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Enhancing Creative Thinking in Design Student by Interactive Media in Art Design Education

(アートデザイン教育におけるインタラクティブメディアによるデザイン専攻学生の創造的思考力への支援についての研究)

Xiaoxiao LIU

Japan Advanced Institute of Science and Technology

Doctoral Dissertation

Enhancing Creative Thinking in Design Student by Interactive Media in Art Design Education

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Xiaoxiao LIU

Supervisor : Yukari Nagai

Graduate School of Advanced Science and Technology
Japan Advanced Institute of Science and Technology
[Knowledge Science]
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Abstract

Mixed reality (MR) technology is an extension of virtual reality (VR) and augmented reality (AR) technology. Owing to its ability to foster learning, its research and application in education are considered technological breakthroughs. Some research has investigated student learning outcomes; however, little has compared MR environments with traditional teaching environments where creative activities are performed. The cultivation of creativity has long been valued in design education. This study used MR to build a virtual learning environment based on Microsoft HoloLens 2, creating an MR educational setting that promotes creativity by combining a physical and a virtual environment. Previous studies have employed virtual environments to advance creativity; however, the educational environments were presented in virtual ones supported by VR technology—a completely unreal milieu. The MR creative environment (MRCE) developed in this study overlays a virtual one with a physical setting and focuses on enhancing usability, flexibility, and creativity. Data on the traditional creative environment and the MRCE were collected separately through a between-group comparison and showed the MRCE to be more helpful in supporting the creative process and improving creative outcomes. This research proposes an application of MR technology to boost the quality of educational settings and offers a new medium for teaching creativity. The study also explores the advantages of MR educational environments in supporting creativity, expanding the environmental dimension in education, and valuing the promotion of the learner's capabilities, as well as the application potential and future development of MR technology in the education field and beyond.

Keywords: mixed reality, creative environment, creativity, art design education, virtual learning environment

Abbreviations

AR: augmented reality

HMD: head-mounted display

MR: mixed reality

MRCE: MR creative environment

OST-HMD: optical see-through head-mounted display

PC: personal computer

PCE: physical creative environment

PUI: physical user interface

RE: real environment

SD: semantic differential

SUS: system usability scale

VLE: virtual learning environment

VUI: virtual user interface

VR: virtual reality

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1. Introduction

1.1. Background

1.1.1. The development trend of educational environment

Educational environments can be divided into traditional educational environments and computer-based educational environments (Romero & Ventura, 2013). Computer-based educational environments include virtual learning environments (VLEs), learning management systems (LMS), massive open online courses (MOOCs), social learning, online education, cognitive tutor systems, computer education, multimodal and mobile environments (Papamitsiou & Economides, 2014). Researchers applying AI in education face the same challenge of finding the relationship between knowledge representation schemes and system performance.

Globally, these developments have led to a re-concept of education as a mobile and flexible exchange of ideas in a given context. It goes beyond the traditional view of classroom teaching and the view of education as the dissemination of knowledge. Rather, education is seen as a continuous process of learning through continuous exploration, engagement, and integration in the various situations, roles, and environments in which individuals engage. Specific content (text, images, audio, video) can help students build relevant and meaningful learning experiences, which enable learners to experience a continuous learning process across environments and integrate these diverse learning experiences through the capabilities provided by technology.

The development of VR, AR, and MR technologies has significantly increased attention in these fields and has become an essential technology for education, learning, and training (Latoschik, Marc Erich, et al., 2019). Interactive media has made progress in the development of distance learning platforms in virtual learning environments (VLEs). VLEs that utilize VR and AR technologies for educational use in collaboration on learning, training, and entertainment issues can enhance, encourage, and motivate learners to understand something (Pan et al., 2006). VR is used in the development of virtual campuses and virtual workspaces, for example VIVE Campus provides a virtual office or learning environment imitating the real world. MR has been used as an educational tool in applications such as mechanical engineering and medical imaging (Pan, Cheok, Yang, Zhu, and Shi, 2006; Strangman & Hall, 2003). The use of MR for simulation teaching and training is popular and there are preliminary results showing its teaching effectiveness (Ke et al., 2016; Hayes et al., 2013a, b; Liarokapis & Anderson, 2010; Hughes et al., 2005).

Horizon Report 2019 (Alexander, B., Ashford-Rowe, K., Barajas-Murphy, N., Dobbin, G., Knott, J., McCormack, M., & Weber, N. ,2019) pointed out that Mixed Reality (MR) related to teaching, learning, or creativity is most for experiential education. In addition, educators have consistently emphasized the importance and necessity of "authentic learning activities" in which students can solve real-world problems (Brown, Collins & Duguid, 1989). Therefore, combining real-world and digital-world learning resources to carry out educational activities for students has become an important and challenging research topic for educators. For example, mobile communication and wireless technology-enabled learning environments allow students to practice anytime, anywhere, image collection (Bidarra & Rusman, 2017).

Virtual Reality (VR) allows users to perform things impossible in the real world and to visit inaccessible places. Augmented Reality (AR) triggers interactions with invisible things in the physical environment. Learners gain experiences reaching wider range of tasks and activities, MR technology enables experiential learning that were not possible before. In 2020, the report (Brown, McCormack, Reeves, Brook, Grajek, Alexander & Weber, 2020) pointed out that driven by 5G technology, AR, VR and MR Technologies have been able to develop vigorously in the field of education. In 2021, the report (Kelly, McCormack, Reeves, Brooks & O'Brien, 2021) stated that blend-learning models, i.e., the possibilities presented by combining the Internet and digital media with established classroom formats, will be more widely used.

1.1.2. The cultivation of creative ability in design education

Many scholars (Al-Oweidi, 2013, Castro, 2011, Cramond, 2015, Demir and Isleyen, 2015, Garaigordobil and Berrueco, 2011, Miller and Dumford, 2015) have focused on creative thinking to foster creativity, especially in educational environment. Viktor Lowenfeld (Lowenfeld, 1987) believes that the purpose of art design education is to make people more creative in the creative process. Designers must be creative to face the challenges of future, and creative activities should accompany the whole process of art design education.

The development of art design requires a better combination of technology and educational environment, constantly improving the creative thinking of designers, and releasing the imagination of designers. The cultivation of creativity takes time and space, both of which are lacking in today's institutions, faculty, and students. Horizon Report 2022 (Pelletier, McCormack, Reeves, Robert & Arbino, 2022) pointed out that there is not enough physical space in higher education environment for creative activities that require dedicated space. In general, design students need extensive knowledge, creativity and a suitable communication environment (Chai & Fan, 2018).

Currently, design education is almost always conducted in a traditional creative setting. We conducted an online questionnaire survey (N=231) on the current creative environment in design education. The results demonstrate that the environment settings in which design students perform creative tasks include: (1) indoor environments, for example, offices or classrooms; (2) creative tools, such as personal computers, mice, keyboards, pen and paper, and other tools for drawing sketches; and (3) design educational media, such as pictures, text, videos, and sound. The survey results also demonstrated that the setting in the traditional educational environment hardly involves the virtual environment and tools; subsequently, this study characterizes the traditional design educational environment as the physical creative environment (PCE).

1.1.3. Interactive media and design education

Many people require creative tools or systems to brainstorm and produce creative designs (Gabriel et al., 2017), including design students, especially when performing creative tasks. Multimedia visualization and multiple learning modalities are supporting tools for learning design (Mayer, 2008); however, most previous work has revolved around instructional environments formed by explanatory text and pictures (Ayres, 2015), with less focus on interactive learning environments. With advancements in computer science, researchers have gradually realized that interactive systems can help cultivate creativity (Voigt & Bergener, 2013).

VR is becoming increasingly popular in education, as it can foster learning motivation (Huang et al., 2016), provide rich interactive feedback (Hussein & Nätterdal, 2015), simulate physical environments, provide realistic experiences, and allow access to remote locals, enhance, motivate and stimulate learners' understanding of certain events (Pan et al., 2006). VR can encourage individual creativity owing to its imaginative, immersive, and interactive properties (Gavish et al., 2015)—three characteristics closely associated with creativity (Csikszentmihalyi, 1996; Jou & Wang, 2013; Witmer & Singer, 1998). However, VR environments have limitations. Immersive VR interfaces introduce a large discontinuity between the real and virtual worlds (Kato & Billinghurst, 1999); users must be trained to operate the virtual system. Further, VR systems can only provide digital tools, separating users from traditional tools. The use of digital design tools in the creative process can interfere with the creativity of design ideas (Atilola et al., 2016). Pen and paper are more accessible for drawing than 2D and 3D technological design tools (Bueno & Turkienicz, 2014).

Mixed reality is an environment that combines VR and AR technologies, in which interactive virtual objects are mapped and integrated with the physical environment. The study of design disciplines is an educational process that involves a range of creative activities (Tang et al., 2020). As a new teaching platform, MR technology can not only cover the learning content, but also realize the application of effective tools (Bidarra and Rusman 2017).

1.2. Background

1.2.1. Identification of gap

Through survey interviews, this study identified technology limitations in current Educational Environment:

Technology limitation 1: The weak connection between the virtual world and the real world leads to the fragmentation of the virtual creative environment and the design process. The user's field of vision will be completely covered by the VR Head Mounted Display, and other hardware devices and tools will not be visible. For example, the usual experience through keyboard, mouse or screen is not applicable. Also, physical creative tools are important for creativity, but it cannot be used in a virtual creative environment powered by virtual reality technology.

Technology limitation 2: The usability of the virtual creative environment is not enough. Compared to the familiar equipment and tools, the virtual creative environment is still very unfamiliar to designer students. Learning how to operate and use a virtual creative environment is necessary, and this unfamiliarity directly affects the user experience and thus the design outcome.

Technology limitation 3: The physical creative environment, as a fixed physical space, is limited by its geographic location and time of use. In addition, PCEs are not easy to switch and change, because changing the physical space requires a lot of time and effort.

Furthermore, based on previous studies in the literature review, the feasibility of mixed reality technology for educational settings has been demonstrated. Thus, the gap of this study is how to apply mixed reality technology to optimize the creative environment in today's art and design education to bridge the negative impact on creative outcomes due to the insufficient support of the physical creative environment and the immersive virtual creative environment for the creative process.

1.2.2. Research aim

Several studies have confirmed the link between VCE and creativity, but there are some flaws in the support of creativity in virtual environments. This study focuses on research on available mixed reality creative environments that enhance the creativity of designer students in art and design education, and the research hypothesis is that MRCE contributes to the enhancement of design students' creativity.

Therefore, the current paper aims to use mixed reality to combine physical creative environment and virtual creative environment as a virtual learning environment in art and design education to improve the creativity of design students. Such creative environment design requirements include:

R1. User can get creativity support in a virtual environment while using physical creative tools.

R2. The user interface with high usability guarantees the design process and enhances creativity.

R3. A flexible, task related, interactive MRCE provides support for enhancing creativity.

R4. The MRCE can support the design process and knowledge creation.

R5. The sound, images, and interactive actions are integrated to enhance the user's senses in the MRCE.

R6. Users have a more positive experience in the MRCE than in a physical creative environment.

To meet these requirements, this study uses Mixed Reality's properties to combine PCE and VCE to form a MRCE that has the best of both worlds. MRCE should accommodate physical creative tools and virtual creative tools, use more flexible virtual creative tools to support the creative process, as a brand-new creative platform, it should be easy to operate and related to creative tasks.

1.2.3. Research questions and hypothesis

Compared with the PCE (Physical Creative Environment), how does this MRCE (Mixed Reality Creative Environment) help design student?

RQ1: Compared with PCE, what is the difference in usability of MRCE? As a virtual creativity support system MRCE, how does its usability affect the creativity of student designers?

RQ2: Compared with the PCE, how does the MRCE stimulate the student designer's five senses? How this kind of stimulation further enhance the student designer's creativity?

RQ3: Compared with the PCE, how does this MRCE help student designers enter the state of Flow?

RQ4: Compared with the PCE, what are the differences in affective experience this MRCE brings to student designers? How does this difference in affective experience enhance the creativity of student designers?

RQ5: Compared with the PCE, how does the MRCE promote Knowledge Creation? What is the relationship between the promotion of Knowledge Creation and the enhancement of student designer’s creativity?

RQ6: Compared with the PCE, how does this MR creative environment support the design process? How does this support help improve the creativity of student designers?

Hypotheses :

The research hypothesis is that design student learning experiences and creative outcomes will benefit more from MR technology-enabled educational environments than from traditional educational environments (Figure 1-1).

Detailed hypotheses include:

H1: The usability of MRCE is helpful to the creativity of design student.

H2: The stimulation of five sense in this MRCE is helpful to the creativity of design student.

H3: This MRCE is helpful to enter the state of Flow for the creativity of design student.

H4: The positive emotions in this MRCE is helpful to the creativity of design student.

H5: The effective knowledge creation is helpful to the creativity of design student.

H6: The support of this MRCE to the design process helps the creativity of design student.

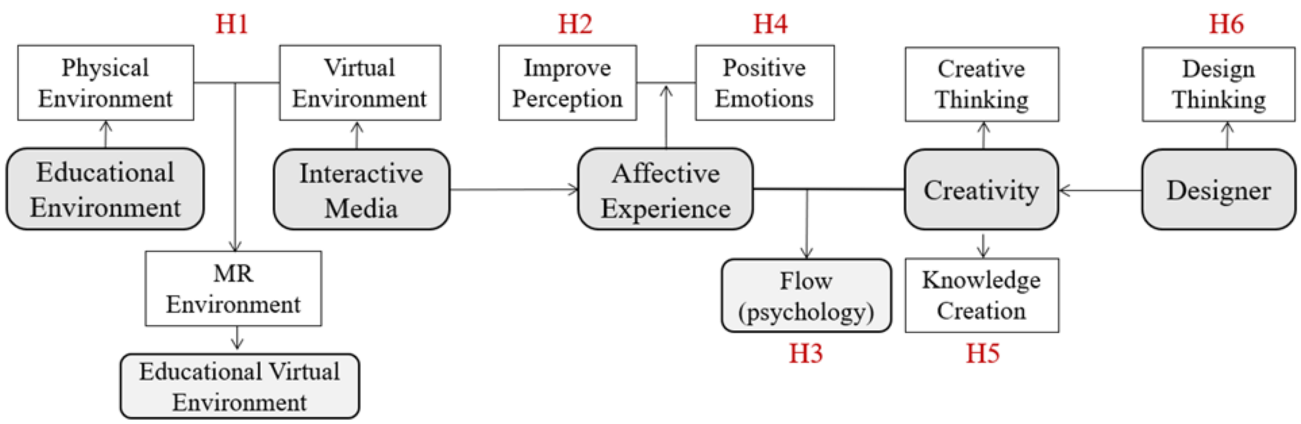


Figure 1-1. Detailed hypothesis

1.3. Objectives and the structure of research

This research identified three gaps in the literature. First, the VR environment is completely separated from the physical world. During the creative process, design students' vision is obscured by VR, and they cannot receive any information from the physical educational context.

Second, VR environments are not widespread. The most common VR devices comprise a head-mounted display (HMD) and two handheld controllers to navigate the VR environment. Design students must learn to operate the VR creative environment proficiently; otherwise, their creative process and outcomes can be negatively impacted. Third, physical creative tools (e.g., pen and paper) are important but cannot be used in virtual environments supported by VR technology.

Moreover, student designers are unfamiliar with using virtual creative tools, which negatively affects creativity.

Therefore, this study explores the use of MR technology to develop learning environments that support students' creative activities to fill the gaps in previous research by filling the shortcomings of previous physical and virtual reality creative environments. This work applies the characteristics of MR technology, retains the traditional creative tools and superimposes the relevant context of interactive virtual learning content, and takes advantage of the MR system to provide students with more diverse learning tools and learning experiences.

In this study, we take design education as an example because of their need for interdisciplinary teamwork and high levels of individual creativity (Chai & Fan, 2018), and further expand the previous related research by comparing students' learning experience in MR environment and traditional education.

The research hypothesis is that design student learning experiences and creative outcomes will benefit from MR technology-enabled educational environments compared to traditional educational environments. The design method of the MR system in this study and the benefits that the MR creative environment brings to the virtual learning environment can also have an impact on education in other disciplines. This study aims to support creative activity and enhance creative outcomes in design education, constructing the MR creative environment as a technological environment that can improve learning and pedagogical processes.

2. Literature review

This chapter presents theories and models relevant to the creative environment, and builds on previous theories and models to map out models relevant to the subject of this study. The definitions and related applications of MR techniques mentioned in this chapter provide reference techniques and application methods for the MR systems developed in this study. The review and analysis of the literature review in this chapter provides a scientific rationale for formulating the development strategy of the MR system for this study.

2.1. Factors affecting creativity in art design education

Design is arguably the most creative human force (Nagai, Y., 2015). Creativity can be based on factors such as learning, experience, motivation, imagination, personality that may influence human creativity. Creativity comes in various forms such as ideas, methods, products, art, systems, solutions, situations, strategies, changes, methods, techniques, designs, treatments and research (Kiymet Selvi, 2007).

Creativity is defined as the ability to achieve an original (new or unexpected) product (idea or concrete realization) while remaining fit (useful or valuable) to the context in which it occurs (Runco and Jaeger, 2012; Lubart, 1999). The essence of design is creativity from creative thinking (Corazza & Agnoli, 2016), and strengthening creative thinking and methods closely related to creativity are the basis for cultivating excellent designers.

Individuals continually learn from their feelings, imaginations, experiences, and their environment. Some external factors of learning, such as education system, learning environment, learning process, teacher's ability, etc., may cause obstacles to creative potential. For example, during school, students do not have enough time and space for learning activities. In addition, the mismatch between the challenge difficulty of the goals proposed in the educational system and the students' abilities may impair creativity (Selvi, K., 2007).

2.1.1. The “Four P’s” model

The creative process needs the support of the environment. The “Four P’s” of creativity model gives a classification of creativity that affects the occurrence of creativity. It refers to Person, Process, Press and Product (Mel Rhodes, 1961). Rhodes pointed out, this “Four P’s” model refers to the phenomenon of a person who has experienced a person who must consider his or her environment (press) after the psychological process of the product.

Each element of the “Four P’s” of creativity model is a characteristic part of the whole creativity and cannot be separated from the others. However, each section represents one or other commonly held view of what creativity is:

"Person" refers to the features of people, what are their characteristics, habits, and thoughts. In general, design students need extensive knowledge, excellent creativity and a resourceful creative environment, as designers require interdisciplinary teamwork skills and a high level of individual creativity (Chai & Fan, 2018).

"Product" is the result of creative activity. Whether a product is creative requires a detailed evaluation.

"Process" refers to the creative process that occurs in the environment, "process" is about how people creatively do what they do. At the same time, a process can also be a "product", for example, an innovative way to accomplish a previous task.

"Press" is defined as an environment around creative people. Also, if the environment around a person is not conducive to creativity, creativity dies very quickly. For example, some scholars have pointed out that p*ress* refers to environmental variables that may promote, hinder or otherwise influence creative participation, and the process involves how creativity occurs from beginning to end (Runco & Kim, 2011). If we want more creative people, then we must provide an enabling environment for creativity to flourish (Scott, Leritz & Mumford, 2004).

Based on the "Four P's" of creativity model, "Person" in the context of art education refers to designer students, and "Press" refers to the relationship between designer students and the creative environment. In a creative context, "Product" refers to the design sketch. Regarding the "Process", this study cites d. school's design thinking (d. School, 2015) to interpret the creative process of designer students. Therefore, based on the 4P model, we correspond to the factors related to creativity in this study and the relationship between them (Figure.2-1).

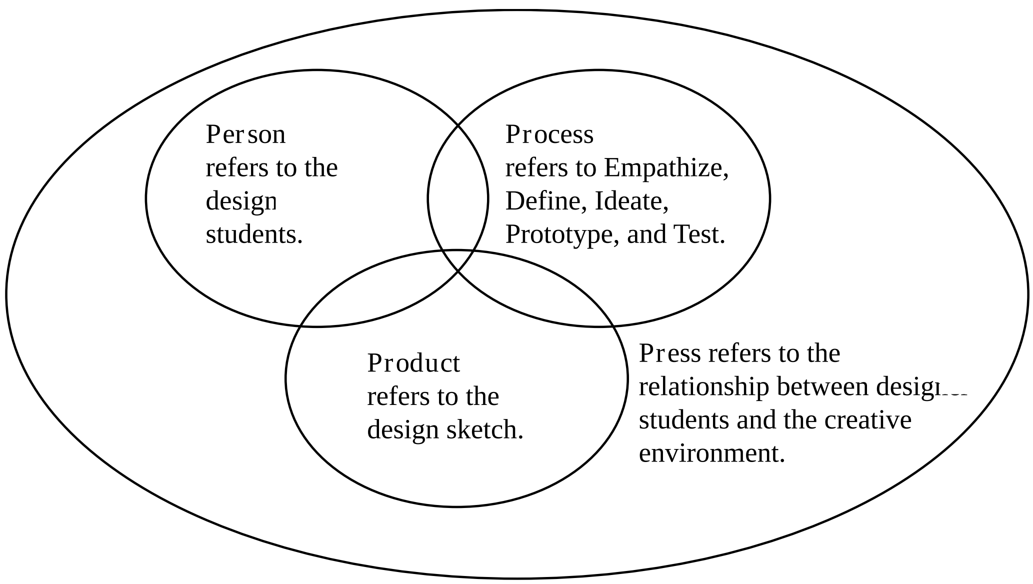


Figure 2-1. Creativity factors in the context of art education based on the 4P model

2.1.2. The design thinking

Design is the creative process of intentionally exploiting things that do not yet exist (Kelley & Kelley, 2013). A designer's creativity and design strategies are influenced by the process and information provided (Buchanan, 2001). Wallace described the creative "thought process" as consisting of four stages: prepare, incubate, inspire and verification (Wallas, G. ,1926).

The Hasso Plattner School of Design at Stanford University (d. School, 2015) describes the design process as a five-stage process: Empathize, Define, Ideate, Prototype, and Test. The creative process is a crucial stage as they greatly influence the quality of the creative product (Jansson and Smith 1991; Le Masson et al. 2011; Liu et al. 2011; Shai et al. 2009). Based on the d. School's design thinking model (Figure. 2-2), "Process" refers to the five-stage of design process. Each step is specifically explained as:

Empathize refers to having an empathic understanding of the problem to be solved, and designers need to gather a lot of information at this stage for use in the next stage. Empathy is crucial to the design process because it allows designers to set aside their own assumptions about the world, with the main purpose of understanding as much as possible about the needs of users and the issues behind the development of the product or service they want to create.

In addition to collecting data on their own, designers can consult experts to learn more about the field and make observations to engage and empathize with users. Even, designers can immerse themselves in the user’s physical environment to gain a deeper understanding of the issues involved and the user’s experience and motivations.

The define phase is used to analyze the information and observations gathered during the transference phase and synthesize them to define the core issue. The define phase will help the design team gather great ideas to build features, functionality and other elements to solve the problem at hand.

The ideate phase refers to challenging assumptions and creating ideas, identifying innovative solutions to the created problem statement. Brainstorming is usually used at the beginning of the ideation phase to stimulate free thinking and expand the problem space, which can generate as many ideas as possible at the beginning of the ideation phase.

The prototype phase is about starting to create a solution, an experimental phase to identify the best possible solution for each problem found. Solutions are implemented in prototypes and investigated one by one based on user experience, and then accepted, improved, or rejected.

The test phase is about trying out solutions, rigorously testing prototypes. Usually, the designer will redefine one or more further questions based on the results of this phase of testing.

It is worth noting that these 5 phases are not always consecutive, and designers often perform them in parallel, repeating them in an out-of-order or iterative manner. That is, designers can go back to previous stages for further iterations, changes, and improvements to find or rule out alternative solutions.

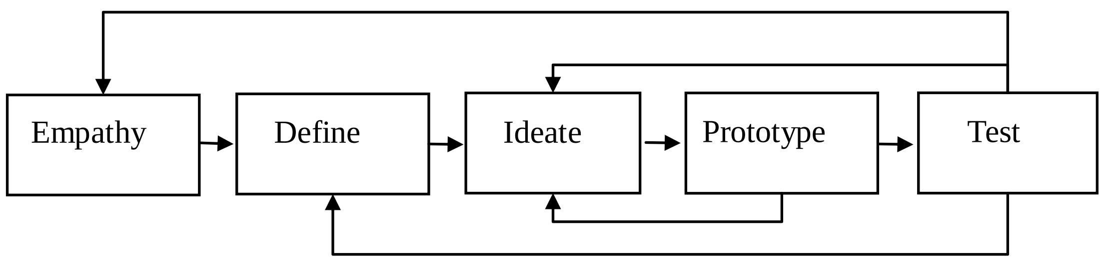


Figure 2-2. The design process (base on the d. School's design thinking model)

2.1.3. Flow

Csikszentmihalyi (1975) proposed flow theory, emphasizing the influence of internal and external environment on individual creativity. Flow theory is defined as the overall experience people feel when they are fully absorbed (Csikszentmihalyi, 1975). The role of flow is when a person exhibits the greatest ability at a manageable level of performance and feels an intrinsic reward (Nakamura & Csikszentmihalyi, 2014).

First, the conditions under which flow occurs are related to whether people perceive challenges (Csikszentmihalyi, 1996; Nakamura & Csikszentmihalyi, 2014). For example, a simple task can be extremely challenging due to lack of skills. If the challenge is too difficult, the user will lack control over the environment and will feel anxious and frustrated. Conversely, if the challenge is too simple, the user will get bored and lose interest. In addition, the flow state has been described by Csikszentmihalyi as the “optimal experience” in that one gets to a level of high gratification from the experience. Third, when the challenge-skill balance is appropriate at high difficulty, flow induces focus on the task, resulting in immersion. Therefore, since design often faces creative challenges in the learning process, the state of flow will have a positive impact on designer students.

Csikszentmihalyi (1990) and Nakamura and Csikszentmihalyi (2002) found the following nine general flow factors: (1) challenge-skill balance; (2) action-awareness merging; (3) clear goals; (4) unambiguous feedback; (5) concentration on the task at hand; (6) a sense of control; (7) loss of self-consciousness; (8) transformation of time; and (9) autotelic experience.

The Flow State Scale (FSS) is a 36-item 5-Point Likert scale that measures the strength of flow (Jackson, S. A., & Marsh, H. W. , 1996) contains 36 test items corresponding to these 9 factors. These 9 flow factors were figuratively described by these questions on the FSS scale (Table.2-1).

This study focuses on the support of MR creative environment for the creativity of design students and the learning experience of design students in this MR creative environment. Therefore, this research mainly focuses on the following three factors of flow theory:

- Sense of control: about confirming that the design student's abilities match the challenge he/she is doing, know what he/she wants to do or should do, whether he/she has control over what he is doing, whether he/she understands the progress of his/her task, and whether he/she has the confidence to complete the task.

- Positive emotional experience: about confirming whether the design student likes what he/she is doing, whether the design student enjoys the creative task, and whether the design student wants to challenge the creative task in this creative environment again.

- Absorption by concentrating: about whether the design student is prone to focus on what he/she is doing, whether he/she forgets time and loses himself when doing tasks.

Finally, this study revolves around these three *flow* factors to screen 36 items in the FSS, and 16 of them are selected as the content of the questionnaire for the experimental participants during the evaluation stage.

Table.2-1 Flow Factors Corresponding to FSS Scale

Flow factors	Items of FSS
Challenge-skill balance	- I was challenged, but I believed my skills would allow me to meet the challenge. - I made the correct movements without thinking about trying to do so. - I knew clearly what I wanted to do. - It was really clear to me that I was doing well.
Action-awareness merging	- My attention was focused entirely on what I was doing. - I felt in total control of what I was doing. - I was not concerned with what others may have been thinking of me. - Time seemed to alter (either slowed down or speeded up).
Clear goals	- I really enjoyed the experience. - My abilities matched the high challenge of the situation. - Things just seemed to be happening automatic - I had a strong sense of what I wanted to do.
Unambiguous feedback	- I was aware of how well I was performing. - It was no effort to keep my mind on what was happening - I felt like I could control what I was doing. - I was not worried about my performance during the event.

Concentration on the task at hand	- The way time passed seemed to be different from normal. - I loved the feeling of that performance and want to capture it again. - I felt I was competent enough to meet the high demands of the situation. - I performed automatically.
A sense of control	- I knew what I wanted to achieve. - I had a good idea while I was performing about how well I was doing. - I had total concentration. - I had a feeling of total control.
Loss of self-consciousness	- I was not concerned with how I was presenting myself. - It felt like time stopped while I was forming performing. - The experience left me feeling great. - The challenge and my skills were at an equally high level.
Transformation of time	- I did things spontaneously and automatically without having to think. - My goals were clearly defined. - I could tell by the way I was performing how well I was doing. - I was completely focused on the task at hand.
Autotelic experience	- I felt in total control of my body. - I was not worried about what others may have been thinking of me. - At times, it almost seemed like things were happening in slow motion. -I found the experience extremely rewarding.

2.1.4. Affective Experience

Creativity researchers point out that positive experience is conducive to promoting creativity. Studies have found that positive experiences can enable individuals to obtain richer and more diverse information (Forgas, 2002). Individuals who experience positive emotions will put more effort into generating more creative responses than other emotions (Martin & Stoner, 1996). The novelty and fun of interactive media technology can improve the user experience, allowing users to actively receive information under positive emotions, which is conducive to creativity.

Positive experience effectively activates the beneficial information stored in the individual's long-term memory system, which positively links the beneficial information in the memory system with the information in the creative material, thereby promoting problem solving (De

Dreu et al., 2008). The immersion of interactive media technology can make users feel immersed in the scene, which will help users to awaken their existing knowledge and connect with the information in the MR environment to generate creativity.

Positive experience can promote regulation and improve cognition, which is beneficial to the improvement of creative problem solving (Ashby, Isen & Turken, 1999). It has been found in research that positive experiences can also provide additional resources to expand the scope of cognition (Lee & Sternthal, 1999). Interactive media technology makes information interactive, making it easier for users to immerse themselves in information, providing users with more positive experiences and better information performance, thereby improving users' cognition and creativity.

2.1.5. Knowledge creation

Design is a process, and the design process brings new knowledge. Design and innovation are both knowledge creation processes (Manhães, 2010). Nonaka believes that knowledge creation is a comprehensive process by which organizations interact with individuals and the environment to transcend the emerging contradictions facing the organization, a process that transfers from tacit knowledge to explicit knowledge and then back to tacit knowledge (Nonaka, Toyama, & Konno, 2000).

Tacit knowledge is personal and available at a specific time and place, making it difficult to formalize and communicate. In contrast, explicit knowledge refers to knowledge that can be communicated in formal, systematic language. Explicit knowledge can transcend a specific time and place, and is theoretical and declarative. Knowledge is divided into explicit knowledge and tacit knowledge (Nonaka, 1991). Knowledge that can be spoken, expressed in sentences, and captured in pictures and writing is explicit knowledge. Knowledge related to senses, motor skills, bodily experience, intuition or implicit experience is tacit knowledge (Polanyi, 1967).

The SECI model of knowledge creation proposed by Nonaka (Figure.2-3), originates from the study of knowledge management, which is related to organizational learning, enterprise management and information systems. The four factors in the SECI model are socialization, externalization, combination, and internalization. Successive iterations in the process form a spiral, each loop amplifying knowledge to a higher level. This model describes four modes of knowledge transfer that arise when tacit and explicit knowledge interact:

-Socialization: is the process of transforming tacit knowledge into new tacit knowledge through shared experiences in daily social interactions.

-Externalization: It is a process of expressing tacit knowledge as explicit knowledge so that it can be shared by others and become new knowledge.

-Composition: This process combines, edits or processes explicit knowledge collected from inside or outside the organization to form more complex and systematic explicit knowledge.

-Internalization: This process refers to the transformation of explicit knowledge created and shared across the organization into tacit knowledge by individuals. This stage can be understood as knowledge being applied and used in practical situations and becomes the basis of new knowledge.

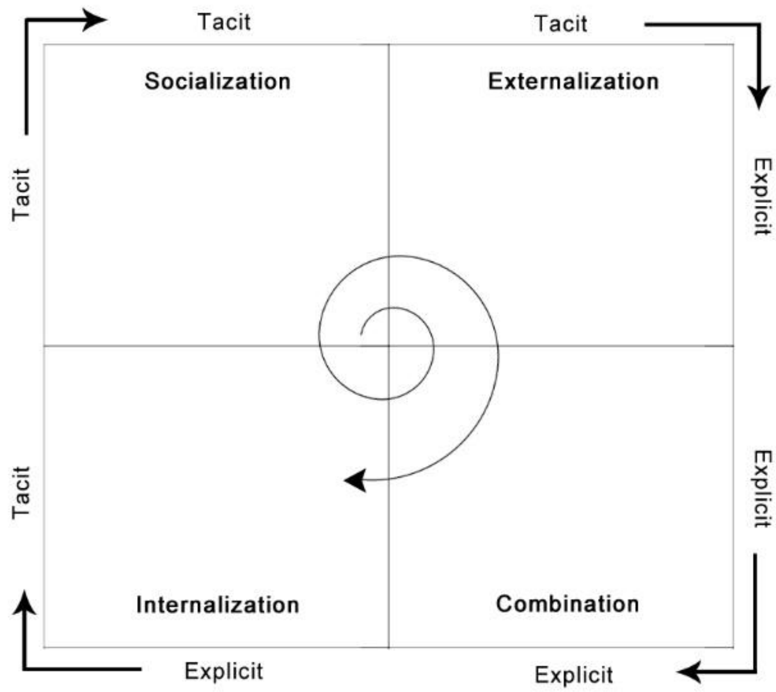


Figure 2-3. The SECI model by Nonaka

It is worth noting that this knowledge creation process is not individual, but from individuals to groups to organizations to communities. This study uses the SECI model to explore the knowledge transfer between individuals and the learning environment based on the theoretical basis of knowledge creation, and combines the five steps of the design process. From the perspective of this study, the SECI model is interpreted as:

- Evocation and Empathy (Socialization): Individuals evoke and create tacit knowledge through direct experience (sight, hearing, smell, touch, taste) in the creative environment. For example, creative environments effectively evoke the knowledge, experience and feelings of design students.

- Manifestation and Definition (Externalization): The individual manifests accumulated tacit knowledge through interaction with the creative environment. For example, these creative environments help express design students' emotions and apply their knowledge and experiences.

- Connection and Creativity (Combination): Individuals gather explicit knowledge from many different sources in a creative environment to integrate, edit and transform for dissemination and utilization. It is a process of systematizing and applying explicit knowledge and information. For example, these creative environments help design students integrate and expand their knowledge, experiences and feelings.

- Prototype and Test (Internalization): Individuals take explicit knowledge, such as product concepts or manufacturing procedures, into their own new tacit knowledge through practice and reflection, learning and acquiring new tacit knowledge in practice. For example, these knowledge, experiences and feelings generated in the creative environment are effectively translated into design results by design students.

Thus, based on the SECI model, we derive a model of the knowledge creation process of individuals in creative environments (Figure.2-4), which covers both explicit and tacit knowledge of people in an environment full of information related to creative activities spiral evolution process. The model studies the relationship between people as individuals and the creative environment.

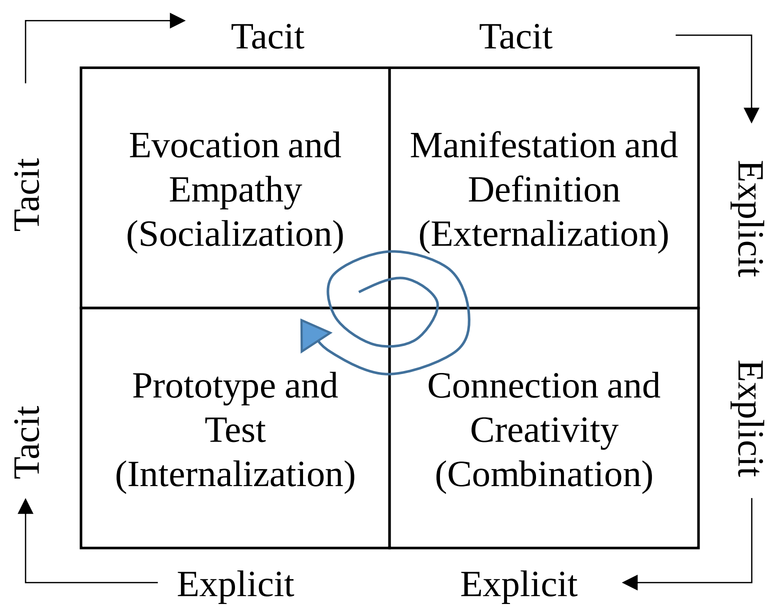


Figure 2-4. The model of the knowledge creation process of individuals in creative environments

2.2. Creativity Assessment

The Torrance Test for Creative Thinking (TTCT) is based on the work of JP Guilford and was created by Ellis Paul Torrance. The Torrance Creative Thinking Test is a creativity test that originally involved a simple test of divergent thinking and other problem-solving skills. Divided into four grades: Fluency, Flexibility, Originality, Elaboration (Torrance, 1966). The third edition of Torrance Test for Creative Thinking in 1984 removed the flexibility scale from the figure test, but added 2 new standard reference scores : “Resistance to Premature Closure” and “Abstractness of Titles”, and 13 reference measures including: emotional expressiveness, story-telling articulateness, movement or actions, expressiveness of titles, synthesises of incomplete figures, synthesis of lines, of circles, unusual visualization, extending or breaking boundaries, humor, richness of imagery, colorfulness of imagery, and fantasy (Cramond & Kim, 2002).

Ideas also have other quality attributes in the multi-attribute definition. For example, Plucker et al. proposed that creativity has two dimensions, novelty and utility, through a content analysis of 90 articles related to the term "creativity" (Plucker et al., 2004)). MacCrimmon and Wagner developed five dimensions of creativity based on research literature, practice literature, and US Patent Office rules, including: Novelty, Non-obviousness, Relevance, Workability, Thoroughness (MacCrimmon & Wagner, 1994). Bessemer and Treffinger proposed four dimensions according to the multi-attribute definition of creative products, including: Novelty, Resolution, Elaboration and Synthesis (Bessemer & Treffinger, 1981). Wagner proposed three dimensions from the study of creative behavior, including: Originality, Purpose and Implementation (Wagner, 1996).

2.3. Physical creative environment

An important aspect of education is the establishment of the environment. The educational environment has a positive impact on student motivation, well-being, achievement, success and satisfaction (Wach, Karbach, Ruffing, Brünken & Spinath, 2016). Students' perceptions of the educational environment have an impact on their learning and experiences (Rothman & Ayoade, 1970). For art design education that focuses on creativity, an environment that supports creativity is particularly important.

The physical work environment that supports creativity depends on the layout of the space, the type of space, and some tangible and intangible office elements. The layout of the space includes privacy, flexibility, layout, size, complexity; space types can be divided into relaxation space, independent space, graffiti space, unusual or interesting space; tangible office elements include furniture, plants, equipment, landscape, Decorative elements, materials; intangible office elements include sound, color, light, temperature, smell, etc. (Meinel, Maier, Wagner & Voigt, 2017).

Building on these physical environmental factors, ownership of a work environment that supports creativity can also improve the learning experience. Ownership is established first by providing students with space, materials, and tools; then building ownership by allowing students to create spaces for themselves; and finally creating meaning in the context, where students decide to study patterns and connections between data, insights, sketches, and ideas (Leurs, Schelling & Mulder, 2013).

There are certain limitations and deficiencies in the physical environment that can affect creativity. Although the field of education has given great investment to the establishment of the environment, the physical environment has insurmountable defects. For example, the physical education environment has time and geographical restrictions; the flexibility of educational facilities is limited and it is not easy to change the location; the style, texture and color of the environment are not easy to switch and so on.

2.4. Virtual reality and its application

2.4.1. Definitions: Virtual reality

Virtual reality (VR) is a simulated experience that uses pose tracking and a 3D near-eye display to give users an immersive feel of a virtual world. Applications of virtual reality include entertainment (e.g., video games), education (e.g., medical or military training), and business (e.g., virtual meetings)(Goode, 2019).

Virtual reality (VR) technology is a simulated experience (Goode, 2019) that involves a head-mounted display (HMD), commonly referred to as a VR headset, which enables users to immerse themselves in a virtual world by masking the real world in (Brooks, 1999). With the latest advances in communication and computer technology, it provides potential users in different fields with a new virtual reality experience that is more realistic and immersive for a wide range of applications in virtual reality.

VR has made significant contributions in various fields such as academic research, engineering, sports, healthcare, design, military, education, architecture and entertainment (Bates, 2012). VR technology is commonly used during planning and prototyping for design visualization (Whyte, 2003), and is also used as a virtual training tool in many sports, aiming to measure athletes' performance and analyze their techniques (Bideau et al., 2010), Also used by the military for combat and response training in dangerous situations (Lele, 2013). There are very commercial applications of VR in entertainment, such as VR games, movies and animation (Jung et al., 2016 ; Molina et al., 2014).

VR is an immersive, engaging, comfortable and fun learning platform (Coyne et al., 2018). VR not only enables experiential learning by simulating a virtual environment, but also supports dynamic forms of learning through activities triggered by the learner's interaction in the virtual environment (Dávideková et al., 2017).

2.4.2. Virtual reality creativity support system

Virtual reality (VR) is rapidly gaining popularity in education due to its immersive, interactive, and imaginative features (Burdea & Coiffet, 2003; Gavish et al. ,2015), three fundamental features closely related to creativity. VR can simulate physical environments, facilitate realistic experiences, allow access to remote environments, and potentially facilitate individual creativity through imaginative, immersive, and interactive spaces (Jou & Wang 2013; Wei et al., 2015).

VR can stimulate learning motivation (Huang et al., 2016; Roussou, 2004) and bring rich interactive feedback (Atilola et al., 2016; Carrozzino & Bergamasco, 2010; Hussein & Nätterdal ,2015; Zhu & Wang ,2013; Kilmon et al. ,2010; Merchant et al., 2014; Thortensen, 2013). Creative ideas are more likely to emerge when people engaging in creative activities are in the process of interacting or are highly immersed in the interaction (Csikszentmihalyi, 1996; Witmer & Singer, 1998). Immersion is often understood as a feeling of being physically in a place, rather than where a person is physically (Sanchez-Vives & Slater, 2005), is the most important characteristic, which can be described as a psychological state isolated from the real world by a VR, and is highly associated with the state of flow (Bhatt, 2004).

Virtual reality environments are completely immersive, so there are also significant limitations. First, immersive VR interfaces introduce a huge discontinuity between the real world and the virtual world (Kato, 1999). Virtual reality systems are fully immersive experiences where the user is closed to the physical world and can only see the virtual environment. Second, users need to be trained to operate the virtual system. Third, VR systems can only provide digital tools, separating users from their traditional tools.

2.4.3. Educational media for student designer

Based on the limitations of VCE, we conducted online interviews with 64 current designer students aged 18-27 (M=22.5, SD=2.43). The interviews included a survey of the design tools commonly used by the designer students, the creative environment of the designer students, and their experience of using the VR system.

The conclusions drawn from the interview include three points. First, the creative tools that designer students are familiar with are computers, mouse and keyboards, and electronic devices such as smartphone. They use these devices to find pictures, text, sounds, or videos related to design tasks as design resources. Designer students express their creativity by drawing hand-drawn sketches. Second, designer students have very little experience with interactive media systems (including virtual reality and augmented reality), and they say that virtual reality systems are not easy to use. Third, the environment in the art and design institute has certain support for creativity, but the layout and facilities in the environment are not easy to move and change, and the time to use the educational environment is also limited.

Based on the results of the above questionnaires, compared to virtual learning environments, this study classifies traditional creative environments as "physical creative environments" (PCE). Most creative tools and facilities in a PCE are non-interactive and less flexible. That is, these physical objects are not easily changed in position, size and quantity. The creative materials in a PCE are also non-interactive and two-dimensional.

2.5. Mixed reality and its application

2.5.1. Definitions: Mixed reality (MR)

VR typically creates a fully artificial virtual environment, thus providing full virtualization (Buhl and Winter, 2009). The real world in a VR environment is completely obscured. The user is completely in a virtual environment, and the virtual objects in the environment are interactive. In a VR environment, users usually need a controller to operate the VR system, but recently some VR glasses have appeared that can recognize the user's gestures to operate. AR augments the real world by adding virtual information to physical reality (Cabero & Barroso, 2016). In an AR environment, users can see both the physical environment and virtual objects, but users cannot interact with virtual objects. Controllers are also needed in order to operate the AR system. However, MR devices are powered by AI sensors, camera tracking, graphics processing unit (GPU), and processors such as graphics cards and chips to process and store data in three dimensions. MR environments combine virtual and real worlds (Wohlgenannt et al., 2020), and where 3D virtual objects interact with the physical environment and the user. That is, the user can see both the physical environment and the virtual environment in the MR environment, and can operate the MR system and interact with virtual objects without the need for a controller (Table.2-2).

Table 2-2. The technology comparison of VR, AR and MR

Interactive media	**Whether the real world can be seen**	**Whether virtual objects can be interacted**	**Whether a controller is required**
VR	No	Yes	Yes
AR	Yes	No	Yes
MR	Yes	Yes	No

Mixed reality was first mentioned in a 1994 research paper by Milgram and Kishino titled "A Taxonomy of Mixed Reality Visual Displays". Mixed reality (MR) is a hybrid system involving physical and virtual elements, described as a sliding scale between a fully physical environment without virtual elements and a fully virtual environment (Barfield, 2016). Milgram and Kishino describe MR as a linear continuum (Figure.2-5) with fully real and fully virtual environments at both ends. The real world is on the far left, and nothing is digital. A completely virtual environment is on the far right, everything is computer-generated. Virtual objects residing in the real world are classified as AR, whereas physical objects integrated into the virtual world are classified as augmented virtual (AV) (Milgram & Kishino, 1994). MR has a higher proportion of physical elements in this continuum.

Although the definition of MR has evolved, the main features of MR can still be observed. Parveaua and Addaa characterize MR in three points: First, it consists of real and virtual content and allows data to be contextualized. Second, digital content is interactive in real time. Third, virtual content is spatially mapped and associated with physical space (Parveaua & Addaa, 2018).

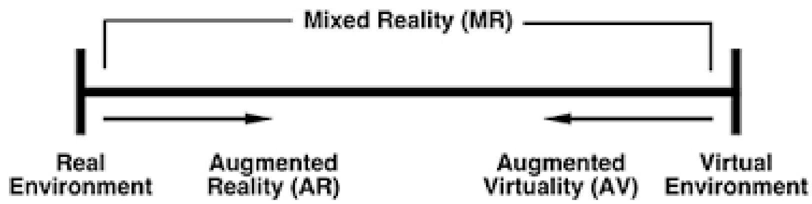


Figure 2-5. Reality-Virtuality (RV) Continuum (Milgram & Kishino, 1994)

2.5.2. Mixed reality and its application

Jad and Steven describe the application and impact of MR on productivity and quality in electrical conduit construction. Research results show that MR builds pipelines faster and with fewer errors. Bordegoni and Caruso propose an innovative approach for the automotive industry using MR technology, allowing closer collaboration between designers, engineers and end users to design certain components of a car. Amouri and Ababsa proposed the application of MR to rehabilitation, rescue settings and educational problems of persons with motor disabilities (Amouri & Ababsa, 2016).

The use of MR for simulation teaching and training is popular and there is preliminary evidence of its teaching effectiveness (Ke et al., 2016; Hayes et al., 2013a, b; Liarokapis & Anderson, 2010; Hughes et al., 2005). Ke pointed out that MR-integrated learning environments have the benefit of enhanced presence and can serve as an immersive platform for active pedagogical training. MR programs are used to teach product design to college students. The findings show that MR applications positively improve students' understanding of geometric relationships and creativity by visualizing 3D geometric shapes as well as exploded views (Tang, Au, & Leung, 2018). Pan explored the educational use of virtual learning environments (VLEs) for learning, training and entertainment issues and concluded that MR can be effectively used to motivate learners (Pan, Cheok, Yang, Zhu & Shi, 2006).

Development of mixed reality (MR) has great potential in the future art design education, which can effectively make up for the shortcomings of the traditional teaching model and traditional educational environment, also enhancing creative thinking. MR is the extension of AR and VR, is the application and integration of multi-disciplinary knowledge and multiple advanced technologies, which can provide designers with various forms of digital content and the mixed contextual creative environment that combines virtual and reality, thereby enhancing the designer's empathy and imagination.

Excellent interactivity and diversity of MR can greatly increase designer’s interest, enthusiasm, autonomy and creativity. Combining virtual scenes with real world, interacting across time and space boundaries can stimulate the designer's five senses to improve perception and experience.

2.6. The usability of mixed reality environment

Usability is context-dependent (Newman & Taylor, 1999) and shaped by interactions between tools, problems, and users (Naur, 1965). Usability signifies people’s ability to use something easily and effectively (Shackel & Richardson,1991, p. 24) or the quality of use (Bevan, 1995); how to use and improve the usability of interactive systems is a central research problem in human-computer interaction (Hornbæk, 2006). New environments of use, such as technologies that support learning, pose challenges for usability and measuring (Soloway et al., 1994).

Compared to controllers used to control VR environments, MR devices support hand tracking, which enables more natural interactions than controllers but often results in lower accuracy and precision (Xiao et al., 2018). As virtual environments are not yet commonplace in education, students are not skilled in using virtual user interfaces (VUIs), which calls into question the usability of creative MR environments. Even if MR technology employs hand-tracking technology that allows users to operate the MR environment with their hands, learners who lack experience in using virtual environments may face certain difficulties.

In terms of usability assessment, the System Usability Scale (SUS) can be used to assess responses to software, websites, or other digital interfaces and measure how easy or difficult they are to use. Moreover, many studies refer to broader dimensions of evaluation, as Hassenzahl & Wessler (2000) argue that commonly used usability measures ignore hedonic qualities, such as originality, innovation, and beauty. Meanwhile, the HCI literature includes discussions of pleasure (Carroll & Thomas, 1988) and aesthetics (Tractinsky, 1997). ISO standards also emphasize the degree of user satisfaction in the definition of usabilities, such as freedom from discomfort and a positive attitude of the user toward products.

To evaluate these human emotions and attitudes, Kansei Engineering proposes the use of perceptual adjectives that can guide users to express their emotional needs, feelings, and emotional states (Jiao et al., 2006). For example, the semantic differential method (Osgood et al., 1957; Osgood, 1962) is widely used in Kansei engineering to investigate the relationship between emotions and products.

The user interface of a creative MR environment must provide usability so that design students can focus on the virtual interaction's information content rather than how to operate the system. Additionally, the evaluation methods and dimensions in the literature provide theoretical support for developing and evaluating the usability and user experience of MRCEs for this study.

3. Mixed reality creative environment design

3.1. MRCE combining PCE and VCE

MR is a combination of AR and VR, an environment in which real and virtual world objects are presented together on a single display (Milgram & Kishino, 1994). MR is the Continuum of Reality and Virtuality, referring to the vast field of continuous transition between the two extremes of Real Environment (RE) to Virtual Reality (VR) (Milgram & Colquhoun, 1999). Real Environment (RE), which is a physical space such as traditional classrooms, labs, conference rooms, etc.; Virtual Environment (VE), which is a completely virtual world supported by VR.

MR supports a high degree of interaction and can present a virtual environment similar to the real world, which can effectively make up for the limitations of VCE. MRE will not completely separate the user from the real world, but the real and virtual worlds coexist and interact in real time to generate new environments and visualizations. The MRCE of this study was designed to preserve the physical creative environment of the workbench, combined with the virtual environment as the context for the creative environment (Figure 3-1).

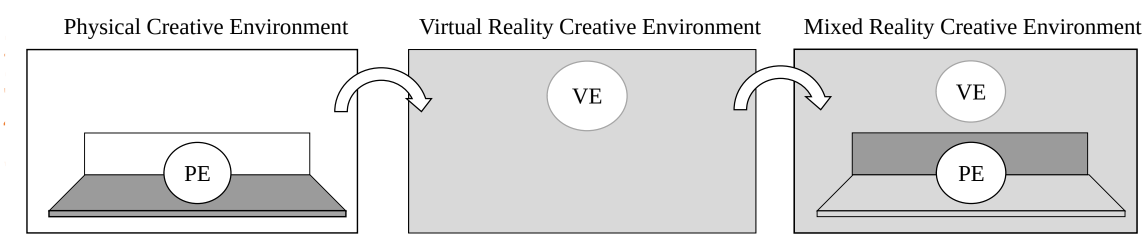


Figure 3-1. MRCE is composed of physical environment and virtual environment (Sourced from the mixed reality creative environment program design by Xiaoxiao Liu)

3.2. Use familiar physical creative tools in MRCE

Creative support tools can offer promising opportunities for creative design and practice (Wang & Nickerson, 2017). The most common VR devices include a head-mounted display (HMD) and two handheld controllers. MR devices support hand tracking, which allows for more natural interactions than controllers, but also often results in lower accuracy and precision, which is a hindrance for precise tasks such as handwriting and sketching (Xiao, Schwarz, Throm, et al., 2018).

Studies have shown that the use of digital design tools in the creative process can interfere with the creativity of design ideas (Cantero et al., 2009 & Atilola et al., 2016). Pen and paper tools used by creative practitioners work better than digital drawing tools. Designers can draw with pen and paper more easily and freely than with 2D and 3D design tools with technology (Bueno & Turkienicz, 2014; Lim et al., 2004). The MRCE in this study enables creative tasks using pen and paper creative tools. Creative tools that designers are very familiar with, such as computers, monitors, mouse, keyboards, pen and paper drawing tools, etc. can be used in MRCE, and these creative tools are also very commonly used in educational settings (Figure 3-2).

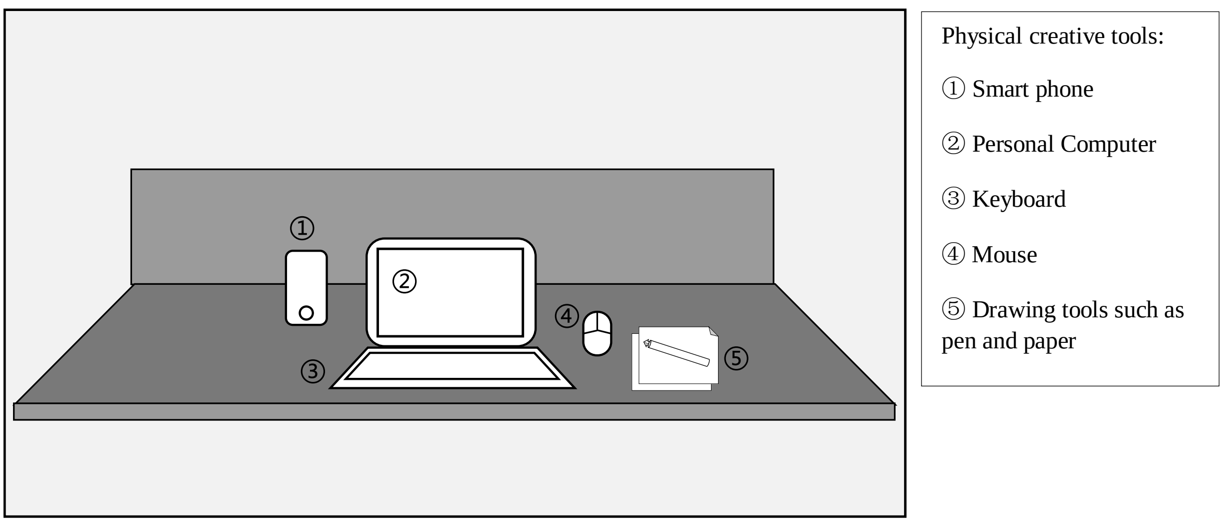


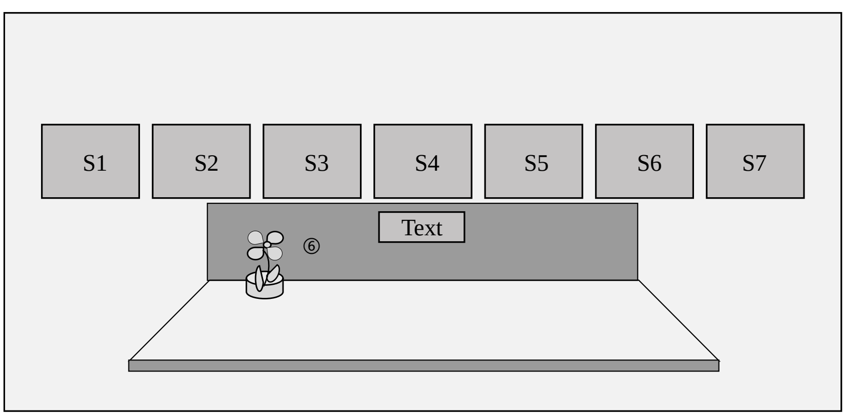
Figure 3-2. Physical creative environments and tools in MRCE (Sourced from the mixed reality creative environment program design by Xiaoxiao Liu)

3.3. Support the Creative Process with virtual creative tools in MRCE

The MRCE of this study is set as an independent space, as well as with tangible virtual office elements such as landscape, plants, decoration, equipment, materials, etc. and intangible virtual office elements such as sound, color, light, etc. Based on these environmental factors, MRCE provides space, materials and tools for designer students to create their own creative space to establish ownership, designer students decide design objects, define problems, establish patterns and connections between ideas and sketches, reflect and improve design outcomes.

The design process involves observing, engaging, and understanding user experiences and motivations. In this process, designers gather a lot of information and immerse themselves in the situation to learn more about the design task, the needs of users, and the problems faced by creative ideas (d.school, 2015). Information can be collected by consulting experts, interviewing users, or fieldwork. In education, inspections or collection of good pictures, video images, sounds, or through text descriptions and other media are often used as information to define problems.

Many people need the help of creative tools or systems to brainstorm ideas and generate creative designs (Gabriel et al., 2016). In this study, seven virtual display screens were set up in MRCE to display pictures and video images uploaded by users. The virtual text description was displayed below the center screen, and the ambient sound was played synchronously with the MRCE, and a virtual plant model was set up on the desk. These virtual creative tools are flexible because they can be easily moved and resized (Figure. 3-3).



Virtual creative tools:

Virtual screen display video (S4).

Virtual screen display picture

(S1, S2, S3, S5, S6, S7).

Virtual screen display text.

Virtual interactive models in Physical Creative Environment：
⑥ Virtual plant

Figure 3-3. Virtual creative tools and settings in MRCE（Sourced from the mixed reality creative environment program design by Xiaoxiao Liu）

3.4. Diverse user interface in MRCE

3.4.1. Physical user interface

The user interface (UI) is the intermediary that the user uses to issue instructions to the hardware, connecting the user and the hardware in a variety of ways (e.g., typing commands, making sounds, and taking actions , etc.). UI allow machines to control output hardware (e.g., computer monitors, speakers, and printers , etc.) through physical input hardware (e.g., keyboard, mouse, or joystick , etc.).

The physical user interface (PUI) referred to in this study refers to the interface used for devices in the physical space that can use a web browser as the user interface. This study focuses on designing a web-based system as the user interface to connect the MR system by physical hardware (personal computer, smart phone).

3.4.2. Virtual user interface

The virtual user interface (VUI) mentioned in this study is relative to the physical user interface, which refers to the user interface that exists in the virtual environment. VUI realizes the connection between man and machine through gesture input through an interactive dynamic interface. VUI is usually some interactable area that exists independently of the virtual environment or is interconnected with specified objects in the physical environment (objects that can be recognized by computer vision, for example, objects with QR codes attached).

The virtual user interface developed for MRCE in this study is in the form of a hand menu. The hand menu is one of the user interfaces in the MR headset called Microsoft HoloLens 2, and is a UI that can be quickly displayed according to the user's gestures. The hand menu allows the user to access it at any time, showing and hiding it easily.

3.4.3. Combination of physical and virtual user interfaces

Functions in the MR system are operated through virtual menus. The Hand menu in MR HMD HoloLens 2 is a kind of virtual menu, which is defined as VUI in this study. Accessible at any time and easy to show and hide, the Hand menu is great for quick actions, but it requires specific gestures to activate and execute in a virtual environment. Because the operation mode and environment of VUI are special, and most designer students have no experience in using VUI, they must learn how to use VUI and adapt to this new operation in order to achieve a good user experience. As a brand-new technology, VUI poses challenges in the usability of MRCE.

This study defines a web-based system as a PUI. Users often use computers and smart phones to browse the web, so users are more familiar with the use of PUI. The web-based system accesses the PUI through a web browser, and the user only needs to touch or click the mouse to operate the MRCE system.

To ensure a good user experience, the MRCE in this study can be operated with a variety of user interfaces, not only through HMD using VUI, but also through PC or smartphone using PUI. Users can choose the UI they are comfortable with, or even use VUI and PUI together. A user interface with better usability proposes an effective solution for the usability of the MRCE system (Figure.3-4).

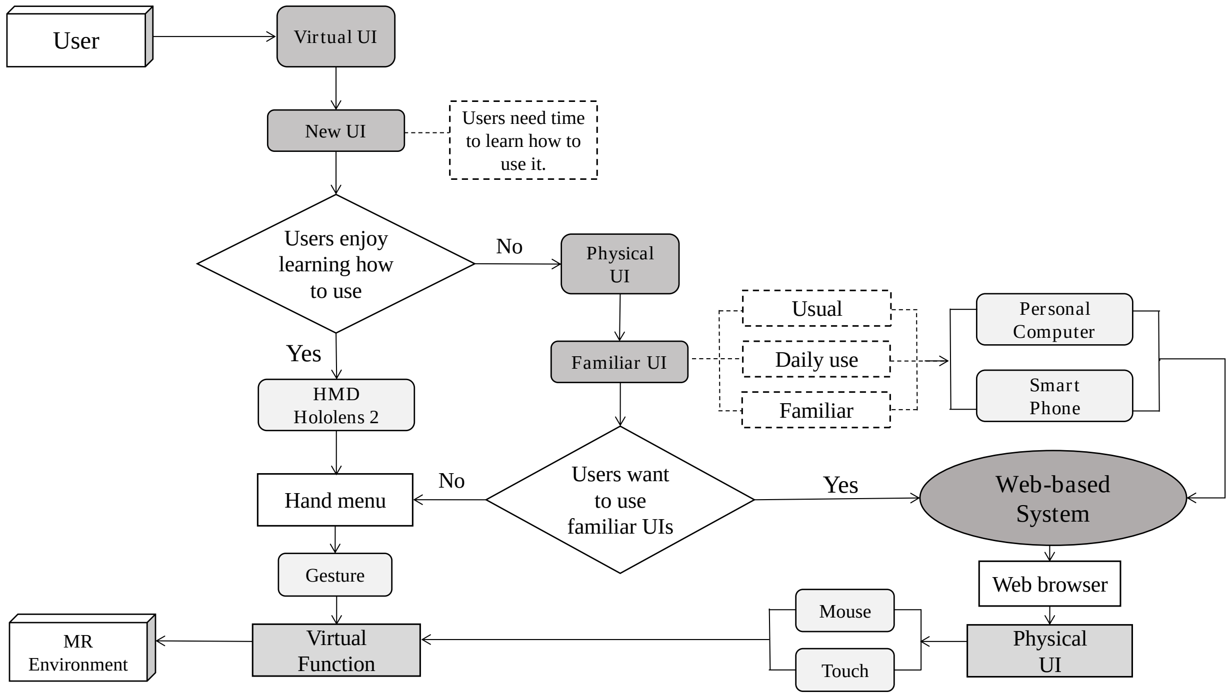
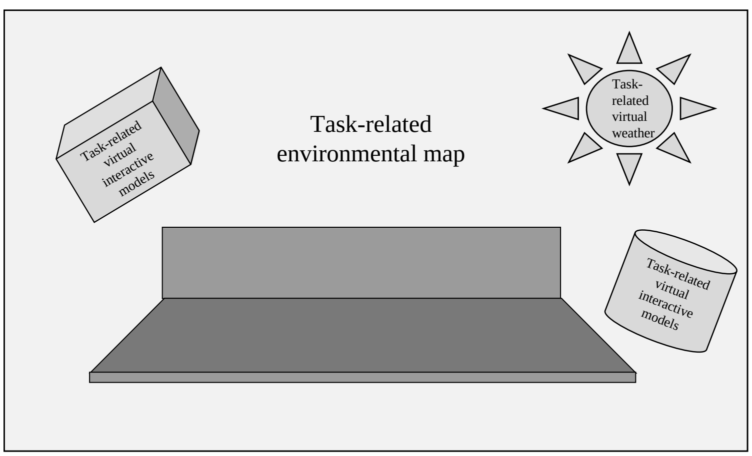


Figure 3-4. MRCE can be operated with a variety of user interfaces (VUI and PUI) to ensure the usability of the system (Sourced from the mixed reality creative environment program design by Xiaoxiao Liu)

3.5. MRCEs related to creativity tasks

The design process often begins by observing the design challenge, which is a deep understanding of the issues and realities of the design object. It involves understanding the difficulties faced by design objects and discovering their underlying needs and desires (Liu, 2021). Therefore, designers need to understand the situation of design objects and their role in the condition, as well as their interaction with the environment. As a creative support environment, the VR environment can facilitate the observation and experience of design challenges, is not limited by geographical location and time, and has the advantage of being able to simulate scenarios in the real world that cannot be experienced in time or safely. In addition, the interactivity of VR can provide timely feedback, which cannot be achieved by traditional physical creative environments.

In the MR environment, users can use both the physical environment and the virtual environment supported by VR technology, as well as real tools in the physical environment and virtual elements and tools in the virtual system. Therefore, a creative environment supported by MR technology allows users to use traditional tools to carry out creative activities in a virtual environment. VCE made with MR has advantages that VR does not have. In this study, environment maps, virtual weather and interaction models related to creative tasks were set in MRCE. Such an MRCE not only provides an immersive experience, but the real and virtual elements of its environment coexist dynamically to increase the immersion and engagement of the designer students, allowing the designer students to interact in the physical environment and operate the virtual environment 3D holographic content, real-time access to information (Figure.3-5).



Task-related mixed reality creative environment：

Task-related environmental map;

Task-related virtual weather;

Task-related virtual interactive models.

Figure 3-5. The content and settings of the virtual creative environment in MRCE (Sourced from the mixed reality creative environment program design by Xiaoxiao Liu)

4. MR system programming

4.1. Hardware and program development

MR is presented in an optical see-through head-mounted display (OST-HMD), which uses various sensors to map the surrounding environment, track physical objects, and render virtual objects at specific locations. These properties can be enabled as the user dynamically navigates the space, providing natural viewing and real-time interaction with virtual objects. In this study, an MR system was developed and applied to HoloLens 2.

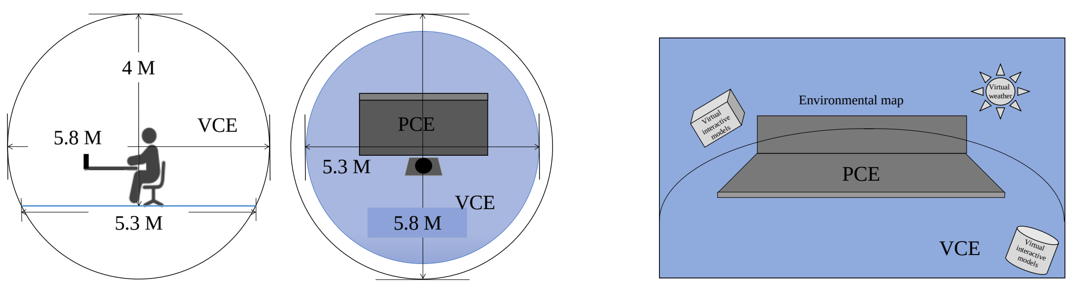
HoloLens is a standalone wireless wearable device that combines multiple types of sensors, high-definition cameras, speakers, and microphones by Microsoft Corporation (Redmond, WA, USA) to compute and execute MR systems. HoloLens provides a true heads-up display capability, capable of placing interactive 2D and 3D virtual interactable objects within the user's field of view. HoloLens can be applied in learning and education (Drexel University 2018; Müller et al. 2018), for example, in various clinical and educational scenarios. Currently, HoloLens is being developed to version 2.

The MRCE system for this study was developed in Unity v2019.4.17f1c1 (Unity Technologies, San Francisco, U.S.), a professional platform for creating VR, AR, and MR applications. Unity provides a graphical user interface and a standard set of tools that can be further enhanced with scripts and SDKs. One such SDK is Mixed Realty Toolkit v2.5.1 (MRTK2.5.1), which is open source and provides a wealth of useful features for creating MR applications. Scripting is handled by the general-purpose programming language C#, and Visual Studio v2019 (Microsoft, Redmond, Washington, U.S.) is used to test, compile, and deploy the application. HoloLens 2 enables self-developed digital content or 3D models to overlap with real environments, such as walls, tables, or other objects, providing users with an immersive environment to explore concepts of reality and human perception with a real-time perspective. Therefore, this study decided to use Unity to develop the application of MRCE on HoloLens 2.

4.2. Space setting

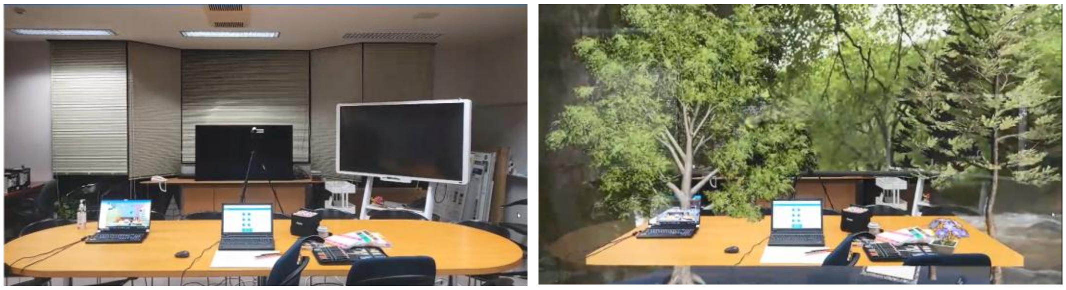
This study applies the principle of spherical screen projection to realize the immersive visual presentation of MRCE. Dome projection technology is a way of projecting panoramic images onto a sphere. It breaks the limitation that the projected images can only be flat regular graphics in the past and brings users an unprecedented visual experience. Users can view the projection screen from 360 degrees, helping to create the most immersive experience.

A spherical MR environment with a diameter of 5.8 meters was built in Unity, and the MRCE ground was set at a height of 1.8 meters from the bottom of the sphere. Panoramic environment maps are attached to the inner walls of the sphere, and interactive 3D models are added on the ground and a virtual weather system to enhance the user experience. The black rectangular workbench in the space is reserved for the physical creative environment (Figure.4-1).



Designing the space of MRCE by using the principle of spherical screen

Complete the application development of MRCE in the Unity development platform



The application development of MRCE realized from PE to MRCE

Figure 4-1. The space setting and realization of MRCE （Sourced from screenshot of the mixed reality creative environment program designed by Xiaoxiao Liu）

4.3. Scene design

An MR environment consisting of a variety of suitable learning elements and decorations under appropriate strategies is important for students to enjoy an immersive experience and acquire knowledge (Schuster et al., 2014). In this study, two scenes are designed as MRCE, they are the natural environment scene and the task scene.

The natural environment scene is set as the initial scene of the MR system, which consists of a virtual natural environment space, virtual interactive plant models, a virtual weather system and a virtual interactive model set at the PCE location; the task scene is set to perform creative tasks. The environment consists of mission-related virtual environment spaces, virtual interactive creative tools, virtual weather systems, and task-related virtual interactive models located at the PCE. Because the creative tasks set for designer students in this study are design ideas related to cherry blossoms and outer space, the theme of the task scene of MRCE is set as the cherry blossom scene and outer space scene (Figure 4-2).

Scene 1: Natural Environment Scene (Initial Scene)   Scene 2: Task 1 scene (cherry blossom scene)

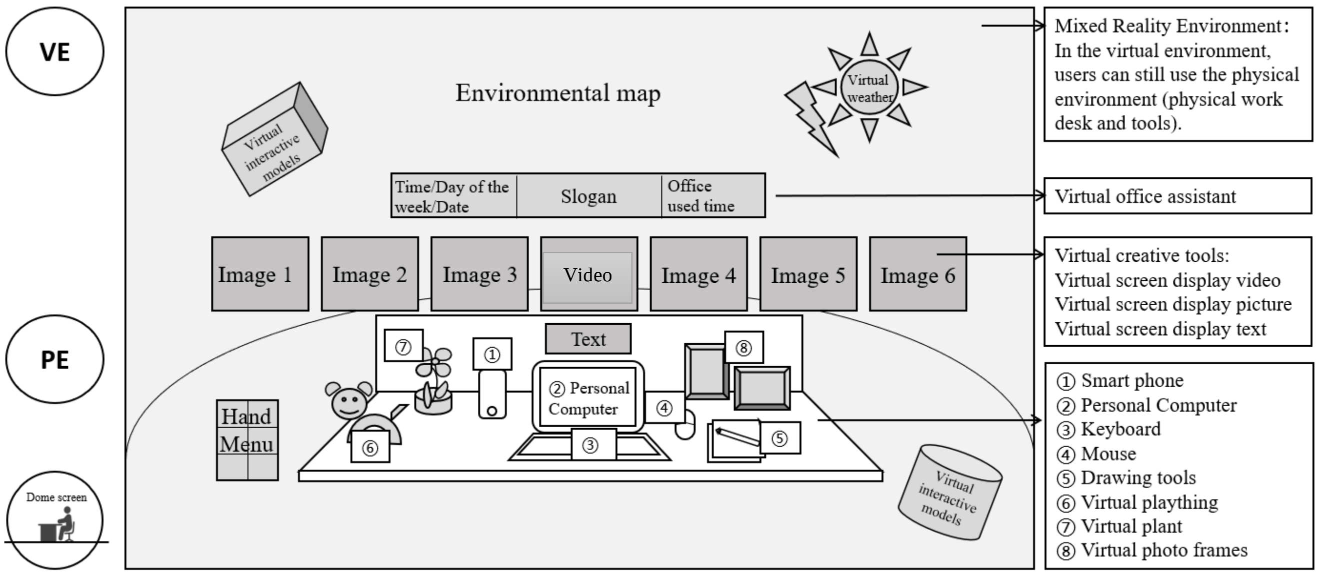
Scene 3: Task 2 scene (outer space scene)

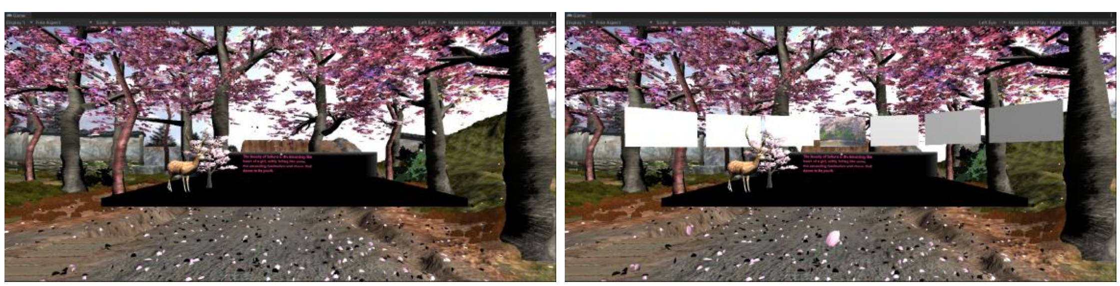
Figure 4-2. The natural environment scene and the task scene （Sourced from screenshots of the mixed reality creative environment program designed by Xiaoxiao Liu）

4.4. Virtual interactive creative tool in MRCE

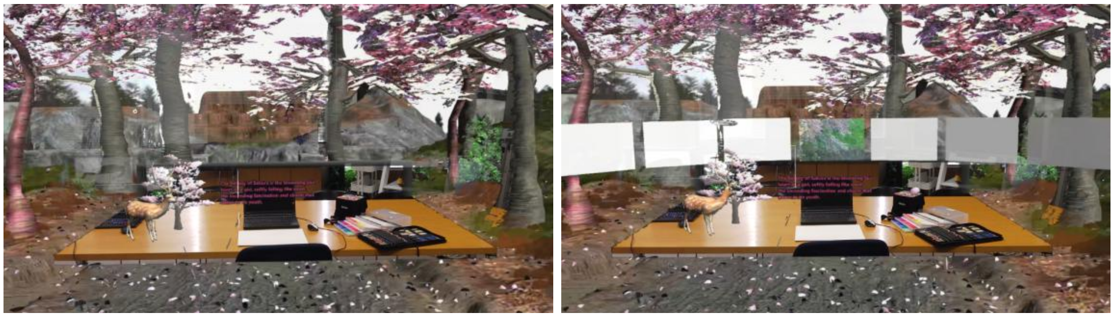
The task scenarios in MRCE integrate the traditional media (pictures, videos, text, sound) that designer students need to use in the creative process to support the design process. In MRCE, 1 virtual screen for video is set in the center of the user's line of sight, and there are a total of 6 virtual screens around it to present pictures. The seven virtual screens float in the environment, and the content they present is customized and uploaded by the user through a personal computer or smartphone, and the virtual screens can be interacted with by the user through hand tracking technology to achieve changes in position and size.

The PCE central location is equipped with 1 virtual text and virtual interaction model and virtual plant model, users can interact with them (grab, zoom in, zoom out, rotate, change position). Ambient sound is set to automatically loop, and users can choose to have ambient sound or mute (Figure 4-3).





Complete the application development of MRCE in the Unity development platform



Realization effect of task scene and virtual creative tools

Figure 4-3. Virtual interactive creative tool in the task scene (Sourced from screenshots of the mixed reality creative environment program designed by Xiaoxiao Liu)

4.5. User interfaces of MRCE

4.5.1. Physical User Interfaces in MR System

The PUI in this study was developed in Node-red v1.2.9 (IBM Emerging Technology, Armonk, New York, U.S.) based on the runtime environment consisting of Node.js v14.15.5. Node-RED is a flow-based visual programming development tool for connecting hardware devices, APIs, and online services together as part of the Internet of Things (Heath, N., 2014). Node-RED describes the behavior of an application as "nodes", where each node has a well-defined purpose. Node-RED consists of a Node.js-based runtime environment that provides a browser-based editor. In this browser editor, the application is deployed and running by dragging nodes from the palette into the workspace and connecting them together. The network is responsible for the flow of data between nodes, and the data is delivered after processing it.

The PUI developed for MRCE in this study has two parts of function. One part is the manipulation of the virtual scene, including: open task scene, close the virtual scene, switch scene, upload pictures from PC, close or open virtual screen, and restore the virtual screen. The other part is for custom uploading of virtual screen content, including 6 buttons for uploading pictures. PUI uses smartphone and PC as devices, and users operate the MRCE through a web page of a smartphone browser or a web page of a PC browser (Figure 4-4).

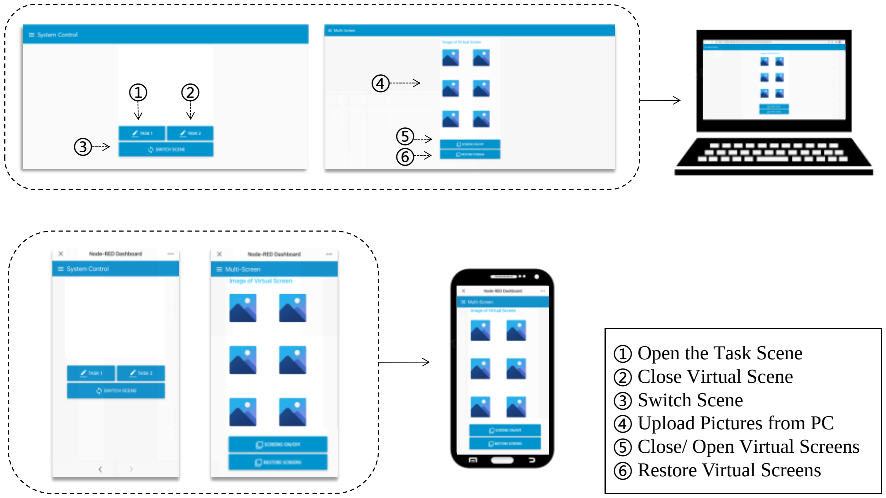


Figure 4-4. Function items and operation methods in PUI (Sourced from screenshots of the mixed reality creative environment program designed by Xiaoxiao Liu)

4.5.2. Virtual User Interface in MR Systems

This research developed the Hand menu as a virtual user interface (VUI). Hand menu is presented in a virtual form and is one of the most unique User Experience (UX) modes in HoloLens 2, which allows users to quickly bring up the hand-attached UI. Hand menu was developed by Mixed Realty Toolkit (MRTK) for Unity, MRTK provides scripts and example scenes for Hand menu. The Hand menu provides options like 'Require Flat Hand' and 'Use Gaze Activation' to prevent unwanted activation when interacting with other objects.

In MRCE, the user stretches out his hand and looks up at the hand to activate the Hand menu, and clicks the button in the Hand menu with the other hand to run the corresponding operation. In this study, six buttons were developed in the Hand menu, which are: switch scene, background music switch, open task scene, close virtual scene, close or open virtual screen and reset virtual screen (Figure. 4-5). The functions of these buttons correspond to the functions in the PUI. Hand menu, as the VUI of MRCE, its virtuality and interactivity supports the user to operate the user interface through gestures, thereby replacing the operation of the user interface through physical devices (handle, mouse, keyboard, touch screen, etc.).

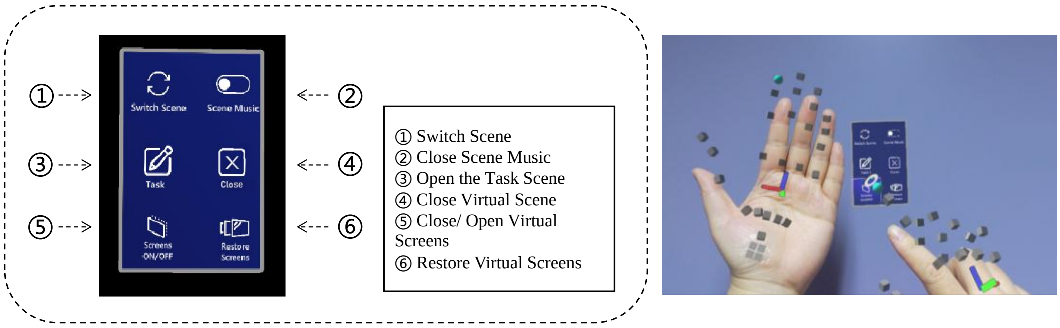


Figure 4-5. Function items and operation methods in VUI (Sourced from the mixed reality creative environment program design by Xiaoxiao Liu)

4.5.3. Mutual support between PUI and VUI

In order to realize the combined operation of MRCE by PUI and VUI, this study uses LAN to connect four parts, including physical device (smartphone and PC), local server, MR system under Unity operation and HoloLens 2. And these four parts should be connected to Wi-Fi with the same SSID (Service Set Identifier). Figure 4-6 explains how these four parts are connected and operate. PUI uses a physical device (smartphone or personal computer) to operate the UI. The physical device connects to the webpage of the user interface through the webpage address generated by Node-RED, and the user sends commands or pictures to the local server through the webpage in the smartphone or personal computer. The local server and Unity are correspondingly connected through IP addresses, Unity calculates the instructions and maps the calculated MRCE to the HoloLens 2 through the Holographic application. VUI sends commands through the Hand menu generated by MRTK for Unity, operates MRCE through Unity operation, and maps the calculated MRCE to HoloLens 2 through the Holographic application.

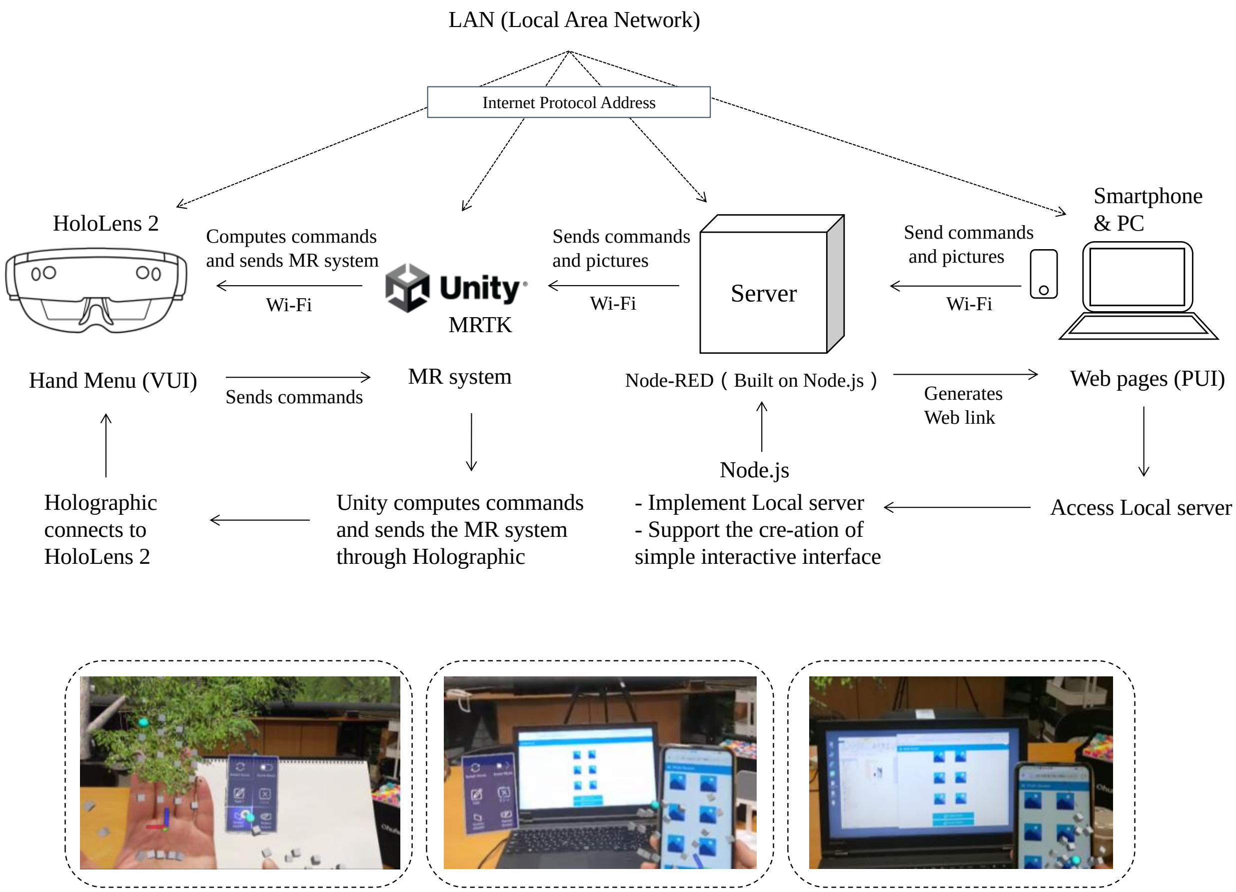


Figure 4-6. Realize the combined operation of MRCE by PUI and VUI （Sourced from the mixed reality creative environment program design by Xiaoxiao Liu）

The mutual support between the physical user interface (web-based user interface) and the virtual user interface (hand menu) in MRCE ensures the usability of the system, and users can use different user interfaces (PC The web browser of the smartphone, the web browser of the smartphone, the hand menu of the HoloLens2) to operate the functions in the virtual environment (Virtual Function).

Based on physical creative environment, MRCE provides virtual user interface (hand menu of HoloLens 2) as an auxiliary support for physical creative environment, and the user activates the hand menu by wearing HoloLens 2. In this case, the user can operate the virtual function in the physical creative environment through the new user interface of the hand menu.

Based on virtual creative environment, MRCE provides a physical user interface (web browser for PC, web browser for smartphone) supported by a web-based system as an auxiliary support for virtual creative environment, and users can control the virtual creative environment through PC and smartphone. In this case, the user can control the Virtual Function through the UI they are very familiar with as a physical user interface (Figure.4-7).

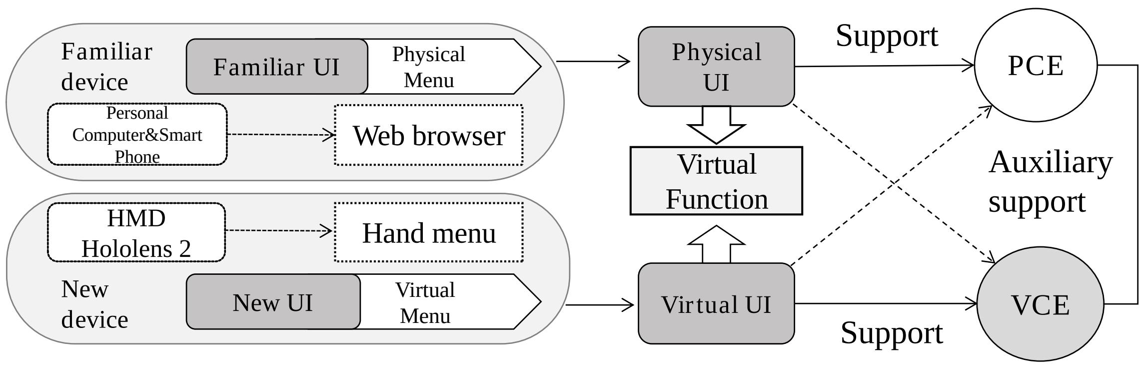


Figure 4-7. The mutual support between the physical user interface and the virtual user interface in MRCE (Sourced from the mixed reality creative environment program design by Xiaoxiao Liu)

5. Experiment

5.1. Evaluation Method

The experiment focused on evaluating the enhancement of creativity in the creative environment of designer students by MRCE with both physical creative tools and virtual creative environment as creativity support. The experiment used between-group comparison, and 24 subjects were divided into PCE group and MRCE group. The comparison goals include: comparing PCE and MRCE for usability, user experience, support for the creative process, and enhancement of creativity.

Before the experiment we asked participants to complete the demographic questions pre-questionnaire, according to which we divided the participants into PCE group and MRCE group. Experimenters were strictly grouped according to major, grade, gender, and academic performance to ensure equivalence of experimenter conditions in the PCE and MRCE groups. The experimental equipment of the PCE group and the MRCE group in the experiment are different, but the experimental process and time are strictly corresponding. The PCE group used a personal computer for design tasks in a physical creative environment and used pen and paper tools to complete the assigned design tasks to generate hand-drawn design sketches and to fill out a questionnaire. The MRCE group wore Microsoft HoloLens 2 and used a personal computer or smartphone to complete design tasks in MRCE and use pen and paper tools to complete hand-drawn design sketches and fill out questionnaires. After the experiment, the hand-drawn design sketches are used as the experimental results to evaluate the creativity of the designer students by creativity experts, thereby to compare the improvement of creativity between PCE and MRCE.

5.1.1 Participant

This study invited 24 designer students from Kanazawa college of art in Japan and 3 design majors of Nagaoka Institute of Design. The participants were conducted in two languages, Japanese and English. There were 24 subjects, including 12 males and 12 females, aged 19-24 years (M = 20.92, SD = 1.69). The Experience with digital user interfaces (Smart phone/tablet/computer) of 24 experimenters is more than 5 years, and the Frequency daily usage of digital user interfaces of 24 experimenters is more than 9 times. That is, the 24 participants were very familiar with the use of personal computers and smartphones. Regarding the experience of using HMD equipment, 21 of the 24 participants had no experience in using interactive media HMD at all, and only 3 experimenters had one experience of VR HMD. These 24 participants were equally divided into the PCE and MRCE groups to achieve an average sampling condition of participants in the PCE and MRCE groups. Each experimenter signed an informed consent form before the experiment, and each participant was paid 5,000 yen after completing the 120-minute experiment. In addition, 5 experts were invited to evaluate the creativity of 24 participants through hand-drawn design sketches.

5.1.2 Experimental equipment and site

The participants in the MRCE group were asked to wear a Microsoft HoloLens 2 for the experiment. Although it is possible to wear Microsoft HoloLens 2 while wearing glasses, we require those who require glasses to wear contact lenses during the experiment to ensure the same conditions for all participants wearing the experimental equipment. Additionally, a personal computer, mouse, keyboard and hand-drawn sketching tools were provided to the participant.

The experiment was started in September 2021, and the experimental site was set up at the Kanazawa Station Office of JAIST (2-15-1 Porte Kanazawa, Hon-machi Kanazawa-shi, Ishikawa, Japan), and the Office of A Building in Nagaoka University of Art and Design (4-197, Senshu, Nagaoka-shi, Niigata-ken, Japan). Due to COVID-19 precautions, the experimental site was disinfected and ventilated. The experimental staff was limited to 2 people and wore masks. The participants were required to wear masks and were tested one by one. After each experimenter was tested, staff disinfected all equipment and facilities. The room temperature of the experimental site is controlled at about 25 degrees Celsius. When the experiment of the MRCE group is carried out, the lighting of the experimental site is set to the state of weak natural light to ensure the visual effect of Microsoft HoloLens 2.

The whole process of the experiment was carried out with the consent of the participant. Two staff members were seated at a distance of 2 meters to the left and rear of the participant. Staff 1 is responsible for monitoring the operation of the MR program and the normal operation of the equipment, and staff 2 is responsible for answering the participant's questions and monitoring the experimental time and progress.

5.1.3 Experimental task

The creative tasks are respectively for the three majors of design, and the participants from each major complete the corresponding creative tasks. The creative tasks are: visual design majors complete symbol design; industrial product design majors complete the chair design; architectural environment design majors complete the art gallery exhibition hall design.

Each creative task is completed in the form of hand-drawn design sketches, and each creative task must contain 3 or more different ideas, which are expressed in the form of colored hand-drawn sketches. The participants were asked to keep all thought processes on hand-drawn sketches and to provide written explanations of completed creative ideas.

5.2 Experimental conditions

The experimental conditions ensure that the design resources (pictures, videos, sounds, text) of MRCE and PCE are equal, but presented in different ways. MRCE presents all design resources through HoloLens 2, while PCE presents design resources through PC monitors and speakers. In order to equalize PCE and design resources, experimenters were asked not to view resources other than the given design resources. In addition, because MRCE can see the virtual environment and PCE cannot, the content of the virtual environment in MRCE is converted into pictures by way of screenshots. The virtual environment in MRCE is captured as 20 "environment" pictures added to the PCE's design resources.

5.2.1 MRCE: Creative space using HoloLens 2 and freehand drawing tools

MRCE includes virtual environment, 1 video of 3 minutes and 2 seconds, 20 pictures related to the design theme from the Internet, 10 pictures of design examples, 1 paragraph of text and 1 paragraph of 70 seconds of ambient sound, 2 virtual interactive model settings at the PCE location. These design resources are all presented in MRCE. Pictures are selected by the participants and uploaded to the virtual screen in MRCE, and videos and pictures can be viewed simultaneously through 7 virtual screens. Ambient sound is integrated into the virtual environment and played along with the scene by the HoloLens 2's built-in speakers (Figure.5-1).

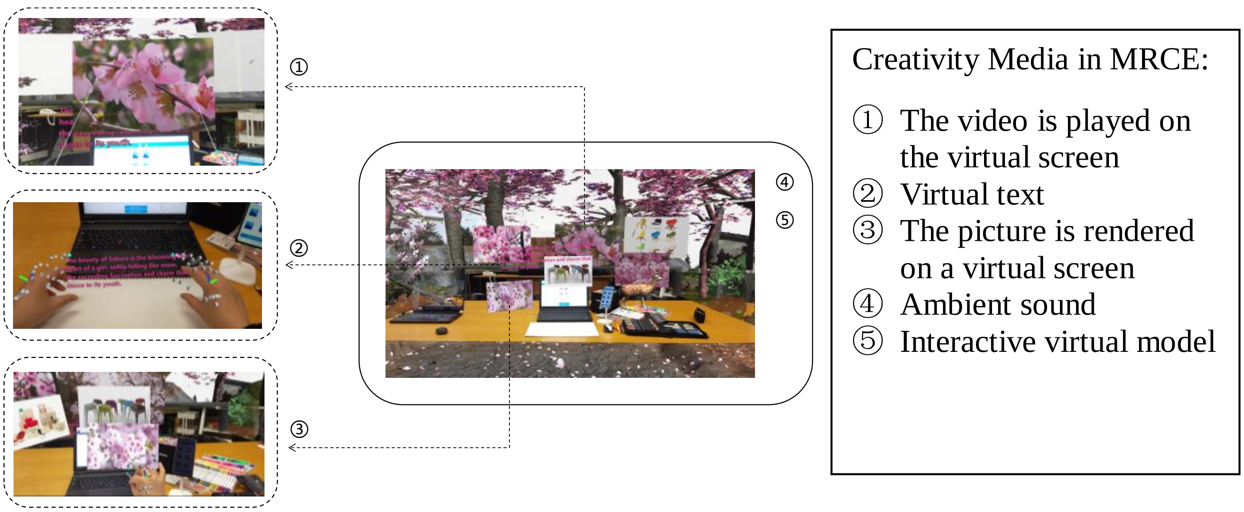
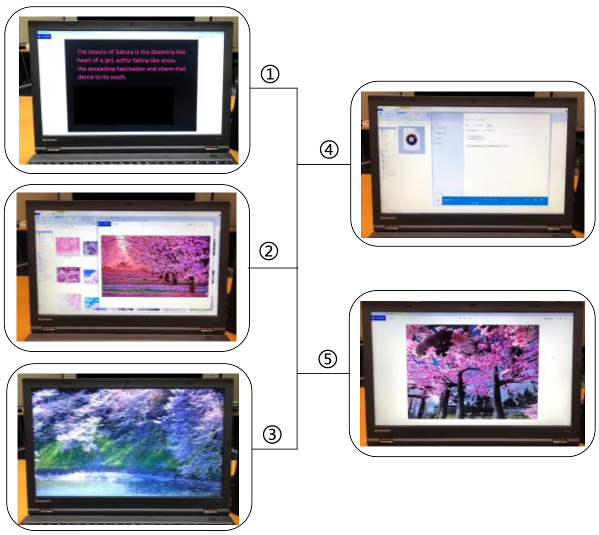


Figure 5-1. Experimental conditions for MRCE （Sourced from the Mixed reality creative environment program design by Xiaoxiao Liu）

5.2.2 PCE: Creative space using personal computers and freehand-painting tools

PCE includes 20 pictures ("environment" pictures) captured in the MRCE environment (including 2 virtual interactive models set at the PCE position), a video of 3 minutes and 2 seconds, and 20 pictures related to the design theme from Internet, 10 pictures of design examples, 1 paragraph of text and 1 paragraph of 70-second sound, all design resources are presented in PC (pictures are presented through the PC's picture browser, ambient sounds are presented through the PC's speakers, and the video is presented through the video player rendered, the text is read through the text document). The pictures and videos were played by the experimenter one by one on the PC monitor or multiple pictures were played simultaneously in multiple windows. The participants can also choose to listen to ambient sounds while looking at pictures (Figure.5-2).



Creativity Media in PCE:

① Text is read through the display of PC
② The picture is presented through the display
③ The video is played through the player
④ Ambient sound
⑤ "environment" pictures taken from the virtual environment

Figure 5-2. Experimental conditions for PCE （Sourced from the Mixed reality creative environment program design by Xiaoxiao Liu）

5.3 Experiment process

The experimental procedure of the MRCE group and the PCE group consisted of 4 steps: i) adapt to the creative environment, ii) conduct creative tasks, iii) complete hand-drawn design sketches in the creative environment, iv) complete questionnaires evaluating the ease of use and overall use of the creative environment

5.3.1 Experiment Ethics Review

This research was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Life Sciences Committee of the Japan Advanced Institute of Science and Technology (Hito 03-008, approved on 1 July, 2021). Informed consent was obtained from all subjects participating in the study. The use of virtual assets in the developed program has all been formally purchased.

5.3.2 MRCE group

The first step in the experimental procedure of the MRCE group is to allow the participant to adapt to the MR creative environment (15 minutes). We asked the experimenter to wear Microsoft HoloLens 2 and enter the virtual scene 1. The participants were asked to become familiar with how to operate virtual objects (grab, rotate, zoom in, zoom out, virtual screen reset), and connect the participant's smartphone to the physical user interface. Also, familiarize the participant with operating the physical user interface by PC and smartphone. The second step is to require the participant to carry out the design task in the virtual scene 2. The participant interacts with the virtual objects and observes the virtual environment through the virtual user interface (Hand menu) and the physical user interface. The participants were required to read virtual text, watch the video on the virtual screen, find pictures to refer to and upload them from the PC to the virtual screen (35 minutes). The third step is for the participant to complete the hand-drawn design sketch as required by 2 creative tasks in the MR creative environment and explain it in words (50 minutes). The fourth step is to ask the participant to answer the questionnaire (15 minutes) (Figure.5-3).

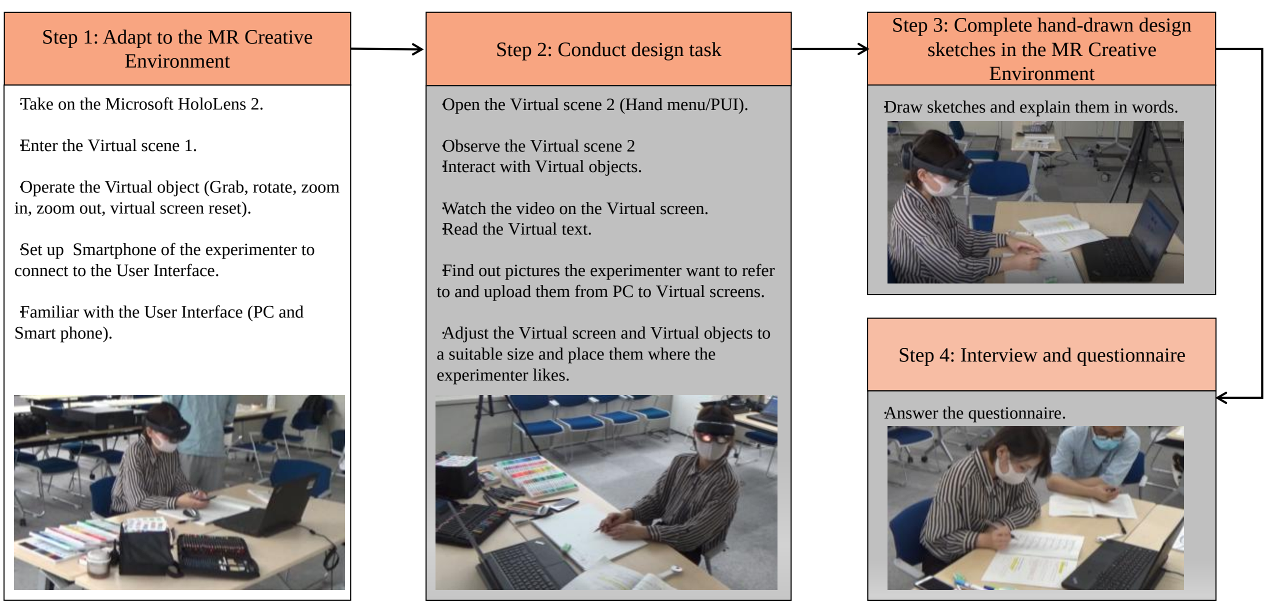


Figure 5-3. Experiment process of MRCE Group

Experimental location : Kanazawa Station Office of JAIST (2-15-1 Porte Kanazawa, Hon machi Kanazawa shi Ishikawa, Japan)

Experiment was approved by the Life Sciences Committee of the Japan Advanced Institute of Science and Technology (Hito 03 008, approved on July 1st, 2021)

5.3.3 PCE group

The first step in the experimental procedure of the PCE group is to allow the participant to adapt to the physical creation environment (15 minutes). The second step is to ask the participant to view the design resource in PCE. Experimenters were asked to use a PC to listen to ambient sounds, look at " environment " pictures, read text, watch videos, watch pictures related to the design theme and design example pictures (35 minutes). The third step is to ask the participant to complete the hand-drawn design sketch as required by 2 creative tasks and explain it in words in the physical creative environment (50 minutes). The fourth step is to ask the participant to answer the questionnaire (15 minutes) (Figure.5-4).

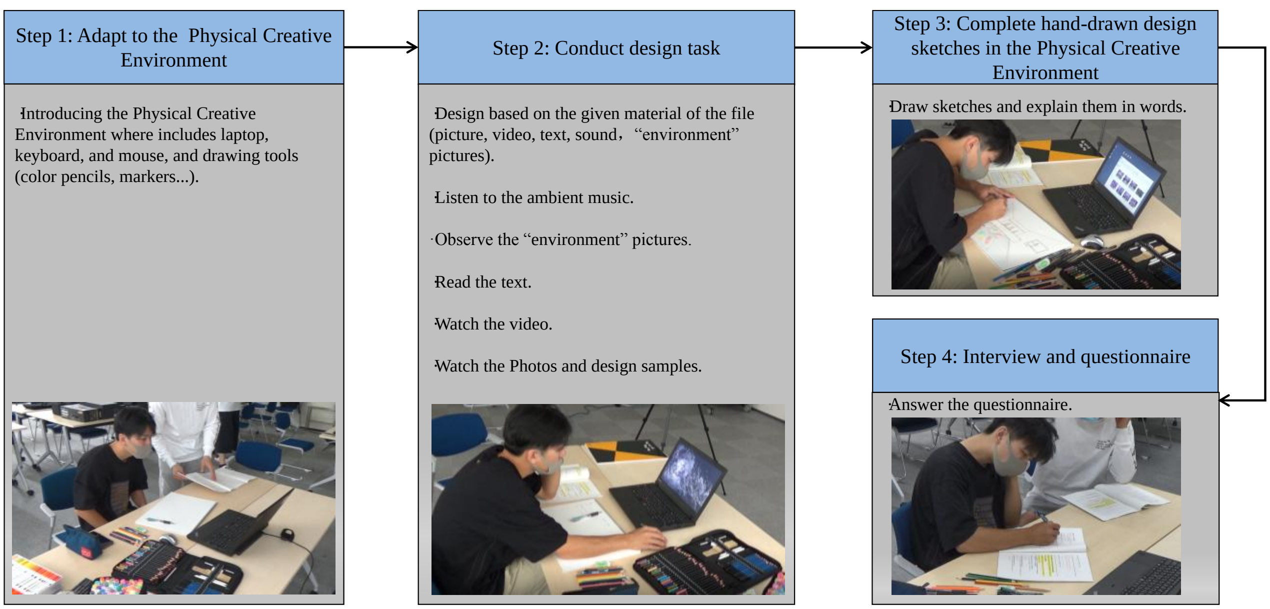


Figure 5-4. Experiment process of PCE Group

Experimental location : Kanazawa Station Office of JAIST (2-15-1 Porte Kanazawa, Hon machi Kanazawa shi Ishikawa, Japan)

Experiment was approved by the Life Sciences Committee of the Japan Advanced Institute of Science and Technology (Hito 03 008, approved on July 1st, 2021)

6. Data analysis and results

6.1. Usability evaluation of creative environment

Usability assessment is an important part of the overall assessment of the MR creative environment. The user interface of the MR creative environment must be used simply and efficiently so that the user can focus on the informational content of the virtual interaction rather than the interface.

The System Usability Scale (SUS) is a very popular tool for evaluating the response to software, websites, or any other digital interface. The SUS modified for the interface used in the current study contains 10 questions, each with a score of 5， from "1" for strong disagreement to "5" for strong agreement (Brooke, 1996). According to the standard definition of the SUS scale factor, any interface with a SUS score higher than 68 can be considered above average (Sauro, 2011). In addition, scores are converted into grades A, B, C, D, and F (0-59 is "F" grade, 60-69 is "D", 70-79 is "C", 80-89 is "B", and above 90 is "A") and approximate values of adjectives assigned (Bangor, Kortum & Miller, 2009).

24 experimenters evaluated the usability of the user interface of their group by SUS after completing the experiment. The assessment content of the MRCE group included VUI and PUI, and the assessment content of the PCE group was PUI. Table 7-1 shows the SUS score, grade and approximate values of adjectives assigned for the 12 experimenters who participated in the MRCE. Table 7-2 shows the mean, grade and approximate values of adjectives assigned for the SUS of the 12 experimenters who participated in PCE.

Table 6-1. SUS assessment for the MRCE group

MRCE Group	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**Mean**
SUS Score	57.5	67.5	82.5	67.5	72.5	67.5	62.5	67.5	85	67.5	67.5	80	70.4
SUS Grade	F	D	B	D	C	D	D	D	B	D	D	B	C
SUS Approximate values	OK	OK	GOOD	OK	GOOD	OK	OK	OK	EXCE-LLENT	OK	OK	GOOD	OK

Table 6-2. SUS assessment for the PCE group

PCE Group	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**Mean**
SUS Score	77.5	85	72.5	67.5	62.5	60	70	87.5	70	72.5	65	70	71.7
SUS Grade	C	B	C	D	D	D	C	B	C	C	D	C	C
SUS Approximate values	GOOD	EXCE-LLENT	GOOD	OK	OK	OK	OK	EXCE-LLENT	OK	GOOD	GOOD	OK	OK

The results in Table 6-1 show that the SUS Score of MRCE is 70.4 is considered a Grade C. The results in Table 6-2 show that the SUS Score of PCE is 71.7 is considered a Grade C. By conventional standards a score of 70.4 higher than 68 is considered to be above average. The SUS Score of MRCE and PCE may be described as ok.

The analysis results show that the average SUS scores of PCE and MRCE are higher than the average level (mean of score = 71.7 > 70.4 > 68), indicating that the usability of these two creative environments is within the normal range and there is no significant difference. In order to get the detailed performance of MRCE in the SUS scale, the One-Sample Test is used to compare the 10 items in the SUS of MRCE one by one.

Table 6-3. One-Sample Statistics for Item 1, 3 ,5, 7, 9 of MRCE

Survey Items	N	Mean	Std. Deviation	Std. Error Mean
1. I will use this interface frequently	12	4.5833*	.90034	.25990
3. Interface is easy to use	12	3.8333*	.83485	.24100
5. Various functions are well integrated	12	4.4167*	.51493	.14865
7. Most people will learn to use very quickly	12	4.3333*	.88763	.25624
9. Very confident using this interface	12	3.9167*	.90034	.25990

*Mean>3.4

Table 6-4. One-Sample Statistics for Item 2, 4 ,6, 8, 10 of MRCE

Survey Items	N	Mean	Std. Deviation	Std. Error Mean
2. Interface is unnecessarily complex	12	2.5833	.79296	.22891
4. Need tech support to be able to use	12	3.0000	1.34840	.38925
6. Too much inconsistency	12	1.5833*	.51493	.14865
8. Very cumbersome to use	12	2.3333	1.37069	.39568
10. Need to learn a lot before using	12	3.5000	1.24316	.35887

*Mean <1.6

According to the evaluation score determination standard of the SUS scale, the analysis results (Table 6-3) show that the average value of items 1, 3, 5, 7, and 9 is greater than 3.4, that is, the performnce of items 1, 5, 7, 9, and 3 is higher than Average (Mean = 4.5833 > 4.4167 > 4.3333 > 3.9167 > 3.8333 > 3.4). The analysis results (Table 6-4) show that the mean value of item 6 is less than 1.6, that is, the performance of items 10, 4, 2, and 8 is lower than the average level (Mean =3.5> 3> 2.5833> 2.3333> 1.6), and the performance of item 6 is high at the average level (Mean =1.5833< 1.6).

Table 6-5. One-Sample Test for Item 1, 3 ,5, 7, 9 of MRCE

Survey Items	Test Value = 3.4					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
1. I will use this interface frequently	4.553	11	.001*	1.18333	.6113	1.7554
3. Interface is easy to use	1.798	11	.100	.43333	-.0971	.9638
5. Various functions are well integrated	6.839	11	.000*	1.01667	.6895	1.3438
7. Most people will learn to use very quickly	3.642	11	.004*	.93333	.3694	1.4973

9. Very confident using this interface	1.988	11	.072	.51667	-.0554	1.0887

*sig.<0.05

The Sig. (2-tailed) values were used to check whether the 10 SUS items of MRCE were significantly different from the evaluation criteria. The results (Table 6-5) show that the two-sided Sig. values of items 1, 5, and 7 are: *p* =.001 rather than *p* <.05, p =.000 rather than *p* <.05, *p* = .004 rather than *p* <.05. Therefore, it is considered that at the significance level of 0.05, the evaluation item scores are significantly different from the standard values (Test Value = 3.4). Items 1, 5, and 7 were significantly better than the average of the system UI with a 95% probability. The results showed significant advantages of the UI of MRCE, including: Users indicated that they would frequently use the UI in MRCE (VUI and PUI), the various features in MRCE are well integrated and most people will learn to use it quickly.

The results in Table 6-6 show that the Sig. (2-tailed) values of items 2, 4, and 10 are: *p* = .001 rather than p <.05, *p* =.004 rather than p <.05, *p* =.000 rather than *p* <.05. Therefore, it is considered that at the significance level of 0.05, the evaluation item score is significantly different from the standard value (Test Value = 1.6), that is, with a probability of 95%, items 1, 5, and 7 are significantly lower than the average of the system's UI. The results show that the UI of MRCE has significant deficiencies, including: the user thinks the interface is unnecessarily complicated, requires technical support to use and it takes a lot of learning before using it.

Table 6-6. One-Sample Test for Item 2, 4 ,6, 8, 10 of MRCE

Survey Items	Test Value = 1.6					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
2. Interface is unnecessarily complex	4.296	11	.001*	.98333	.4795	1.4872

4. Need tech support to be able to use	3.597	11	.004*	1.40000	.5433	2.2567
6. Too much inconsistency	-.112	11	.913	-.01667	-.3438	.3105
8. Very cumbersome to use	1.853	11	.091	.73333	-.1376	1.6042
10. Need to learn a lot before using	5.294	11	.000*	1.90000	1.1101	2.6899

*sig.<0.05

This result shows that the usability of MRCE and PCE is approximately the same. The user interface in the MRCE supports the design student's operating system and ensures the creative process. Although the design students feel that the user interfaces in the MRCEs are complex and must be learned before they can be used, they believe that these user interfaces are well integrated with the functions, and the usage methods are quick for the users to learn. They want to be able to use MRCE's user interfaces frequently.

6.2. Semantic Difference (SD) Method for evaluation system

Because human emotions are extremely subjective, context-related, and individualized. In this regard, kansei engineering proposes a new perspective on human emotions, that is, using perceptual words or adjectives to represent various emotions (Ota & Aoyama, 2001). Using perceptual adjectives, users can be guided to express their emotional needs, feelings, and emotional states ((Jiao et al., 2006). The Semantic Difference (SD) method was proposed by Osgood (Osgood, 1962, Osgood et al., 1957), It has been widely used in kansei engineering to explore the relationship between emotion and product. The semantic difference scale is widely used in perceptual engineering to compare differences between cultures, individuals and groups, as well as the study of attitudes and perceptions of the surrounding environment or project. Based on a series of adjectives and their antonyms, using adjectives with positive or negative connotations, the scale provides a unified platform to quantify subjective assessments with high reliability and validity.

When software has usability, it is efficient, easy to remember, less error-prone, and subjectively pleasing (Nielsen, 1993). Hassenzhal et al argue that commonly used usability measures ignore what they call hedonic qualities such as originality, innovation, beauty, etc. (Hassenzahl et al., 2000). The HCI literature now contains discussions of pleasure (Carroll & Thomas, 1988), aesthetics (Tractinsky, 1997). ISO standards also emphasize the degree of user satisfaction in the definition of usability, such as freedom from discomfort and positive attitude of user towards products (ISO, 1998, all p. 2). Due to the limited evaluation of the user interface and system by the SUS scale, the SD scale used in this study which adopted five dimensions related to users' subjective emotions, including operability, functionality, aesthetics, creativity support, and affective experience to study experimenters' experiences and thoughts on MRCE and PCE.

The SD scales evaluated in this study used the bipolar adjectives (Table.6-7). The SD scale is a Likert scale in which each adjective is 7 points away from its antonym, and its application requires experimenters to record the strength of their responses to different adjectives and their antonyms. The experimenter's perception can be reflected by the chosen interval between the chosen pairs of opposing adjectives.

Results of SD graphically shows the difference in SD evaluation results between MRCE and PCE (Fig.6-1). One-way ANOVA analysis was performed to compare each Bipolar Adjective Pairs values of the MRCE with PCE, and the results of the analysis showed significant differences in adjectives for each dimension (Table.6-8). The results (Fig. 6-1) showed that PCE was slightly better in operability overall than MRCE, but MRCE was slightly better in convenience. One-way ANOVA comparative analysis of PCE and MRCE in terms of familiarity (Table.6-8) showed a significant statistical difference (p =.012 rather than p <.05). That is to say, the user's familiarity with the operation of MRCE is significantly lower than that of PCE.

Table 6-7. Bipolar Adjectives for SD Method

Evaluation dimension	Bipolar Adjective Pairs	
Operability	Convenient, Simple, Clear, Safe, Familiar, Smooth	Inconvenient, Complex, Unclear, Dangerous, Unfamiliar, Rough
Functionality	Useful, Efficient, Intelligent, Original, Innovative, Flexible, Reliable, Powerful, Necessary	Useless, Ineffective, Unintelligent, Imitative, Traditional, Inflexible, Unreliable, Weak, Unnecessary
Aesthetics	Dynamic, Beautiful, Harmonious, Graceful	Static, Ugly, Inharmonious, Graceless
Creativity support	Novel, Interactive, Imaginative, Immersive, Multi-channel	Ordinary, Non-interactive, Unimaginative, Detached, Single channel
Affective experience	Funny, Comfortable, Relaxed, Agreeable	Boring, Uncomfortable, Tense, Disagreeable

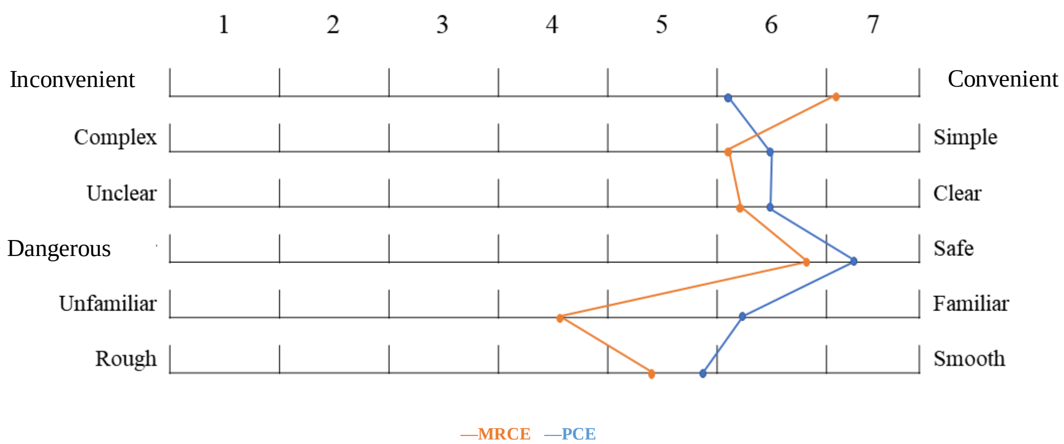


Figure 6-1. Results of operability evaluation

Table 6-8. ANOVA of operability evaluation

Evaluation dimension	Between Groups		Sum of Squares	df	Mean Square	F	Sig.
Operability	Convenience	Inconvenience	6.000	1	6.000	4.213	.052
	Simple	Complex	.667	1	.667	.512	.482
	Clear	Unclear	.375	1	.375	.182	.674
	Safe	Dangerous	1.500	1	1.500	.780	.387
	Familiar	Unfamiliar	16.667	1	16.667	7.458	.012*
	Smooth	Rough	1.500	1	1.500	.534	.473

*Sig. <0.05

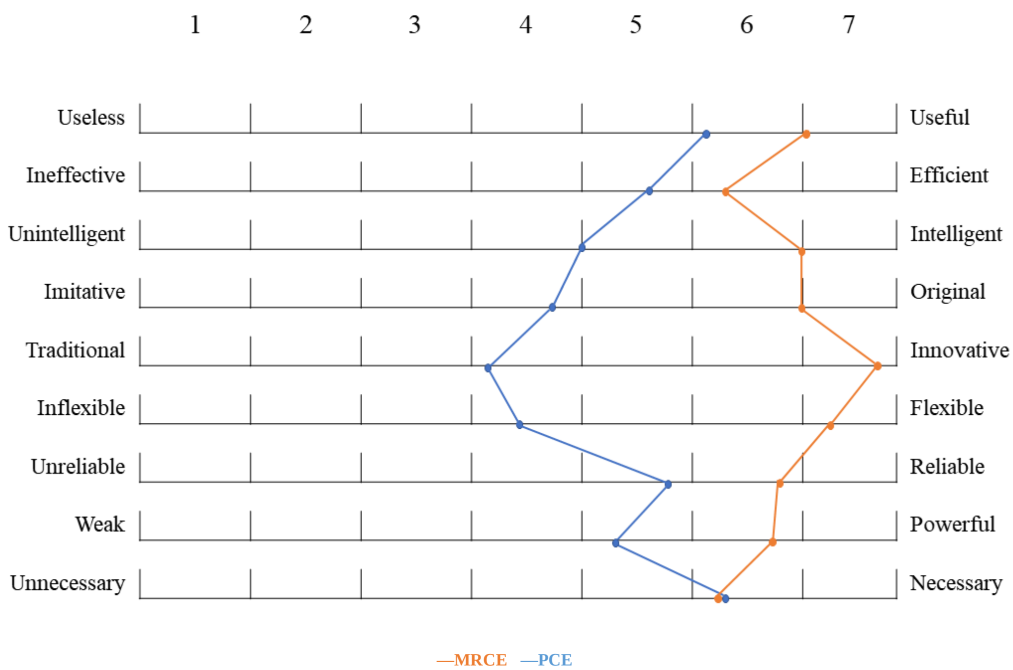


Figure 6-2. Results of functionality evaluation

Table 6-9 ANOVA of functionality evaluation

Evaluation dimension	Between Groups		Sum of Squares	df	Mean Square	F	Sig.
Functionality	Useful	Useless	5.042	1	5.042	2.733	.112
	Efficient	Ineffective	3.375	1	3.375	1.497	.234
	Intelligent	Unintelligent	24.000	1	24.000	18.857	.000*
	Original	Imitative	30.375	1	30.375	19.511	.000*
	Innovative	Traditional	73.500	1	73.500	50.010	.000*
	Flexible	Inflexible	48.167	1	48.167	22.466	.000*
	Reliable	Unreliable	7.042	1	7.042	7.068	.014*
	Powerful	Weak	12.042	1	12.042	4.824	.039*
	Necessary	Unnecessary	.042	1	.042	.044	.836

*Sig. <0.05

The results in Figure.6-2 show that MRCE is overall better than PCE in terms of functionality. One-way ANOVA comparative analysis results of PCE and MRCE on Intelligent, Original, Innovative and Flexible (Table.6-9) showed extremely significant statistical differences (p =.000 rather than p <.05). That is, users perceive MRCE to be functionally intelligent, original, innovative and flexible, and these properties are significantly higher than PCE. In addition, the functions of MRCE also showed significant statistical differences in Reliable and Powerful compared with PCE (p =.014 rather than p <.05, p =.039 rather than p <.05). The results showed that MRCE generally outperformed PCE in terms of aesthetics (Figure.6-3). One-way ANOVA analysis results (Table.6-10) showed that the advantages of MRCE compared to PCE were extremely significant statistical difference in terms of dynamics (p =.000 rather than p <.05).

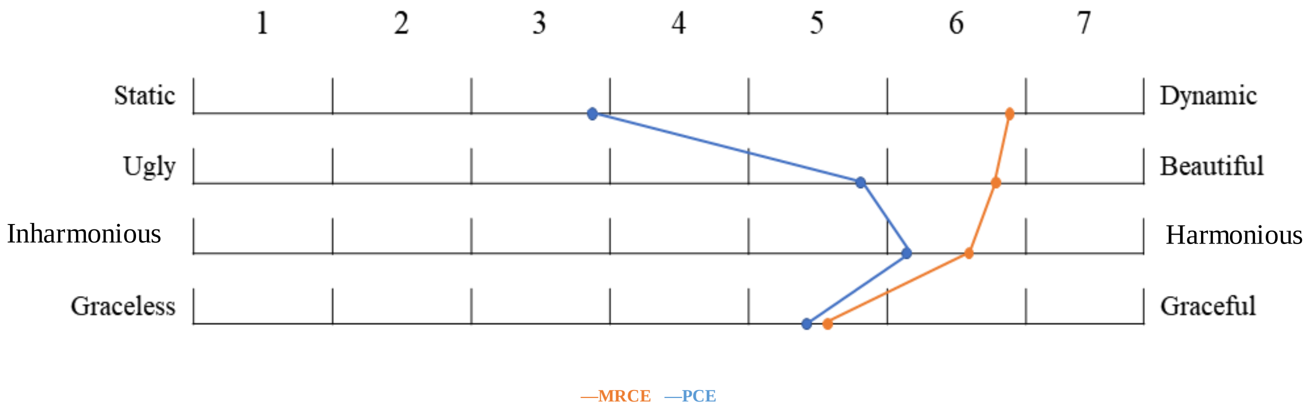


Figure 6-3. Results of aesthetics evaluation

Table 6-10. ANOVA of aesthetics evaluation

Evaluation dimension	Between Groups		Sum of Squares	df	Mean Square	F	Sig.
Aesthetics	Dynamic	Static	54.000	1	54.000	17.514	.000*
	Beautiful	Ugly	6.000	1	6.000	3.960	.059
	Harmonious	Inharmonious	1.042	1	1.042	.802	.380
	Graceful	Graceless	.167	1	.167	.132	.720

*Sig. <0.05

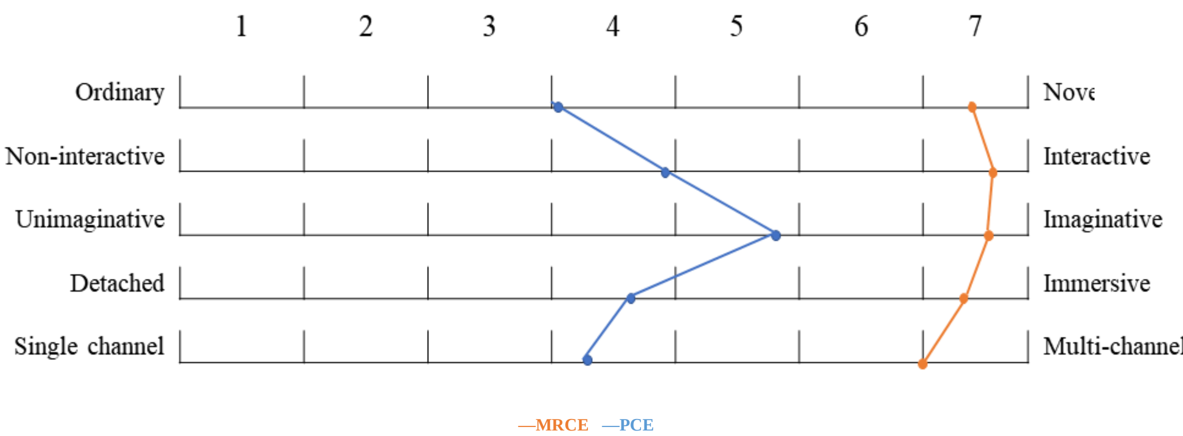


Figure 6-4. Results of creativity support evaluation

Table 6-11. ANOVA of creativity support evaluation

Evaluation dimension	Between Groups		Sum of Squares	df	Mean Square	F	Sig.
Creativity support	Novel	Ordinary	66.667	1	66.667	38.767	.000*
	Interactive	Non-interactive	42.667	1	42.667	33.725	.000*
	Imaginative	Unimaginative	16.667	1	16.667	8.594	.008*
	Immersive	Detached	42.667	1	42.667	25.143	.000*
	Multi-channel	Single channel	45.375	1	45.375	21.584	.000*

*Sig. <0.05

The results showed that MRCE was overall better than PCE in terms of creativity support (Figure. 6-4). One-way ANOVA analysis results (Table.6-11) showed that MRCE showed extremely significant advantages in terms of Novelty, Interactive, Immersive, Multi-channel and Imaginative in terms of creativity support (p =.000 rather than p<.05, p = .008 rather than p < .05). The results (Figure. 6-5) show that MRCE is generally better than PCE in terms of positive experiences. One-way ANOVA analysis results (Table.6-12) showed that in terms of interestingness, the advantage of MRCE compared to PCE was extremely significant statistical difference (p =.000 rather than p <.05).

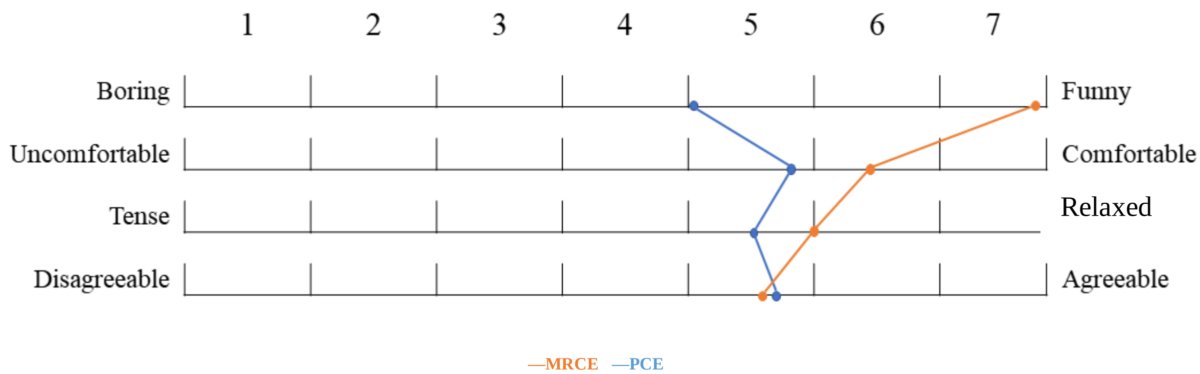


Figure 6-5. Results of affective experience evaluation

Table 6-12. ANOVA of affective experience evaluation

Evaluation dimension	Between Groups		Sum of Squares	df	Mean Square	F	Sig.
Affective experience	Funny	Boring	48.167	1	48.167	59.421	.000*
	Comfortable	Uncomfortable	2.667	1	2.667	1.244	.277
	Relaxed	Tense	1.500	1	1.500	.579	.455
	Agreeable	Disagreeable	.042	1	.042	.018	.895

*Sig. <0.05

6.3. Task content-related knowledge assessment

Since two creative tasks were set up in this study, we investigated the subject's knowledge or experience related to the creative task theme, and compared and analyzed the results. The theme of task 1 was cherry blossoms, so we asked participants to choose one of the following 5 items:

①I have never seen cherry blossoms.

②I saw cherry blossoms only one time.

③I have seen cherry blossoms several times.

④I have seen cherry blossoms a few times.

⑤I have seen cherry blossoms a lot of times.

The theme of task 2 is outer space, so we asked experimenters to choose one of the following 5 items:

① I don't know outer space at all.

② I know a little about outer space.

③ I have some knowledge about outer space.

④ I have a lot of knowledge about outer space.

⑤ I know outer space very well.

In this study, the corresponding scores were collected according to the answers of the participant, and the comparison between groups was carried out for task 1 and task 2 (Table.6-13, Table.6-14). The mean of task 1 in Table.7-13 is MRCE = 4.6667, PCE = 4.8333; the mean of task 2 is MRCE = 2.0833, PCE = 1.9167. The variance results of Table.6-15 are: p of MRCE = .514, p of PCE = .548. This result shows that there is no statistically significant difference in the understanding and experience of task 1 and task 2 between the MRCE group and the PCE group. That is, the knowledge bases of the experimenters in the MRCE group and the PCE group were equal.

Therefore, this study conducts further analysis by comparing the knowledge and experience of the experimenters about task 1 and task 2 (Table.6-15, Table.6-16). The variance results in Table.6-18 show that the $F(1.22) = 91.922$, $p = .000$ rather than $p < .05$ of the MRCE group and the PCE group ($F(1.22) = 130.825$, $p = .000$ rather than $p < .05$), indicating that the experimenters in the MRCE group and the PCE group have extremely significant differences in the knowledge of task 1 and task 2. That is, all experimenters had significantly more relevant knowledge and familiarity with Task 1 than with Task 2. This result lays the foundation for this study to explore the extent to which creative environments support experimenters' creativity.

Table 6-13. Descriptives of task content-related knowledge assessment (comparison between creative environments)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	Minimum	Maximum

MRCE-PCE						Lower Bound	Upper Bound		
Task 1	MRCE	12	4.6667	.65134	.18803	4.2528	5.0805	3.00	5.00
	PCE	12	4.8333	.57735	.16667	4.4665	5.2002	3.00	5.00
	Total	24	4.7500	.60792	.12409	4.4933	5.0067	3.00	5.00
Task 2	MRCE	12	2.0833	.66856	.19300	1.6586	2.5081	1.00	3.00
	PCE	12	1.9167	.66856	.19300	1.4919	2.3414	1.00	3.00
	Total	24	2.0000	.65938	.13460	1.7216	2.2784	1.00	3.00

Table 6-14. ANOVA of task content-related knowledge assessment (comparison between creative environments)

MRCE-PCE		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Task 1	Between Groups	.167	1	.167	.440	.514
	Within Groups	8.333	22	.379		
	Total	8.500	23			
Task 2	Between Groups	.167	1	.167	.373	.548
	Within Groups	9.833	22	.447		
	Total	10.000	23			

*Sig. <0.05

Table 6-15. Descriptives of task content-related knowledge assessment (comparison between tasks)

TASK1-2	**N**	**Mean**	**Std. Deviation**	**Std. Error**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**
					Lower Bound	**Upper Bound**		

MRCE Group	**Task 1**	12	4.6667	.65134	.18803	4.2528	5.0805	3.00	5.00
	Task 2	12	2.0833	.66856	.19300	1.6586	2.5081	1.00	3.00
	Total	24	3.3750	1.46888	.29983	2.7547	3.9953	1.00	5.00
PCE Group	**Task 1**	12	4.8333	.57735	.16667	4.4665	5.2002	3.00	5.00
	Task 2	12	1.9167	.66856	.19300	1.4919	2.3414	1.00	3.00
	Total	24	3.3750	1.61009	.32866	2.6951	4.0549	1.00	5.00

Table 6-16. ANOVA of task content-related knowledge assessment (comparison between tasks)

TASK1-2		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MRCE	Between Groups	40.042	1	40.042	91.922	.000*
	Within Groups	9.583	22	.436		
	Total	49.625	23			
PCE	Between Groups	51.042	1	51.042	130.825	.000*
	Within Groups	8.583	22	.390		
	Total	59.625	23			

*sig<0.05

6.4. Five senses Assessment

The five human senses, including sight, smell, hearing, taste, and touch, are considered to be distinct sensory types that structure information accordingly through their special functions (Liu et al, 2021). During sensory processes, sensory organs are involved in the collection and transmission of stimuli (Privtera, 2020).

Industrial designer Jinsop Lee proposed a set of "five senses" and created a "five senses scale" to evaluate various senses. The vertical axis of the "Five Senses Table" gradually increases from the origin to the positive direction, with 1 as the unit, and the scoring range is 0 to 10. The horizontal axis extends from the origin to the positive direction, representing the five senses. So we asked the participants these questions: compared to your usual design environment, how about your five senses in this creative environment? Specifically, participants were asked to answer the following five questions on a scale of 0 to 10 (0= very weak to 10= very strong). The 5 questions are as follows:

① Sight: In this creative environment, my visual experience is very strong.
② Touch: In this creative environment, my sense of touch is very strong.
③ Hearing: In this creative environment, my hearing experience is very strong.
④ Smell: In this creative environment, my sense of smell is very strong.
⑤ Taste: In this creative environment, my sense of taste is very strong.

Scores of participants on these five questions were used as the data source for the Five Senses Scale. Scores in the "Five Senses Scale" can intuitively show how well the sensory system responds to stimuli. The Five Senses Scale (Figure 7-6) was plotted according to the mean values in Table 6-17.

Table 6-17. Descriptives of five senses (comparison between creative environments)

Task 1 MRCE-PCE Task 2 MRCE-PCE			**N**	**Mean**	**Std. Deviation**	**Std. Error**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**
							Lower Bound	**Upper Bound**		
Task 1	**Sight**	**MRCE**	12	8.8333	1.19342	.34451	8.0751	9.5916	7.00	10.00
		PCE	12	7.0833	2.02073	.58333	5.7994	8.3672	4.00	10.00
		Total	24	7.9583	1.85283	.37821	7.1760	8.7407	4.00	10.00
	Touch	**MRCE**	12	6.0000	2.52262	.72822	4.3972	7.6028	1.00	10.00
		PCE	12	1.5833	2.46644	.71200	.0162	3.1504	.00	8.00

		Total	24	3.7917	3.32290	.67828	2.3885	5.1948	.00	10.00
	Hearing	**MRCE**	12	8.6667	1.23091	.35533	7.8846	9.4488	6.00	10.00
		PCE	12	5.8333	2.28963	.66096	4.3786	7.2881	.00	9.00
		Total	24	7.2500	2.30783	.47108	6.2755	8.2245	.00	10.00
	Smell	**MRCE**	12	1.2500	1.86474	.53831	.0652	2.4348	.00	5.00
		PCE	12	.3333	.77850	.22473	-.1613	.8280	.00	2.00
		Total	24	.7917	1.47381	.30084	.1693	1.4140	.00	5.00
	Taste	**MRCE**	12	.7500	1.48477	.42862	-.1934	1.6934	.00	5.00
		PCE	12	.1667	.57735	.16667	-.2002	.5335	.00	2.00
		Total	24	.4583	1.14129	.23296	-.0236	.9403	.00	5.00
Task 2	**Sight**	**MRCE**	12	9.6667	.49237	.14213	9.3538	9.9795	9.00	10.00
		PCE	12	7.5833	1.83196	.52884	6.4194	8.7473	4.00	10.00
		Total	24	8.6250	1.68916	.34480	7.9117	9.3383	4.00	10.00
	Touch	**MRCE**	12	5.7500	3.67114	1.05977	3.4175	8.0825	.00	10.00
		PCE	12	1.4167	2.57464	.74324	-.2192	3.0525	.00	8.00
		Total	24	3.5833	3.80979	.77767	1.9746	5.1921	.00	10.00
	Hearing	**MRCE**	12	8.4167	1.37895	.39807	7.5405	9.2928	5.00	10.00
		PCE	12	6.5000	2.61116	.75378	4.8409	8.1591	.00	9.00
		Total	24	7.4583	2.26465	.46227	6.5021	8.4146	.00	10.00
	Smell	**MRCE**	12	1.0833	1.92865	.55675	-.1421	2.3087	.00	5.00
		PCE	12	.0833	.28868	.08333	-.1001	.2667	.00	1.00
		Total	24	.5833	1.44212	.29437	-.0256	1.1923	.00	5.00
	Taste	**MRCE**	12	1.0000	1.90693	.55048	-.2116	2.2116	.00	5.00
		PCE	12	.0000	.00000	.00000	.0000	.0000	.00	.00
		Total	24	.5000	1.41421	.28868	-.0972	1.0972	.00	5.00

Figure 6-6. The Five Senses Scale

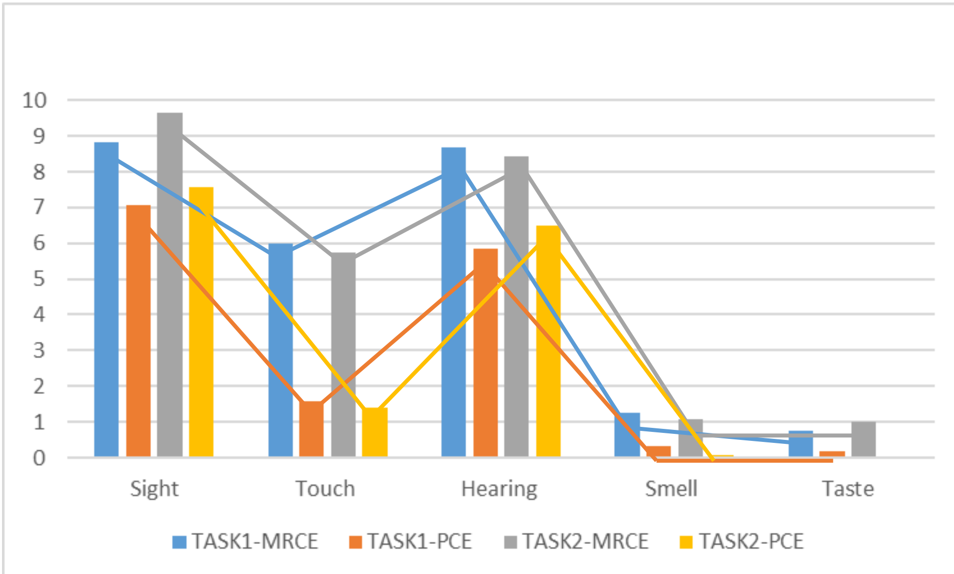


Table 6-18. ANOVA of five senses (comparison between creative environments)

MRCE-PCE			Sum of Squares	df	Mean Square	F	Sig.
Task 1	**Sight**	**Between Groups**	18.375	1	18.375	6.673	.017*
		Within Groups	60.583	22	2.754		
		Total	78.958	23			
	Touch	**Between Groups**	117.042	1	117.042	18.806	.000*
		Within Groups	136.917	22	6.223		
		Total	253.958	23			
	Hearing	**Between Groups**	48.167	1	48.167	14.256	.001*
		Within Groups	74.333	22	3.379		
		Total	122.500	23			
		Between Groups	5.042	1	5.042	2.469	.130

		Within Groups	44.917	22	2.042		
		Total	49.958	23			
	Smell	**Between Groups**	2.042	1	2.042	1.609	.218
		Within Groups	27.917	22	1.269		
		Total	29.958	23			
Task 2	**Sight**	**Between Groups**	26.042	1	26.042	14.474	.001*
		Within Groups	39.583	22	1.799		
		Total	65.625	23			
	Touch	**Between Groups**	112.667	1	112.667	11.207	.003*
		Within Groups	221.167	22	10.053		
		Total	333.833	23			
	Hearing	**Between Groups**	22.042	1	22.042	5.056	.035*
		Within Groups	95.917	22	4.360		
		Total	117.958	23			
		Between Groups	6.000	1	6.000	3.155	.090
		Within Groups	41.833	22	1.902		
		Total	47.833	23			
	Smell	**Between Groups**	6.000	1	6.000	3.300	.083
		Within Groups	40.000	22	1.818		
		Total	46.000	23			

*sig<0.05

The analysis of variance in Table.6-18 shows that the MRCE in task 1 is significantly different from PCE in terms of touch, hearing and sight (p =.000 rather than p < .05, p =.001 rather than p

< .05, *p* =.017 rather than *p* < .05); compared with PCE, MRCE in task 2 showed significant differences in sight, touch and hearing (*p* =.001 rather than *p* < .05, *p* =.003 rather than *p* < .05, *p* =.035 rather than *p* < .05). This study further compared the stimulation levels of the five senses between MRCE and PCE in different tasks. Table 6-19 gives the mean values of the five senses performance of MRCE and PCE in Task 1 and Task 2. The analysis of variance in Table 6-20 shows that the visual performance of MRCE in task 1 and task 2 is significantly different (*p* =.036 rather than *p* < .05).

Table 6-19. Descriptives of five senses (comparison between tasks)

Task1-2							**95% Confidence Interval for Mean**			
			N	**Mean**	**Std. Deviation**	**Std. Error**	**Lower Bound**	**Upper Bound**	**Minimum**	**Maximum**
MRCE	**Sight**	**Task 1**	12	8.8333	1.19342	.34451	8.0751	9.5916	7.00	10.00
		Task 2	12	9.6667	.49237	.14213	9.3538	9.9795	9.00	10.00
		Total	24	9.2500	.98907	.20189	8.8324	9.6676	7.00	10.00
	Touch	**Task 1**	12	6.0000	2.52262	.72822	4.3972	7.6028	1.00	10.00
		Task 2	12	5.7500	3.67114	1.05977	3.4175	8.0825	.00	10.00
		Total	24	5.8750	3.08309	.62933	4.5731	7.1769	.00	10.00
	Hearing	**Task 1**	12	8.6667	1.23091	.35533	7.8846	9.4488	6.00	10.00
		Task 2	12	8.4167	1.37895	.39807	7.5405	9.2928	5.00	10.00
		Total	24	8.5417	1.28466	.26223	7.9992	9.0841	5.00	10.00

	Smell	**Task 1**	12	1.2500	1.86474	.53831	.0652	2.4348	.00	5.00
		Task 2	12	1.0833	1.92865	.55675	-.1421	2.3087	.00	5.00
		Total	24	1.1667	1.85722	.37910	.3824	1.9509	.00	5.00
	Taste	**Task 1**	12	.7500	1.48477	.42862	-.1934	1.6934	.00	5.00
		Task 2	12	1.0000	1.90693	.55048	-.2116	2.2116	.00	5.00
		Total	24	.8750	1.67624	.34216	.1672	1.5828	.00	5.00
PCE	**Sight**	**Task 1**	12	7.0833	2.02073	.58333	5.7994	8.3672	4.00	10.00
		Task 2	12	7.5833	1.83196	.52884	6.4194	8.7473	4.00	10.00
		Total	24	7.3333	1.90347	.38854	6.5296	8.1371	4.00	10.00
	Touch	**Task 1**	12	1.5833	2.46644	.71200	.0162	3.1504	.00	8.00
		Task 2	12	1.4167	2.57464	.74324	-.2192	3.0525	.00	8.00
		Total	24	1.5000	2.46718	.50361	.4582	2.5418	.00	8.00
	Hearing	**Task 1**	12	5.8333	2.28963	.66096	4.3786	7.2881	.00	9.00
		Task 2	12	6.5000	2.61116	.75378	4.8409	8.1591	.00	9.00
		Total	24	6.1667	2.42571	.49515	5.1424	7.1910	.00	9.00
	Smell	**Task 1**	12	.3333	.77850	.22473	-.1613	.8280	.00	2.00
		Task 2	12	.0833	.28868	.08333	-.1001	.2667	.00	1.00

		Total	24	.2083	.58823	.12007	-.0401	.4567	.00	2.00
	Taste	**Task 1**	12	.1667	.57735	.16667	-.2002	.5335	.00	2.00
		Task 2	12	.0000	.00000	.00000	.0000	.0000	.00	.00
		Total	24	.0833	.40825	.08333	-.0891	.2557	.00	2.00

Table 6-20. ANOVA of five senses (comparison between tasks)

Task1-2			**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MRCE	**Sight**	Between Groups	4.167	1	4.167	5.000	.036*
		Within Groups	18.333	22	.833		
		Total	22.500	23			
	Touch	Between Groups	.375	1	.375	.038	.848
		Within Groups	218.250	22	9.920		
		Total	218.625	23			
	Hearing	Between Groups	.375	1	.375	.220	.644
		Within Groups	37.583	22	1.708		
		Total	37.958	23			
	Smell	Between Groups	.167	1	.167	.046	.832
		Within Groups	79.167	22	3.598		
		Total	79.333	23			
	Taste	Between Groups	.375	1	.375	.128	.724
		Within Groups	64.250	22	2.920		
		Total	64.625	23			

PCE	**Sight**	Between Groups	1.500	1	1.500	.403	.532
		Within Groups	81.833	22	3.720		
		Total	83.333	23			
	Touch	Between Groups	.167	1	.167	.026	.873
		Within Groups	139.833	22	6.356		
		Total	140.000	23			
	Hearing	Between Groups	2.667	1	2.667	.442	.513
		Within Groups	132.667	22	6.030		
		Total	135.333	23			
	Smell	Between Groups	.375	1	.375	1.088	.308
		Within Groups	7.583	22	.345		
		Total	7.958	23			
	Taste	Between Groups	.167	1	.167	1.000	.328
		Within Groups	3.667	22	.167		
		Total	3.833	23			

*Sig. <0.05

6.5. Evaluation for Flow

In order to evaluate the flow performance of MRCE and PCE in the three dimensions of sense of control, positive emotional experience and absorption by concentrating, this study extracted 14 items related to these three dimensions in the Flow State Scale (Jackson & Marsh, 1996), and applied 7-Point Likert scale to evaluate (Table.6-21). From the mean values in Table.6-22, it can be preliminarily seen that only Q5 shows a slight disadvantage of MRCE compared to PCE. The experimenter stated that sense of control of PCE was better than MRCE, but for the rest of the test items, MRCE performed better than PCE. In order to further analyze the difference between MRCE and PCE, this study made further analysis.

Table 6-21. 14 items related the flow performance

Dimension	No.	Item
Sense of control	**Q1**	I knew clearly what I wanted to do or what I should do at every moment.
	Q2	My abilities matched the challenge of what I was doing.
	Q3	I felt that I could deal with whatever might happen next.
	Q4	I knew how well I was dealing with the task.
	Q5	I had a sense of great control over everything I was doing.
	Q6	I was aware of how well the task was going.
Positive emotional experience	**Q7**	I had a meaningful time.
	Q8	I really enjoyed what I was doing.
	Q9	The task was really boring.
	Q10	I wanted to do it again.
Absorption by concentrating	**Q11**	It felt like time passed quickly.
	Q12	It was easy to concentrate on what I was doing.
	Q13	I lost track of time while doing the task.
	Q14	I lost myself in doing the task.

Table 6-22. Descriptives of 14 items related the flow performance

Flow Scale		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	MRCE	12	6.5000	.67420	.19462	6.0716	6.9284	5.00	7.00
	PCE	12	4.7500	1.48477	.42862	3.8066	5.6934	1.00	6.00
	Total	24	5.6250	1.43898	.29373	5.0174	6.2326	1.00	7.00
Q2	MRCE	12	5.7500	1.42223	.41056	4.8464	6.6536	2.00	7.00
	PCE	12	4.6667	1.77525	.51247	3.5387	5.7946	1.00	7.00
	Total	24	5.2083	1.66757	.34039	4.5042	5.9125	1.00	7.00
Q3	MRCE	12	4.5000	1.50756	.43519	3.5421	5.4579	1.00	6.00
	PCE	12	4.5000	1.73205	.50000	3.3995	5.6005	1.00	7.00

	Total	24	4.5000	1.58800	.32415	3.8294	5.1706	1.00	7.00
Q4	MRCE	12	4.6667	1.15470	.33333	3.9330	5.4003	2.00	7.00
	PCE	12	4.5000	1.50756	.43519	3.5421	5.4579	2.00	7.00
	Total	24	4.5833	1.31601	.26863	4.0276	5.1390	2.00	7.00
Q5	MRCE	12	4.1667	1.33712	.38599	3.3171	5.0162	2.00	6.00
	PCE	12	4.2500	1.71226	.49429	3.1621	5.3379	1.00	7.00
	Total	24	4.2083	1.50302	.30680	3.5737	4.8430	1.00	7.00
Q6	MRCE	12	4.8333	1.26730	.36584	4.0281	5.6385	2.00	7.00
	PCE	12	4.0000	1.59545	.46057	2.9863	5.0137	1.00	6.00
	Total	24	4.4167	1.47196	.30046	3.7951	5.0382	1.00	7.00
Q7	MRCE	12	6.7500	.45227	.13056	6.4626	7.0374	6.00	7.00
	PCE	12	5.3333	1.77525	.51247	4.2054	6.4613	1.00	7.00
	Total	24	6.0417	1.45898	.29781	5.4256	6.6577	1.00	7.00
Q8	MRCE	12	6.7500	.45227	.13056	6.4626	7.0374	6.00	7.00
	PCE	12	5.0000	1.90693	.55048	3.7884	6.2116	1.00	7.00
	Total	24	5.8750	1.62354	.33140	5.1894	6.5606	1.00	7.00
Q9	MRCE	12	1.3333	.65134	.18803	.9195	1.7472	1.00	3.00
	PCE	12	2.5000	1.08711	.31382	1.8093	3.1907	1.00	4.00
	Total	24	1.9167	1.05981	.21633	1.4691	2.3642	1.00	4.00
Q10	MRCE	12	6.1667	.83485	.24100	5.6362	6.6971	5.00	7.00
	PCE	12	4.5000	1.50756	.43519	3.5421	5.4579	1.00	6.00
	Total	24	5.3333	1.46456	.29895	4.7149	5.9518	1.00	7.00
Q11	MRCE	12	6.1667	1.02986	.29729	5.5123	6.8210	4.00	7.00
	PCE	12	5.1667	1.69670	.48979	4.0886	6.2447	1.00	7.00
	Total	24	5.6667	1.46456	.29895	5.0482	6.2851	1.00	7.00

Q12	MRCE	12	6.4167	.79296	.22891	5.9128	6.9205	5.00	7.00
	PCE	12	5.2500	1.48477	.42862	4.3066	6.1934	3.00	7.00
	Total	24	5.8333	1.30773	.26694	5.2811	6.3855	3.00	7.00
Q13	MRCE	12	6.0833	1.31137	.37856	5.2501	6.9165	3.00	7.00
	PCE	12	5.5833	1.16450	.33616	4.8434	6.3232	3.00	7.00
	Total	24	5.8333	1.23945	.25300	5.3100	6.3567	3.00	7.00
Q14	MRCE	12	6.5000	.67420	.19462	6.0716	6.9284	5.00	7.00
	PCE	12	5.7500	1.05529	.30464	5.0795	6.4205	3.00	7.00
	Total	24	6.1250	.94696	.19330	5.7251	6.5249	3.00	7.00

Analysis of One-way ANOVA (Table.6-23) showed the following results: compared with PCE, the experimenters in the MRCE group had a significantly better sense of control over what they were doing than with PCE ($F(1,22) = 9.568$, $p = .001$ rather than $p < .005$); experimenters in MRCE had significantly better positive experiences than PCE, for example, experimenters enjoyed what they were doing in MRCE more ($F(1,22) = 18.375$, $p = .005$ rather than $p < .05$) and spent meaningful time in MRCE ($F(1,22) = 7.176$, $p = .014$ rather than $p < .05$), experimenters in MRCE thought the creative task was more interesting ($F(1,22) = 10.170$, $p = .004$ rather than $p < .05$), and they wanted to do the creative task again ($F(1,22) = 11.224$, $p = .003$ rather than $p < .05$). Regarding concentrating, experimenters in the MRCE indicated that they were more likely to focus on what they were doing ($F(1,22) = 5.765$, $p = .025$ rather than $p < .05$), and to lose track of themselves ($F(1,22) = 4.304$, $p = .050$) when doing creative tasks.

Table 6-23. ANOVA of 14 items related the flow performance

MRCE - PCE			**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Sense of control	**Q1**	Between Groups	18.375	1	18.375	13.821	.001*

		Within Groups	29.250	22	1.330		
		Total	47.625	23			
	Q2	Between Groups	7.042	1	7.042	2.722	.113
		Within Groups	56.917	22	2.587		
		Total	63.958	23			
	Q3	Between Groups	.000	1	.000	.000	1.000
		Within Groups	58.000	22	2.636		
		Total	58.000	23			
	Q4	Between Groups	.167	1	.167	.092	.764
		Within Groups	39.667	22	1.803		
		Total	39.833	23			
	Q5	Between Groups	.042	1	.042	.018	.895
		Within Groups	51.917	22	2.360		
		Total	51.958	23			
	Q6	Between Groups	4.167	1	4.167	2.007	.171
		Within Groups	45.667	22	2.076		
		Total	49.833	23			
Positive emotional experience	**Q7**	Between Groups	12.042	1	12.042	7.176	.014*
		Within Groups	36.917	22	1.678		
		Total	48.958	23			
	Q8	Between Groups	18.375	1	18.375	9.568	.005*

		Within Groups	42.250	22	1.920		
		Total	60.625	23			
	Q9	Between Groups	8.167	1	8.167	10.170	.004*
		Within Groups	17.667	22	.803		
		Total	25.833	23			
	Q10	Between Groups	16.667	1	16.667	11.224	.003*
		Within Groups	32.667	22	1.485		
		Total	49.333	23			
Absorption by concentrating	**Q11**	Between Groups	6.000	1	6.000	3.046	.095
		Within Groups	43.333	22	1.970		
		Total	49.333	23			
	Q12	Between Groups	8.167	1	8.167	5.765	.025*
		Within Groups	31.167	22	1.417		
		Total	39.333	23			
	Q13	Between Groups	1.500	1	1.500	.975	.334
		Within Groups	33.833	22	1.538		
		Total	35.333	23			
	Q14	Between Groups	3.375	1	3.375	4.304	.050*
		Within Groups	17.250	22	.784		
		Total	20.625	23			

*Sig. <0.05

6.6. Creativity self-assessment by participants

Experimenters in the MRCE group and the PCE group evaluated the level of creativity support in their creative environment. Participants were asked questions such as: How this environment supports your creativity? Participants were asked to answer this question on a scale of 1 to 7 (1= Very poor to 7 = Very Helpful). The results of the analysis of means in Table 6-24 show that MRCE is better than PCE in terms of creative support for both task 1 and task 2. The analysis results in Table 6-25 show that MRCE's support for task 1 is significantly better than PCE ($F(1,22) = 4.477$, $p = .046$ rather than $p < .05$), and the creative support for task 2 is extremely significantly better than PCE ($F(1,22) = 13.646$, $p = .001$ rather than $p < .05$).

This study analyzed respectively the support of MRCE and PCE for task1 and task 2. The results of analysis of means in Table 6-26 show that MRCE and PCE have better creative support for task 2 than task 1. The analysis results in Table 6-27 show that the support of MRCE for task 2 is significantly better than that for task 1 ($F(1,22) = 6.962$, $p = .015$ rather than $p < .05$).

Table 6-24. Descriptives of creativity self-assessment by participants (comparison between creative environments)

MRCE-PCE						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Task 1	MRCE	12	4.9167	.79296	.22891	4.4128	5.4205	4.00	6.00
	PCE	12	4.1667	.93744	.27061	3.5710	4.7623	3.00	6.00
	Total	24	4.5417	.93153	.19015	4.1483	4.9350	3.00	6.00
Task 2	MRCE	12	5.7500	.75378	.21760	5.2711	6.2289	5.00	7.00

	PCE	12	4.5833	.79296	.22891	4.0795	5.0872	3.00	6.00
	Total	24	5.1667	.96309	.19659	4.7600	5.5733	3.00	7.00

Table 6-25. ANOVA of creativity self-assessment by participants (comparison between creative environments)

MRCE-PCE		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Task 1	**Between Groups**	3.375	1	3.375	4.477	.046*
	Within Groups	16.583	22	.754		
	Total	19.958	23			
Task 2	**Between Groups**	8.167	1	8.167	13.646	.001*
	Within Groups	13.167	22	.598		
	Total	21.333	23			

*sig<0.05

Table 6-26. Descriptives of creativity self-assessment by participants (comparison between tasks)

Task 1-Task 2						**95% Confidence Interval for Mean**			
		N	**Mean**	**Std. Deviation**	**Std. Error**	**Lower Bound**	**Upper Bound**	**Minimum**	**Maximum**
MRCE	**Task 1**	12	4.9167	.79296	.22891	4.4128	5.4205	4.00	6.00
	Task 2	12	5.7500	.75378	.21760	5.2711	6.2289	5.00	7.00
	Total	24	5.3333	.86811	.17720	4.9668	5.6999	4.00	7.00
PCE	**Task 1**	12	4.1667	.93744	.27061	3.5710	4.7623	3.00	6.00
	Task 2	12	4.5833	.79296	.22891	4.0795	5.0872	3.00	6.00
	Total	24	4.3750	.87539	.17869	4.0054	4.7446	3.00	6.00

Table 6-27. ANOVA of creativity self-assessment by participants (comparison between tasks)

Task 1-Task 2		Sum of Squares	df	Mean Square	F	Sig.
MRCE	**Between Groups**	4.167	1	4.167	6.962	.015*
	Within Groups	13.167	22	.598		
	Total	17.333	23			
PCE	**Between Groups**	1.042	1	1.042	1.382	.252
	Within Groups	16.583	22	.754		
	Total	17.625	23			

*sig<0.05

6.7. Evaluation to support the creative process

Experimenters have evaluated the creative environment, or "Press". In order to evaluate "Process", the evaluation dimension of this study draws on the five stages of the design process of IDEO Design Thinking Model (d.school, 2015). The questionnaire of the 7-level Likert scale (1= strongly disagree to 7= strongly agree) was developed based on the characteristics of these 5 stages as:

− Empathy : Deep understanding of the problems and reality of the person to be designed.

− Define :Reframing and defining the problem.

− Define & Ideate : Establish sufficient connections from definition to idea.

− Ideate : Creating many ideas in ideation sessions.

- Prototype & Test : Adopting a hands on approach in prototyping. Developing a testable prototype/solution to the problem.

The 5 questions in the questionnaire are as follows:

① Empathy: These work environments effectively helped me understand the design challenge.

② Define: These work environments help me re-framing and defining the design problem.

③ Define & Ideate: These work environments helped me to establish a connection between ideas and solutions.

④ Ideate: These work environments help me creating many ideas.

⑥ Prototype & Test: This environment is very helpful for making sketches.

The experimenter was asked to answer after completing the design task. Experimenters in the MRCE group and the PCE group expressed their agreement with the content of the description through a 7-level score based on the description of each stage.

Table 6-28. Descriptives of evaluation to support the creative process

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Empathize	1	12	5.92	.669	.193	5.49	6.34	5	7
	2	12	4.58	1.240	.358	3.80	5.37	2	6
	Total	24	5.25	1.189	.243	4.75	5.75	2	7
Define	1	12	5.50	1.087	.314	4.81	6.19	4	7
	2	12	4.17	1.467	.423	3.23	5.10	1	7
	Total	24	4.83	1.435	.293	4.23	5.44	1	7
Define & Ideate	1	12	5.83	1.030	.297	5.18	6.49	4	7
	2	12	4.50	1.732	.500	3.40	5.60	1	7

	Total	24	5.17	1.551	.317	4.51	5.82	1	7
Ideate	1	12	5.92	.996	.288	5.28	6.55	4	7
	2	12	4.42	1.621	.468	3.39	5.45	3	7
	Total	24	5.17	1.523	.311	4.52	5.81	3	7
Prototype & Test	1	12	5.25	1.815	.524	4.10	6.40	2	7
	2	12	5.17	1.528	.441	4.20	6.14	3	7
	Total	24	5.21	1.641	.335	4.52	5.90	2	7

Table 6-29. ANOVA of evaluation to support the creative process

The creative process		Sum of Squares	df	Mean Square	F	Sig.
Empathize	Between Groups	10.667	1	10.667	10.748	.003*
	Within Groups	21.833	22	.992		
	Total	32.500	23			
Define	Between Groups	10.667	1	10.667	6.400	.019*
	Within Groups	36.667	22	1.667		
	Total	47.333	23			
Define & Ideate	Between Groups	10.667	1	10.667	5.254	.032*
	Within Groups	44.667	22	2.030		
	Total	55.333	23			

Ideate	Between Groups	13.500	1	13.500	7.456	.012*
	Within Groups	39.833	22	1.811		
	Total	53.333	23			
Prototype & Test	Between Groups	.042	1	.042	.015	.904
	Within Groups	61.917	22	2.814		
	Total	61.958	23			

*Sig. <0.05

The evaluation results were analyzed by One-way ANOVA. The averages in the descriptive statistics results in Table 6-28 show that MRCE outperforms PCE in supporting all five stages of the creative process. One way ANOVA analysis results (Table 6-29) show that, F (1,22) = 10.748, p of *empathiz*e = .003 rather than p <.05; F (1,22) = 6.400, p of *define* =.019 rather than p <.05; F (1,22) = 5.254, p of *define & Ideate* = .032 rather than p <.05; F (1,22) = 7.465, p of *Ideate* = .012 rather than p <.05, it is considered that There are significant statistical differences between MRCE and PCE. From the strength of the significant difference (p =.003 rather than p =0.012 rather than p =0.019 rather than p =0.032), *Empathize* showed the strongest significance, followed by *Define and Define & Ideate*, and *Ideate* showed weaker significance.

6.8. Evaluation for knowledge creation

This study applied a 7-level Likert scale based on the 4 stages of SECI model of knowledge creation and asked the experimenter to evaluate it with the following 4 related questions. The question about socialization: these creative environments effectively evoke my knowledge, experience and feelings. The question about externalization: these creative environments help express my feelings and apply my knowledge and experience. The question about combination:

these creative environments help me combine and extend information. The question about internalization: these knowledge, experience and feelings aroused in the creative environments are effectively transformed into design results. These concepts were explained to the participants in the questionnaire, and participants were asked 4 questions around these concepts.

The results of the mean analysis in Table 6-30 show that the experimenter's knowledge creation in the MRCE is better than that in the PCE in all four stages. Figure 6-7 shows that the experimenter's knowledge creation in the MRCE is better active. The analysis results in Table 6-31 show that the experimenter's socialization, externalization and combination in MRCE are significantly better than PCE ($F(1,22) = 7.477$, p of externalization=.012 rather than $p < .05$; $F(1,22) = 6.528$, p of socialization=.018 rather than $p < .05$; $F(1,22) = 5.400$, p of combination=.030 rather than $p < .05$).

In addition, from the mean values in Table 6-30, it can be seen that the performance of the experimenters in the four stages of knowledge creation from strong to weak in MRCE is: combination, internalization, socialization, and externalization (mean of combination = 6 > mean of internalization = 5.9167 > mean of socialization = 5.8333 > mean of externalization = 5.5833), the order of performance from strong to weak in PCE is: internalization, combination, socialization, externalization (mean of internalization = 5.3333 > mean of combination = 4.5 > mean of socialization = 4.4167 > mean of externalization = 4.3333).

Table 6-30. Descriptives of evaluation for knowledge creation

MRCE-PCE		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
S	MRCE	12	5.8333	.83485	.24100	5.3029	6.3638	4.00	7.00
	PCE	12	4.4167	1.72986	.49937	3.3176	5.5158	1.00	7.00

	Total	24	5.1250	1.51263	.30876	4.4863	5.7637	1.00	7.00
E	MRCE	12	5.5833	.79296	.22891	5.0795	6.0872	4.00	7.00
	PCE	12	4.3333	1.37069	.39568	3.4624	5.2042	2.00	6.00
	Total	24	4.9583	1.26763	.25875	4.4231	5.4936	2.00	7.00
C	MRCE	12	6.0000	.95346	.27524	5.3942	6.6058	5.00	7.00
	PCE	12	4.5000	2.02260	.58387	3.2149	5.7851	1.00	7.00
	Total	24	5.2500	1.72576	.35227	4.5213	5.9787	1.00	7.00
I	MRCE	12	5.9167	.99620	.28758	5.2837	6.5496	4.00	7.00
	PCE	12	5.3333	1.55700	.44947	4.3441	6.3226	1.00	7.00
	Total	24	5.6250	1.31256	.26793	5.0708	6.1792	1.00	7.00

Figure 6-7. The performance of knowledge creation based on the SECI model

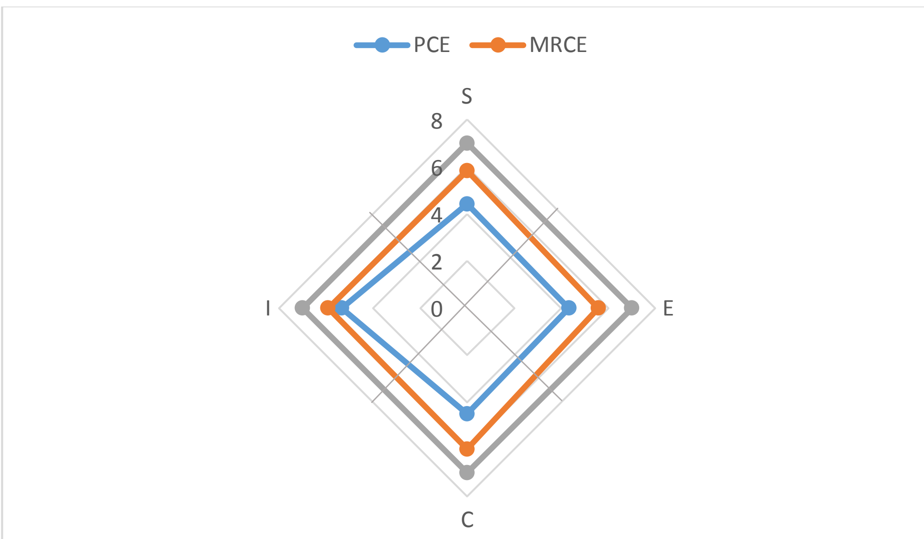


Table 6-31. ANOVA of evaluation for knowledge creation

MRCE-PCE	Sum of Squares	df	Mean Square	F	Sig.

Socialization	Between Groups	12.042	1	12.042	6.528	.018*
	Within Groups	40.583	22	1.845		
	Total	52.625	23			
Externalization	Between Groups	9.375	1	9.375	7.477	.012*
	Within Groups	27.583	22	1.254		
	Total	36.958	23			
Combination	Between Groups	13.500	1	13.500	5.400	.030*
	Within Groups	55.000	22	2.500		
	Total	68.500	23			
Internalization	Between Groups	2.042	1	2.042	1.195	.286
	Within Groups	37.583	22	1.708		
	Total	39.625	23			

*Sig. <0.05

6.9. Creativity assessment by expert

6.9.1. PCE vs MRCE

This study extracted seven evaluation dimensions based on the theories of creativity evaluation (Table 6-32). Because the experiments required the number of hand-drawn sketches and limited the categories of design tasks, the number and categories of creative ideas were excluded from the evaluation dimensions of this assessment scale. Five creativity experts were invited to rate the hand-drawn sketches of 24 subjects in the MREC and PCE groups using a 7-level Likert scale according to these 7 evaluate dimensions, and gave comments after completing the scoring. The 5 creativity experts have extensive experience in creativity-related training in educational institutions, including 3 males and 2 females, aged 39-55 years old (M=48.6, SD=5.678), and they are engaged in creativity activities 17- 33 years (M=25.4, SD=5.238).

Table 6-32. The creativity evaluation dimensions based on creativity literature

Dimension of creativity	Evaluation items	Evaluation items description	Creativity Literature
Fluency	Quality	The ideas expressed in the sketches are interpretable and compliant with the design task.	Torrance， 1966
Elaboration	Clear	Ideas and concepts expressed in sketches are well expressed.	Torrance ，1966； Bessemer and Treffinger, 1981
Novelty	Novel	The ideas expressed in the sketches are novel, original, unusual, surprising.	Mac Crimmon & Wagner , 1994
Thoroughness	Detailed	The sketches provide detailed explanations (materials, structures, processes, etc.) or steps to make the idea work.	Mac Crimmon & Wagner , 1994
Relevance	Relevant to the usage scenario	Concepts and ideas expressed in sketches are linked to the user's usage scenario.	Mac Crimmon & Wagner , 1994
Movement or actions	Interactive	Creativity is vivid and dynamic. Creativity interacts with external environmental factors.	Cramond, B., & Kim, K. H. , 2002
Implementation	Motivation	The creative enthusiasm of the author is shown in the sketches.	Wagner, 1996

Table 6-33. Test Statistics for Inter-rater reliability

N	5
Kendall's W[a]	.401
Chi-Square	22.037
df	11
Asymp. Sig.	.041*

a. Kendall's Coefficient of Concordance

5 creativity experts evaluated the design sketches of 24 experimenters. In this study, the K Related Samples Test was used to analyze the scorer reliability of the evaluation results of the 5 experts. The analysis results (Table 6-33) show that the evaluation results of the five experts were statistically consistent (Wa = .401, Chi-Square = 22.037, p = .41 < .05).

One-way ANOVA was used to analyze the evaluation items for the task 1 by five experts. The results (Table 6-34) indicated that the creativity assessment results of the MRCE group were higher than the PCE on all items. The comparison results of MRCE and PCE (Table 6-35) showed significant statistical differences in the creativity dimension of Implementation, Movement or actions, Relevance and Elaboration (F (1,22) = 12.560, p = .002 rather than p <.05; F (1,22) = 9.512, p = .005 rather than p <.05; F (1,22) = 7.795, p = .011 rather than p <.05; F (1,22) = 5.851, p =.024 rather than p <.05). The results of this analysis show that compared to PCE, the creative results of MRCE on cherry blossom-themed creative tasks are clearer, dynamic and closely related to the scene used in the creative, and the creative motivation is more obvious.

The results (Table 6-36) of One-way ANOVA for the task 2 by five experts indicated that the creativity assessment results of the MRCE group were higher than the PCE on all items. The comparison results of MRCE and PCE (Table 6-37) showed extremely significant statistical differences in the creativity dimension of novelty, relevance and implementation (F (1,22) = 22.132, p =.000 rather than p <.01; F (1,22) = 25.070, p =.000 rather than p <.01; F (1,22) = 12.560, p =.000 rather than p <.01).The evaluation items as movement or actions, thoroughness and fluency showed significant statistical differences (F (1,22) = 9.374, p = .006 rather than p <.05; F (1,22) = 8.432, p = .008 rather than p <.05; F (1,22) = 5.163, p = .033 rather than p <.05). This result shows that the experimenter's creativity on the theme of outer space in MRCE is more fluent and novel, and the creative expression is more detailed. And the creativity is more vivid and related to the scene it is used in. It can be seen from the creative results that the experimenters are more enthusiastic.

Table 6-34. Descriptives of the evaluation items for the task 1 by five experts

Task 1 MRCE-PCE		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Fluency	MRCE	12	5.6500	.47578	.13734	5.3477	5.9523	5.00	6.60
	PCE	12	5.6167	.34597	.09987	5.3968	5.8365	5.00	6.20
	Total	24	5.6333	.40718	.08312	5.4614	5.8053	5.00	6.60
Elaboration	MRCE	12	5.5833	.37618	.10860	5.3443	5.8223	5.20	6.20
	PCE	12	5.2167	.36639	.10577	4.9839	5.4495	4.60	6.00
	Total	24	5.4000	.40860	.08341	5.2275	5.5725	4.60	6.20
Novelty	MRCE	12	4.8000	.54606	.15763	4.4530	5.1470	4.00	5.60
	PCE	12	4.6500	.37295	.10766	4.4130	4.8870	4.00	5.20
	Total	24	4.7250	.46368	.09465	4.5292	4.9208	4.00	5.60
Thoroughness	MRCE	12	5.1167	.42176	.12175	4.8487	5.3846	4.40	5.60

	PCE	12	4.8500	.29695	.08572	4.6613	5.0387	4.40	5.40
	Total	24	4.9833	.38183	.07794	4.8221	5.1446	4.40	5.60
Relevance	MRCE	12	6.2167	.39505	.11404	5.9657	6.4677	5.40	6.60
	PCE	12	5.7167	.47832	.13808	5.4128	6.0206	5.00	6.40
	Total	24	5.9667	.49927	.10191	5.7558	6.1775	5.00	6.60
Movement or actions	MRCE	12	5.4833	.54910	.15851	5.1344	5.8322	4.40	6.20
	PCE	12	4.8333	.48116	.13890	4.5276	5.1390	4.00	5.80
	Total	24	5.1583	.60427	.12335	4.9032	5.4135	4.00	6.20
Implementation	MRCE	12	5.6500	.29695	.08572	5.4613	5.8387	5.20	6.00
	PCE	12	5.0333	.52455	.15142	4.7001	5.3666	4.20	6.00
	Total	24	5.3417	.52247	.10665	5.1210	5.5623	4.20	6.00

Table 6-35. ANOVA of the evaluation items for the task 1 by five experts

Task 1 MRCE-PCE		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Fluency	Between Groups	.007	1	.007	.039	.846
	Within Groups	3.807	22	.173		
	Total	3.813	23			
Elaboration	Between Groups	.807	1	.807	5.851	.024*
	Within Groups	3.033	22	.138		
	Total	3.840	23			
Novelty	Between Groups	.135	1	.135	.617	.440
	Within Groups	4.810	22	.219		
	Total	4.945	23			
Thoroughness	Between Groups	.427	1	.427	3.207	.087
	Within Groups	2.927	22	.133		
	Total	3.353	23			
Relevance	Between Groups	1.500	1	1.500	7.795	.011*
	Within Groups	4.233	22	.192		
	Total	5.733	23			
Movement or actions	Between Groups	2.535	1	2.535	9.512	.005*
	Within Groups	5.863	22	.267		
	Total	8.398	23			
Implementation	Between Groups	2.282	1	2.282	12.560	.002*
	Within Groups	3.997	22	.182		
	Total	6.278	23			

*Sig. <0.05

Table 6-36. Descriptives of the evaluation items for the task 2 by five experts

Task 2 MRCE-PCE		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Fluency	MRCE	12	5.6833	.41304	.11924	5.4209	5.9458	5.00	6.40
	PCE	12	5.3000	.41341	.11934	5.0373	5.5627	4.40	5.80
	Total	24	5.4917	.44907	.09167	5.3020	5.6813	4.40	6.40
Elaboration	MRCE	12	5.4667	.23094	.06667	5.3199	5.6134	5.00	5.80
	PCE	12	5.1667	.32845	.09482	4.9580	5.3754	4.60	5.60
	Total	24	5.3167	.31714	.06474	5.1827	5.4506	4.60	5.80
Novelty	MRCE	12	5.2333	.33934	.09796	5.0177	5.4489	4.60	5.60
	PCE	12	4.5167	.40415	.11667	4.2599	4.7734	3.80	5.20
	Total	24	4.8750	.51689	.10551	4.6567	5.0933	3.80	5.60
Thoroughness	MRCE	12	5.1500	.45227	.13056	4.8626	5.4374	4.40	5.60
	PCE	12	4.7000	.28920	.08348	4.5163	4.8837	4.40	5.40
	Total	24	4.9250	.43664	.08913	4.7406	5.1094	4.40	5.60
Relevance	MRCE	12	6.2500	.35291	.10188	6.0258	6.4742	5.60	6.60
	PCE	12	5.5500	.33166	.09574	5.3393	5.7607	5.00	6.00
	Total	24	5.9000	.48990	.10000	5.6931	6.1069	5.00	6.60
	MRCE	12	5.2000	.37173	.10731	4.9638	5.4362	4.40	5.60
	PCE	12	4.7333	.37497	.10825	4.4951	4.9716	4.20	5.60
	Total	24	4.9667	.43606	.08901	4.7825	5.1508	4.20	5.60
Movement or actions	MRCE	12	5.9333	.32287	.09320	5.7282	6.1385	5.40	6.40
	PCE	12	5.0167	.42176	.12175	4.7487	5.2846	4.20	5.60
	Total	24	5.4750	.59509	.12147	5.2237	5.7263	4.20	6.40

Table 6-37. ANOVA of the evaluation items for the task 2 by five experts

Task 2 MRCE-PCE		Sum of Squares	df	Mean Square	F	Sig.
Fluency	Between Groups	.882	1	.882	5.163	.033*
	Within Groups	3.757	22	.171		
	Total	4.638	23			
Elaboration	Between Groups	.540	1	.540	6.699	.017*
	Within Groups	1.773	22	.081		
	Total	2.313	23			
Novelty	Between Groups	3.082	1	3.082	22.132	.000*
	Within Groups	3.063	22	.139		
	Total	6.145	23			
Thoroughness	Between Groups	1.215	1	1.215	8.432	.008*
	Within Groups	3.170	22	.144		
	Total	4.385	23			
Relevance	Between Groups	2.940	1	2.940	25.070	.000*
	Within Groups	2.580	22	.117		
	Total	5.520	23			
Movement or actions	Between Groups	1.307	1	1.307	9.374	.006*
	Within Groups	3.067	22	.139		
	Total	4.373	23			
Implementation	Between Groups	5.042	1	5.042	35.741	.000*
	Within Groups	3.103	22	.141		
	Total	8.145	23			

*Sig. <0.05

6.9.2. MRCE vs MRCE

After comparing the support for creativity of MRCE and PCE, this study compared the support of creativity for two task scenarios in MRCE. The mean values in Table 6-38 show that the creative support of MRCE for task 2 is better than that for task 1. The analysis results of One-way ANOVA in Table. 6-39 show that MRCE has a significant advantage for the creative support of task 2 in terms of novelty and implementation than for task 1 ($F(1,22) = 5.452$, $p = .029$ rather than $p < .05$; $F(1,22) = 5.006$, $p = .036$ rather than $p < .05$). That is, MRCE has a more significant support for outer space-themed creative task in terms of novelty and motivation for implementation.

This study then compared the creative support of PCE for Tasks 1 and 2 (Table 6-40). Table 6-41 shows that there was no statistically significant difference in creative support for tasks 1 and 2 by PCE. That is, there is no significant difference between PCE's creative support for cherry blossoms -themed design task and outer space-themed design task.

Table 6-38. Descriptives of tasks in MRCE

MRCE Task1 - Task1		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	
						Lower Bound	Upper Bound			
Fluency	Task1	12	5.6500	.47578	.13734	5.3477	5.9523	5.00	6.60	
	Task2	12	5.6833	.41304	.11924	5.4209	5.9458	5.00	6.40	

	Total	24	5.6667	.43606	.08901	5.4825	5.8508	5.00	6.60	
Elaboration	Task1	12	5.5833	.37618	.10860	5.3443	5.8223	5.20	6.20	
	Task2	12	5.4667	.23094	.06667	5.3199	5.6134	5.00	5.80	
	Total	24	5.5250	.31103	.06349	5.3937	5.6563	5.00	6.20	
Novelty	Task1	12	4.8000	.54606	.15763	4.4530	5.1470	4.00	5.60	
	Task2	12	5.2333	.33934	.09796	5.0177	5.4489	4.60	5.60	
	Total	24	5.0167	.49666	.10138	4.8069	5.2264	4.00	5.60	
Thoroughness	Task1	12	5.1167	.42176	.12175	4.8487	5.3846	4.40	5.60	
	Task2	12	5.1500	.45227	.13056	4.8626	5.4374	4.40	5.60	
	Total	24	5.1333	.42801	.08737	4.9526	5.3141	4.40	5.60	
Relevance	Task1	12	6.2167	.39505	.11404	5.9657	6.4677	5.40	6.60	
	Task2	12	6.2500	.35291	.10188	6.0258	6.4742	5.60	6.60	
	Total	24	6.2333	.36673	.07486	6.0785	6.3882	5.40	6.60	
Movement or actions	Task1	12	5.4833	.54910	.15851	5.1344	5.8322	4.40	6.20	
	Task2	12	5.2000	.37173	.10731	4.9638	5.4362	4.40	5.60	

	Total		24	5.3417	.48087	.09816	5.1386	5.5447	4.40	6.20	
	Model	Fixed Effects			.46888	.09571	5.1432	5.5402			
		Random Effects				.14167	3.5416	7.1417			.02182
Implementation	Task1		12	5.6500	.29695	.08572	5.4613	5.8387	5.20	6.00	
	Task2		12	5.9333	.32287	.09320	5.7282	6.1385	5.40	6.40	
	Total		24	5.7917	.33611	.06861	5.6497	5.9336	5.20	6.40	

Table 6-39. ANOVA of tasks in MRCE

MRCE Task1 -Task2		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Fluency	Between Groups	.007	1	.007	.034	.856
	Within Groups	4.367	22	.198		
	Total	4.373	23			
Elaboration	Between Groups	.082	1	.082	.838	.370
	Within Groups	2.143	22	.097		
	Total	2.225	23			
Novelty	Between Groups	1.127	1	1.127	5.452	.029*
	Within Groups	4.547	22	.207		

	Total	5.673	23			
Thoroughness	Between Groups	.007	1	.007	.035	.854
	Within Groups	4.207	22	.191		
	Total	4.213	23			
Relevance	Between Groups	.007	1	.007	.048	.829
	Within Groups	3.087	22	.140		
	Total	3.093	23			
Movement or actions	Between Groups	.482	1	.482	2.191	.153
	Within Groups	4.837	22	.220		
	Total	5.318	23			
Implementation	Between Groups	.482	1	.482	5.006	.036*
	Within Groups	2.117	22	.096		
	Total	2.598	23			

*Sig. <0.05

Table 6-40. Descriptives of tasks in PCE

PCE Task1 -Task2		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Fluency	Task1	12	5.6167	.34597	.09987	5.3968	5.8365	5.00	6.20
	Task2	12	5.3000	.41341	.11934	5.0373	5.5627	4.40	5.80
	Total	24	5.4583	.40638	.08295	5.2867	5.6299	4.40	6.20

Elaboration	Task1	12	5.2167	.36639	.10577	4.9839	5.4495	4.60	6.00
	Task2	12	5.1667	.32845	.09482	4.9580	5.3754	4.60	5.60
	Total	24	5.1917	.34125	.06966	5.0476	5.3358	4.60	6.00
Novelty	Task1	12	4.6500	.37295	.10766	4.4130	4.8870	4.00	5.20
	Task2	12	4.5167	.40415	.11667	4.2599	4.7734	3.80	5.20
	Total	24	4.5833	.38636	.07887	4.4202	4.7465	3.80	5.20
Thoroughness	Task1	12	4.8500	.29695	.08572	4.6613	5.0387	4.40	5.40
	Task2	12	4.7000	.28920	.08348	4.5163	4.8837	4.40	5.40
	Total	24	4.7750	.29672	.06057	4.6497	4.9003	4.40	5.40
Relevance	Task1	12	5.7167	.47832	.13808	5.4128	6.0206	5.00	6.40
	Task2	12	5.5500	.33166	.09574	5.3393	5.7607	5.00	6.00
	Total	24	5.6333	.41143	.08398	5.4596	5.8071	5.00	6.40
Movement or actions	Task1	12	4.8333	.48116	.13890	4.5276	5.1390	4.00	5.80
	Task2	12	4.7333	.37497	.10825	4.4951	4.9716	4.20	5.60
	Total	24	4.7833	.42495	.08674	4.6039	4.9628	4.00	5.80
Implementation	Task1	12	5.0333	.52455	.15142	4.7001	5.3666	4.20	6.00
	Task2	12	5.0167	.42176	.12175	4.7487	5.2846	4.20	5.60
	Total	24	5.0250	.46555	.09503	4.8284	5.2216	4.20	6.00

Table 6-41. ANOVA of tasks in PCE

PCE Task1 -Task2		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Fluency	Between Groups	.602	1	.602	4.141	.054
	Within Groups	3.197	22	.145		

	Total	3.798	23			
Elaboration	Between Groups	.015	1	.015	.124	.728
	Within Groups	2.663	22	.121		
	Total	2.678	23			
Novelty	Between Groups	.107	1	.107	.705	.410
	Within Groups	3.327	22	.151		
	Total	3.433	23			
Thoroughness	Between Groups	.135	1	.135	1.571	.223
	Within Groups	1.890	22	.086		
	Total	2.025	23			
Relevance	Between Groups	.167	1	.167	.984	.332
	Within Groups	3.727	22	.169		
	Total	3.893	23			
Movement or actions	Between Groups	.060	1	.060	.322	.576
	Within Groups	4.093	22	.186		
	Total	4.153	23			
Implementation	Between Groups	.002	1	.002	.007	.932
	Within Groups	4.983	22	.227		
	Total	4.985	23			

*Sig. <0.05

7. Discussion

7.1. Pedagogical usability in MR creative environment

This study is novel in two aspects. First, at the technical level of interactive media, there has been discussion on the feasibility of applying VR and AR technologies in education. We found that the application of MR technology in education is feasible and has usability by comparing the MRCE and PCE. Second, previous MR technology has mostly been used in education to train users in operational skills, such as familiarizing users with medical operations and training them in installation machinery, while we applied MR technology to stimulate an ability, such as creativity. Therefore, the MRCE in this study has reference value for the innovative application of the MR educational environment and its pedagogical usability.

The term “pedagogical usability” indicates whether the tools, content, and interfaces in the MRCE support the chosen instructional goals; the instructional activities in the MRCE are conducted according to the training method of creativity. The pedagogical usability of an MRCE includes instructions and exercises that support creativity, promote the organization of the creative process, and improve the quality of the completion of creative tasks and a pedagogical vision for developing of students’ creativity.

7.2. MRCE enhances the instruction and practice of creativity

Compared with the previous virtual learning environment, students in the creative environment of MR have no negative impact on creativity teaching and practice because they are separated from the physical space. Additionally, objects that are not needed or are obstructive in the real learning environment can be hidden, optimizing the creative environment.

Furthermore, the user interface in the MRCE ensures the user-friendliness of teaching. The web-based user interface, in combination with the virtual hand menu, guarantees the usability of the MR system and largely avoids operating errors. This smooth operation enables students to focus on the learning content and provides users with various user interface choices in different usage states. In this study, students were attracted to the virtual handheld menu, and most students utilized it until they had difficulty operating it. Subsequently, they completed the operations through the web-based user interface. Thus, the application of the virtual handheld menu in the educational environment has considerable potential; it is popular among students due to its natural operations and quick interactions.

7.2.1. MRCE enhances organization of the creative process

The educational environment focuses on practical implementation. A virtual learning environment only provides information about itself and cannot support the overall creative practice, leading to a disconnect in the creative process. The advantage an MR environment has over a virtual learning setting is that it is compatible with the physical milieu and retains physical tools, which supports prototyping, refinement, and reflection in the creative process. Real-time interactivity promotes empathy, definitions, and the creative phases.

Virtual creative tools can aid the process, significantly reduce educational costs, and expand educational resources. For example, the MRCE features 7 virtual screens that can be sized, positioned, and filled with content by the students themselves. Compared to the physical setting, the virtual environment in the MRCE is richer and more flexible, and thus of improved quality.

It is difficult for students to have a comprehensive understanding of creative tasks in traditional education if they do not have appropriate experiences. Through the MRCE, students can have sensory interactions with virtual objects to obtain something close to a “real” experience; imagination provides more cognitive material for the associative process and helps increase the originality of students’ ideas. Further, immersion enables students to have an immersive experience that helps them spontaneously penetrate context-related constructions and memories, thereby activating their knowledge reserves, linking beneficial information in the memory system with information in creative materials, and making positive connections.

7.2.2. MRCE enhances motivation for creativity

The creative process is an extremely challenging activity that requires continuous effort. Motivated students are more likely to persevere and complete tasks (Csikszentmihalyi, 1991; Schmidt, 2007). We found that students in the MRCE actively explored environmental information and interacted enthusiastically with virtual objects and also created new objects and sights by iteratively combining and overlaying virtual models.

First, the MRCE leads to knowledge situations, stimulates students' curiosity, and promotes students' active gathering and processing of information. Second, the MRCE makes knowledge transfer more personal and is more helpful for students' personality development and their ability to construct knowledge independently. Third, the vivid content in the MRCE stimulates students' learning enthusiasm; they experience the fun of learning in the real and virtual worlds. Hence, the MRCE focuses on the students and encourages their learning initiatives. Students break away from the original structure of the classroom and are equipped with certain observation and decision-making skills for their development.

7.3. Added value of the educational environment supported by MR technology in education

7.3.1. Dimensional expansion of MRCE

Students' perceptions tend to be intuitive, and the information resources in traditional education denote that students often ignore the sensory feedback the 3D world provides. Although previous virtual environments have also provided 3D interactions, learners could only interact in the virtual world. In an AR-enabled environment, learners usually interact by simply clicking or swiping.

The learning environment supported by MR technology extends a one-dimensional interaction to a 3D one based on a 2D interaction, realizes operations such as grasping, zooming in, zooming out, rotating, and changing position in the 3D space, and integrates various real-time interaction methods to construct the space. The MR learning environment takes full advantage of the learners’ manipulation capabilities; they perceive the space as more natural.

MR technology builds an interactive feedback information loop between the virtual world, the real world, and the learner based on maintaining the learner’s normal perception of the real world. It integrates the virtual and real worlds seamlessly and extends the learner’s senses to the virtual world. The MR educational setting facilitates real-time interactions and covers diverse modalities such as vision, hearing, and somatosensory skills, making the visual display vivid and intuitive, and making knowledge visible, tangible, and accessible. This multisensory transmission of information allows learners to return to the most primitive senses of human perception and assess the environment using their sensory organs, which can partially alleviate the negative emotions that the abstract instructions of traditional teaching evoke in students. MR educational environments transform learners into participants of another world. The learner enhances the substitution in the immersive experience and acquires first-hand experience.

7.3.2. The cognitive enhancement and perceptual expansion of the learner

Cognition cannot be separated from the specific context and content; the closer the specific context and content are to the real world, the more conducive it is to effective cognition. However, in the traditional educational environment, it is affected by factors such as time, space, funding, etc., and all teaching cannot be carried out in the form of real activities, nor can it provide various situations. The previous virtual learning environment can provide a variety of situations, but it is still essentially and in terms of sensory experience a “virtual world.” The MR learning environment is an immersive learning space created by complementing the virtual and real worlds according to learning needs. The dynamic interaction between knowledge and situation is created by integrating the real world and virtual world to shape the situation, which can solve the visualization of teaching content and knowledge. This is beneficial for promoting effective cognition in learners.

The cognitive phase is mainly about understanding the learning task. Positive experiences can provide additional resources for expanding cognition (Lee & Sternthal, 1999). The MR learning environment can provide a large amount of holographic information, multi-channel information transmission, and rich sensory experiences to stimulate learners' interest, enthusiasm, and creativity, and encourage them to act and try out boldly so that they can expand their cognitive horizons through rich stimuli.

Second, MR technology can intuitively represent abstract, micro, and macro knowledge from multiple perspectives so that learners can better understand relevant knowledge through macro and micro situations. Learners explore things by smoothly zooming in, zooming out, and rotating virtual learning content, discovering more possibilities and improving perception and understanding.

Third, MR educational environments can provide students with specific experiences that they could not have in traditional educational environments. The advantage is that they can simulate scenarios that cannot be experienced in the real world in a timely and safe manner. In addition, through virtual simulations, the creative MR environment can superimpose time travel, the sun and moon shining together, space travel, and other specific scenes into any real learning environment. The creative MR environment can directly transform the original space to be imagined into a "real" space of sensory experience, with the ability to give users data beyond the scope of their senses or experience. This allows students to do things that are impossible in the real world and visit specific locations, trigger interactions with things that are not visible in the physical environment, and significantly expand students' perceptual capabilities.

The safety of education comes first, so it is important that students are protected from harm. Compared to the learning environment supported by VR technology, MR technology allows users to see the real environment and avoid collisions with things in the real environment. The learners who are in it can use their senses to the maximum extent to perceive and recognize the environment, and do not need to worry about the existence of hazards. Moreover, learners exploring things in the MR learning environment will not suffer any real harm from possible dangers. Instead, experiencing hazards enables learners to deepen their memory and expand their perception, such as volcano eruptions and air walks. etc.

8. Conclusion and implications

This study demonstrates that the MRCE contributes to creativity. However, it also has some limitations. First, feedback from experimenters indicates that the clarity and accuracy of the MR environment used in the experiments could be improved. The Microsoft HoloLens 2 HMD must be used in a low-light environment to ensure visual impact. Therefore, the use of the MRCE developed in this study is limited in environments with particularly strong or dim light. Additionally, the instability of the local network may affect the quality of access to virtual content.

Second, the MRCE in this study contained only two virtual task scenes; the quality and aesthetics of the virtual models employed to build the scenes need to be improved. The expansion of virtual teaching scenarios denotes an increase in the value of the educational environment, which provides more advanced teaching media for experiential education. The expansion of MR educational scenarios will further promote the teaching application of MR technology in different disciplines.

Third, the number of participants and the duration of the experiment were also limited. Hence, we could only examine the short-term effects of the MRCE on creativity, but not its long-term effects, on the students. This research encourages the application of MR technology in education; it should involve a stage of teaching activities in the MR educational setting to derive important findings.

Finally, the MRCE developed in this study only supports individual use and not multi-person collaboration. Therefore, we only test creativity generated by individuals and not by collaboration. MR technology can provide a virtual environment for multi-person collaboration; it does not require an avatar to be shown to the collaborators like in VR technology, but directly shares the same MRCE with real collaborators. As such, the development of an MRCE that can support co-creation is also promising.

This research aims to apply MR technology to create a virtual educational environment that focuses on supporting creativity, and realizes application in Microsoft HoloLens 2 through the development of the MR platform. The results show that MRCE can promote the development of creativity among design students compared with traditional creative environments, especially support for empathy, definition, and idea generation. The creativity outcomes achieved under MR conditions were of higher quality, especially in terms of implementation, dynamics, relevance, detail, thus achieving the goals of this study.

This study employs a virtual handheld menu and a web-based user interface as user interfaces that complement and support each other. Moreover, the characteristics of digital and traditional learning tools are very different and can be compatible under MR conditions, which ensures the teaching process and creates the conditions for learners to explore digital learning tools. Therefore, the development strategies and technical means used in this study are instructive for the design and development of other MR systems.

The MR creative environment designed in this study proposes new educational media and learning environments and opens up a new field for the application of human-computer interaction, especially the application of mixed reality technology. Compared with the educational environment supported by VR technology, the MR education environment promotes integrating the physical space environment and the digital virtual environment. The expansion of the dimension of the educational environment and the improvement of the learner's cognition and perception through the MR educational environment can promote the innovative application of the virtual educational environment. The virtual education environment supported by MR technology not only has great potential in the application of design education, but can also be applied to all other disciplines in education, and even other fields related to creativity, and can bring considerable innovation and value.

Statements and Declarations

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Availability of data and material: The data of this research is not open to the public due to participant privacy.

Ethics approval: This research was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Life Sciences Committee of the Japan Advanced Institute of Science and Technology (Hito 03-008, approved on July 1st, 2021).

Consent to participate: Informed consent was obtained from all participants. The virtual assets in the developed program have been formally purchased.

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