardware requirement. In addition, the computer must install a high-performance graphics processing unit (GPU) to run the software. Therefore, we selected students' computers with a high-performance GPU to run the VR experiment for other students in the class.

(**a**) (**b**)

Fig. 3. Student work. (**a**) Digital version of student project and (**b**) Physical model of the project.

Fig. 4. VR experiment with student projects.

4. Results

To evaluate the outcome of the VR experiment and the contribution to their design thinking, we conducted a questionnaire survey at the end of the semester (Table 2). Since the sample number was limited, we looked at the normality of the data. The questionnaire survey result showed that their VR experiences provided a firm understanding of their design and helped them improve in design. Regarding the preference to understand and design their space, working on the physical model was still prioritized by students. One of the possible reasons was students' low computer modeling skills. Therefore, it was not practical for them to work on a digital model. After the questionnaire survey and the analysis of the responses, we explored the normality of the data (Fig. 5). The result showed significant asymmetry and a positive effect of using VR on their learning through this project with positive responses to the use of VR. VR promoted students' design thinking and supported their project development.

Table 2. Questionnaire survey result of post-course VR experience (participant N = 27).

Questions	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean	SD
Q1. Did the VR experience provide you with an understanding of your Personal Space design?	0	0	0	6	21	4.78	0.42
Q2. Was the physical model easier to understand your Personal Space design than VR?	0	4	11	4	8	3.59	1.06
Q3. Did you find any improvements in your Personal Space design after the VR experience?	0	3	4	12	8	3.93	0.94
Q4. Did you prefer the digital model to physical models when designing your Personal Space?	0	1	6	11	9	4.04	0.84
Q5. Was the VR experience of your Personal Space design as expected?	0	1	2	16	8	4.15	0.7
Q6. Did the Real-Time Visualization (Lumion/Twinmotion) help you develop your design?	0	0	3	5	19	4.59	0.68
Q7. Did Real-Time Visualization help you make design decisions?	0	0	3	9	15	4.44	0.69
Q8. Did the Real-Time Visualization provide you with feedback on your design decisions?	0	0	1	12	14	4.48	0.57
Q9. Did the VR experience help you decide your design?	0	0	1	13	13	4.44	0.57
Q10. Did the VR experience provide you with feedback on your design decisions?	0	0	0	13	14	4.52	0.5

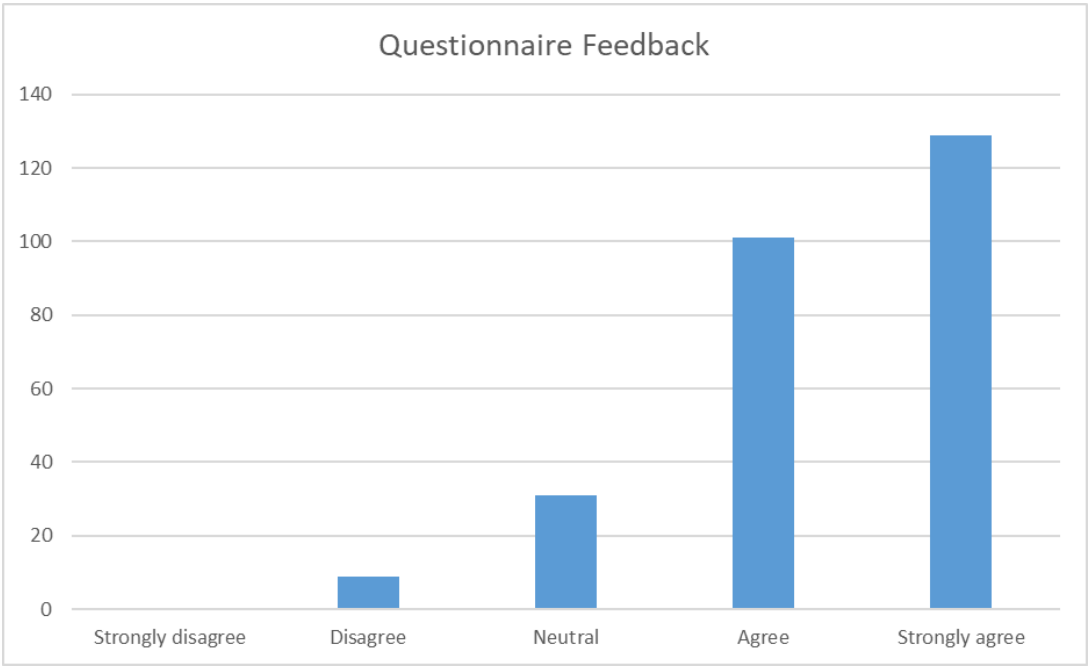

Fig. 5. Normality data of responses to questionnaire.

5. Discussion

How to implement perceptual learning for promoting students' design thinking in interior design projects was related to issues in the design studio system and the importance of feedback in design dynamics. Prototyping plays a critical role in design thinking.

Today's society faces problems and issues that are multifaceted, complex, and dynamic. Therefore, a new educational method needs to be more compatible with the technology-enhanced current lifestyle. Design thinking develops students' creative and adaptive capacities (Koh, Chai, Wong, & Hong, 2015). Therefore, the development of digital technology provides a new development platform for students, and the teaching method needs to be rearranged to motivate design thinking innovation (Hu & Fu, 2022). Perceptual learning starts with a philosophical argument about how humans learn through perception. However, a systematic approach has evolved in many disciplines to use this learning method. With the current development of digital technology, VR provides a more accurate visual perception for students to experience their design outcomes than any traditional medium (Sagun, 2002). Moreover, it provides an opportunity to train students in design thinking and develop their cognitive skills in critical thinking and problem-solving in design education.

6. Conclusions

We investigated perceptual learning for promoting design thinking in space design by employing VR technology. In the investigation, the results showed positive feedback on the VR implementation from the students. The VR experience assisted in understanding space and encourages students to find improvements significantly. However, the VR experience differed in students' computer skills. Furthermore, if the students were unfamiliar with designing the space with computer modeling, it was challenging to adopt the feedback from the VR experience. Therefore, to have the best result of perceptual learning in space design, a proper course curriculum needs to be set up to acquire basic knowledge of hand drawing, model making, and computer modeling.

In this study, the number of participants was small, and the background knowledge and skill were different for each participant. Therefore, the VR implementation in perceptual learning could have a different outcome for students. Moreover, it is also essential to investigate design thinking in perceptual learning and course curricula to establish the framework of assignment topics, lecture contents, and review systems in future research. Therefore, further investigation is proposed for different themes for the design topic, such as more functional space or larger interior area projects to examine the outcome of students' development and feedback through VR experience for perceptual learning.

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