A CONCEPTUAL MODEL OF ENHANCING SPATIAL ABILITY THROUGH IMMERSIVE LEARNING ENVIRONMENT FOR ART STUDENTS

JIAN YI

DOCTOR OF PHILOSOPHY
UNIVERSITI UTARA MALAYSIA
2024

Awang Had Salleh
Graduate School
of Arts And Sciences

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Abstrak

Keupayaan spatial ialah keupayaan kognitif penting dalam kognisi spatial, yang memainkan peranan penting dalam kehidupan seharian atau pelbagai bidang subjek. Terutama dalam pendidikan seni, keupayaan spatial telah menjadi kritikal kerana fungsinya yang unik dalam membangunkan kreativiti. Walau bagaimanapun, dalam pendidikan seni semasa, kepentingan keupayaan spatial belum mendapat perhatian yang mencukupi. Pengajaran bilik darjah tradisional tidak mempunyai syarat (seperti alat teknikal) untuk membangunkan keupayaan spatial. Sebaliknya, kebanyakan kursus seni dijalankan dengan persembahan media dua dimensi, yang tidak kondusif untuk membangunkan keupayaan spatial pelajar dan pemahaman konsep spatial. Oleh itu, mengguna pakai alat pengajaran yang lebih sesuai dan persekitaran pengajaran yang inovatif telah menjadi perlu untuk membangunkan keupayaan spatial. Oleh itu, kajian ini terutamanya meneroka bagaimana persekitaran pembelajaran imersif (ILE) yang dibina berdasarkan teknologi realiti maya (VR) akan menjejaskan keupayaan spatial pelajar, terutamanya prestasi pembelajaran. Objektif kajian ini adalah (i) untuk menentukan faktor-faktor yang meningkatkan keupayaan spatial melalui persekitaran pembelajaran yang mengasyikkan dalam pendidikan seni, (ii) untuk membina model konseptual peningkatan keupayaan spatial melalui persekitaran pembelajaran yang mengasyikkan dalam pendidikan seni berdasarkan faktor-faktor yang dikenal pasti, (iii) untuk menilai model konseptual peningkatan keupayaan spatial melalui persekitaran pembelajaran yang mengasyikkan dalam pendidikan seni dengan perubahan prestasi pembelajaran pelajar. Kajian ini memilih 58 pelajar seni kolej tahun pertama sebagai peserta dalam eksperimen. Perubahan prestasi pembelajaran pelajar sebelum dan selepas eksperimen dibandingkan untuk menilai keberkesanan model konseptual ILE dalam meningkatkan keupayaan spatial pelajar. Keputusan menunjukkan, antara penemuan lain, mod ILE boleh membantu pembelajaran pelajar dengan lebih baik, meningkatkan keupayaan spatial dan kemahiran akademik mereka, dan merangsang imaginasi spatial dan kebolehan berfikir spatial mereka dengan perbezaan ketara 4.621 nilai min berbanding mod tradisional. Dari perspektif keperluan pendidikan pelajar seni untuk memupuk keupayaan spatial, kajian ini menyediakan model konseptual untuk meningkatkan keupayaan spatial melalui persekitaran pembelajaran yang mengasyikkan untuk pelajar seni dengan demonstrasi empirikal penggunaan teknologi VR.

Kata kunci: Keupayaan spatial; Realiti maya; Persekitaran pembelajaran yang mengasyikkan; Prestasi pembelajaran; Pendidikan Seni.

Abstract

Spatial ability is an essential cognitive ability in spatial cognition, which plays a vital role in daily life or diverse subject areas. Especially in art education, spatial ability has become critical because of its unique functions in developing creativity. However, in the current art education, the importance of spatial ability has not received enough attention. Traditional classroom teaching lacks the conditions (such as technical tools) to develop spatial ability. Conversely, most art courses are carried out by two-dimensional media presentation, which is not conducive to developing students' spatial ability and understanding of spatial concepts. Therefore, adopting more suitable teaching tools and innovative teaching environments has become necessary to develop spatial ability. Thus, this study mainly explores how an immersive learning environment (ILE) built based on virtual reality (VR) technology will affect students' spatial ability, especially learning performance. The objectives of this study are (i) to determine the factors that enhance spatial ability through the immersive learning environment in art education, (ii) to construct a conceptual model of enhancing spatial ability through the immersive learning environment in art education based on the identified factors, (iii) to evaluate a conceptual model of enhancing spatial ability through the immersive learning environment in art education by the changes in students' learning performance. This study selected 58 first-year college art students as participants in the experiment. The change in students' learning performance before and after the experiment was compared to evaluate the effectiveness of the ILE conceptual model in enhancing students' spatial ability. The results show, among other findings, that ILE mode can better help students' learning, improve their spatial ability and academic skills, and stimulate their spatial imagination and spatial thinking abilities with a significant difference of 4.621 mean values compared with traditional mode. From the perspective of the educational needs of art students to cultivate spatial ability, this study provides a conceptual model of enhancing spatial ability through the immersive learning environment for art students with the empirical demonstration of the use of VR technology.

Keywords: Spatial ability; Virtual reality; Immersive learning environment; Learning performance; Art Education

Acknowledgement

First of all, I would like to express my most incredible gratitude to my supervisor, Associate Prof. Ts. Dr. Juliana Aida Abu Bakar. Without her guidance and help, this thesis would not have been possible. Her competence in the field of research contributed unlimited support, energy and time to this achievement. I would like to thank her for her excellent guidance, support, kindness, patience and motivation. I am truly fortunate to have such a supportive, enthusiastic, dedicated mentor guiding me throughout my research journey.

Secondly, I would like to thank all the SCIMPA teachers for their help and guidance throughout my study. I am also very grateful for the other regulations and services Universiti Nord Malaysia (UUM) provided, which made the research process smoother. Meanwhile, It is a pleasure to acknowledge the experts who have reviewed and added value to my work. Thank you for the constructive pieces of advice and suggestions.

Finally, I would like to thank Dr.Huang(my husband) for encouraging and motivating me and giving me the greatest support when I struggled to study.

I hope this thesis can present the best of me for you.

With Gratitude,
Jian Yi
Universiti Utara Malaysia (UUM)
11th August 2024.

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List of Abbreviations

2D	Two-dimension/Two-dimensional
3D	Three-dimenssion/Three-dimenssional
AAT	Academic Ability Test
AI	Adobe Illustrator
APP	Application
AR	Augmented Reality
BMP	Bitmap
CAD	Computer Aided Design
CDR	CorelDraw
CG	Control Group
CL	Cognitive Load
CMRT	Chronometric Mental Rotation Tasks
CRT	Card Rotation Test
CVR	Content Validity Ratio
df	Degree of Freedom
EFT	Embedded Figure Test
EG	Experimental Group
HMD	Head Mounted Display
ILE	Immersive Learning Environment
IVRSA	Immersive Virtual Reality Spatial Ability
JPEG	Joint Photographic Experts Group
M	Mean
ME	Mental Effort
MR	Mental Rotation
MR	Mix Reality
MRT	Mental Rotation Test
MW	Mental Workload
N	Number
OM	Object Manipulation
PC	Personal Computer
PFT	Paper Folding Test

PT	Psychometric Tests
PVRT	Purdue Visualization of Rotations Test
SA	Spatial Ability
SAS	Spatial Ability Self-perception
SAST	Spatial Ability Standard Test
S-CVI	Scale Content Validity Index
SD	Standard Deviation
SDT	Surface Development Test
SE	Standard Error
SMRT	Mental Rotation Test by Shepard and Metzler
SN	Spatial Navigation
SO	Spatial Orientation
SP	Spatial Perception
SPSS	Statistical Package for the Social Science
SR	Spatial relationship
STEM	Science, Technology, Engineering & Mathematics
SV	Spatial Visualization
TIFF	Tagged Image File Format
UE4	Unreal Engine 4
VE	Virtual Environment
VMRT	Mental Rotation Test by Vandenberg and Kuse
VR	Virtual Reality

CHAPTER ONE

INTRODUCTION

This chapter outlines the whole research process, including background research, problem statement, research question, research objective, research scope, operational definition, and thesis structure.

1.1 Overview

In his book, Smith (1964), an American writer, wrote, "The technological revolution has improved spatial ability at all levels, whether it is tiling or topology." It is illustrated that spatial ability plays a vital role in human life. Spatial ability refers to the power of individuals to recognize, manipulate, and transform the spatial characteristics of objects and is an essential ability for human actions and thinking (Bruce et al., 2016). It is critical to human intelligence, language, and calculation ability (Abich et al., 2021).

1.1.1 Great Concern for Spatial Ability

Spatial ability has become a necessary critical ability in people's daily activities. Many real-life situations rely on spatial problem-solving ability (Noviani et al., 2017). For example, when packing, we must mentally visualize how different items can fit together in the suitcase. We must match and combine the manual's two-dimensional and three-dimensional (3D) furniture parts when assembling furniture. When solving a third-order Rubik's cube, we need to imagine what the cube will look like after being rotated. At the same time, spatial abilities are also applied to various technological tools. Examples include using the iPad to design a flat house structure, using the computer to play Tetris, using immersive media to create 3D creative works, and using a mobile APP to navigate maps, photograph, or visualize personal health data. It follows that without spatial ability, we cannot understand the position and relationship between objects and the possible change and direction of the dimension or part of a particular shape.

Some researchers believe that spatial ability can predict job performance and has a specific predictive power for career success (Muenks et al., 2019). As Ursyn (1997) said, Learning, problem-solving, and memorization require the ability to visualize scientific concepts. Without good spatial ability skills, success in professional knowledge will be limited (Rahmawati et al., 2021).

Art is generally regarded as a subject that requires high-dimensional artistic interaction throughout the learning process. The core goal of its education is to help students see beauty through perceptual learning, and the key to seeing beauty lies in spatial ability, which can use visual thinking, solve visual problems, and enhance mental imagery (Haanstra, 1996). For example, in visual communication design, spatial ability is important not only because designers need to express design ideas graphically but also because it can help solve problems involving abstract objects and understand other designers' sketches and solutions (Jiawei & Mokmin, 2023). Sutton and Williams (2010) believe that spatial ability plays a crucial role in architectural art design and the learning experience of art students. The spatial ability allows them to easily convert two-dimensional (2D) images of a given location into 3D images, meaning they can effortlessly create a three-dimensional depiction of the area being designed in their mind while dealing with a 2D layout on paper (Patera, 2009). Therefore, reading, understanding, and comprehending 2D information in a 3D environment (spatial ability) is essential for design communication and generation (Cho, 2012; Oxman, 2002). For art students, the cultivation of spatial ability is the initial task and the ultimate goal.

In addition, Suh and Cho (2020) have also demonstrated the importance of spatial ability in diverse disciplines, especially in engineering and design-related disciplines, where spatial ability is regarded as an essential factor in developing vocational skills. For example, a display designer, when designing a clothing exhibition, will present a vivid image of various clothing exhibitions through the use of striking images to thinking and spatial ability, the image pursuit, repeated analysis, comparison, selection, and recombination, and add some of their unique design, formed a new blueprint (Moritz & Youn, 2022).

To sum up, spatial ability plays a vital role in most subjects. Given the strong relationship between spatial ability and arts, mathematics, STEM subjects, and other subject areas, learners must be trained to develop their spatial ability to prepare for excellence in a diverse range of subject areas.

Spatial abilities are malleable, meaning students' spatial ability can be improved through educational interventions (learning) and training (Lane & Sorby, 2021). In art education, spatial ability training is usually realized through teaching. In traditional teaching, students' spatial modelling and thinking abilities are trained through sketching, three-dimensional composition, projection drawing, three-dimensional physical modelling, and other means. With the development of computer graphics and network technology, learners can carry out all kinds of learning activities based on a virtual environment with a high sense of reality.

Many researchers often combine the spatial ability requirements of specific majors and apply 3D models, CAD, virtual reality, 3D animation, computer games, and other means to train students' spatial ability (Papakostas et al., 2021). Alternatively, supplemented with data gloves, stereo glasses, helmets, and other peripheral devices to help learners better observe and experience learning objects and enhance the spatial environment's cognition and recognition ability (Loiko, 2023). The spatial learning experience supported by technical tools and well-designed teaching activities can potentially affect the construction of a learning environment oriented toward developing spatial ability. Schools provide a suitable place to develop such skills. Therefore, integrating the spatial ability training process into classroom teaching activities can train and improve students' spatial ability to cultivate students' professional qualifications and skills (Klyce & Ryker, 2024; Tuker, 2024).

1.1.2 Virtual Reality Provides Teaching Support for Spatial Ability Development

The Chinese government attaches great importance to the application and development of modern information technology (such as virtual and augmented reality) in education. It has issued a series of policies to support and promote the integration and application of information technology in education. For example, the Chinese government points out that artificial intelligence, virtual reality, and other technologies should be comprehensively used to explore new models of future education and teaching (The State Council, 2017). China's Ministry of Industry and Information Technology also clearly pointed out the importance of applying virtual reality technology in diverse disciplines (Ministry of Industry and Information Technology, 2018).

Virtual Reality (VR) is one of the most promising educational visualization technologies. VR allows learners to visualize abstract concepts and provides an immersive 3D virtual environment accessible from anywhere (Kye et al., 2021). VR can also improve the initiative and participation of learners, making learners more focused on learning activities. At the same time, the learning process of VR is more exciting, thus improving learners' motivation and attention (Alfalah, 2018). In addition, VR can also simulate and integrate information and interact with virtual objects.

With the vigorous development of VR in education, virtual teaching spaces based on VR, AR, and other technologies have been practised and applied in teaching. VR has unique advantages in improving spatial ability and training design thinking (Flint et al., 2018; Ibrahim & Ali, 2018). Some researchers apply virtual reality technology to cultivate students' spatial ability, focusing on how to provide better technical support for spatial learning (Obeid & Demirkan, 2020).

For example, Canberra Grammar School in Australia changed students' paper books into e-books and developed a 3D Periodic Table App, which caused a fundamental change in the medium of instruction (Xu et al., 2022); Microsoft HoloLens, co-developed by Microsoft and Case Western Reserve University, has created a 3D hologram that can explain object structure to students in an all-round way (CWRU links, 2015). In the Mixed Reality Laser and Mirror Game developed by Palmer High School in the United States (Microsoft HoloLens, 2017), teachers use these tools to ask some students to explain content to other students. In other words, students who do well in one subject can share their learning experiences to help their classmates understand what they have learned in different classes. The Communication University of China opened a virtual University on the Metaverse platform. With the help of digital technologies such as street view maps, 3D reconstruction, and 3D engines, the entire campus buildings, public facilities, and their proportional relations were vividly reproduced, and the digital twin campus was accurately built. Users can access the Xirang platform freely through VR, mobile terminal, or PC terminal and start a roaming tour of the future campus with the virtual avatar (CUC, 2022). VR technique provides necessary learning technology support for learning technology disciplines, abstract art, astronomical phenomena, dangerous situations, complex space, and other concepts.

With the development of VR, it becomes more critical to support spatial ability development. For example, VR is increasingly recognized as a potential tool for assessing and restoring human cognitive and functional processes (Bell et al., 2020). In real life, people acquire information not only through listening and reading but also through the interaction with their environment and the perception and cognitive performance of things they are in contact with to acquire all kinds of information in an all-around way. Moreover, VR emphasizes the dominant role of people in the virtual environment. Users will be able to use and integrate high-performance computer hardware and software. All kinds of advanced sensing devices, immersed into the virtual computer system created by the virtual environment, should interact with the multidimensional interaction information environment, and from the qualitative and quantitative integrated environment are rational and perceptual knowledge, and develop concepts and generate new ideas. Therefore, VR can not only build a suitable environment to promote the spatial cognitive process (Supli & Yan, 2023) but also avoid the problem of keeping distance from the "environment" or "object" in other types of computer learning environments (Mou et al., 2023). It can be seen that VR can provide practical technical tools to support the development of spatial ability.

The nature of VR also has positive advantages in supporting spatial abilities. For example, the interactive nature of the VR and its dynamic display to the user can be used as a general tool to enhance spatial visualization. Liu et al. (2020) pointed out that VR positively impacts learners' orientation and visualization skills. VR allows participants to control the stimulus material, and virtual objects can be created and modified very quickly, which is often difficult when using natural objects. In addition, the two most important advantages of VR are spatial visualization and the 3D interactive functions provided (Tian, 2021), which allow participants to engage in hands-on practice intuitively and are very effective for educational purposes.

In addition, VR also positively affects the regulation of individual differences in spatial abilities. Different levels of spatial ability of individuals will affect their performance on specific tasks in virtual environments (Sun et al., 2018). For example, compared with learners with low spatial orientation, those with high spatial orientation can accumulate more spatial investigation knowledge during spatial learning related to virtual navigation (D'Urso et al., 2023). Alternatively, learners with weak spatial ability showed more significant improvement in the VR learning environment than in the traditional teaching environment. Similarly, learners with strong spatial ability pay more attention to the dominance and controllability of learning than ordinary learners (Lee & Wong, 2014).

1.2 Problem Statement

Spatial ability plays an important role in art education, such as performing arts, visual arts, and music/dance, and is an important skill for art students (Mercan & Kandr, 2022), which enables art students to form good spatial perception and visualization ability (Porat & Ceobanu, 2024). Therefore, to enhance art students' multiple disciplines and equip them with essential skills for future social development, more educational and training opportunities related to spatial ability should be created for them. However, the current classroom lacks research on developing spatial ability and applying modern information technology (Tóth et al., 2023).

1.2.1 The Particularity of Arts Leads to a Very High Demand for Spatial Ability

Art design discipline has characteristics such as cross-border integration professional cross, especially in creative play, requiring high flexibility. Art design courses pay more attention to the practice of professional knowledge and course considerable freedom. Spatial ability uniquely functions in creativity development; thus, it is the critical content of art design courses (Tang et al., 2022). As Buhalis et al. (2022) said, in realising creative design schemes, designers must be able to accurately estimate the size and distance and visualize the possible scene effects of complex interior spaces from different perspectives. Gomez-Tone et al. (2021) believe that the ability to manipulate and rotate objects is an essential contribution to creating the design, while the ability to control and turn things and judge size mentally and distance falls under the category of spatial cognition.

In art and design classes, students learn by doing things and thinking about what they are doing (Freeman et al., 2014). Whether the traditional art course or the appreciation of artworks based on Western educational ideas, they are eager to present a strong sense of space in the works displayed. However, traditional digital media presents a relatively small sense of space (Zhou, 2024). Although creativity and spatial ability are important factors in art design, there is limited research on cultivating spatial ability to stimulate creativity in students (Cho, 2017; Yang et al., 2024). The common teaching methods for cultivating spatial ability in schools combine teaching slides and video or two-dimensional animation displays. Students can only internalize relevant knowledge by integrating notes, textbook content, and their understanding, which may increase the cognitive load of spatial learning. Thus, it inhibits the students' understanding of spatial concepts and the development of spatial ability (Osman & Kuit, 2021).

Therefore, in the teaching of art courses, the combination of pictures, text, sound and images through virtual reality technology will help to create a vivid teaching situation, mobilize students' sensory responses from multiple angles, and transmit and share lively teaching content with pictures and images (Feng & Zhang, 2022). This teaching process can not only maximize the amount of teaching information and enrich the teaching content but also make students have a strong interest in what they learn and stimulate their thirst for knowledge (Som et al., 2023). Virtual reality technology can make the teaching content coherent and dynamic and deliver it to students novelly. In such a teaching situation, students can feel the vivid picture, naturally attract their attention, and naturally have a strong interest in the teaching content, which cannot be achieved in ordinary classroom teaching (Castaneda et al., 2021).

1.2.2 The Factors Influencing Spatial Ability are Ignored

Many factors affect the development of spatial ability, such as the classroom environment, curriculum content, teachers and students, etc. The interrelation of different educational factors will significantly impact the cultivation and development of spatial ability (Bufasi et al., 2024). For example, learning situations in ordinary classrooms may limit the development of spatial ability. VR in teaching spatial ability is expected to provide students with a different way to visualize spatial concepts, enabling students to absorb and better understand invisible and abstract spatial content (Tuker, 2024). In art courses, the traditional learning activity is for students to learn the theory and accept the teacher's guidance. However, one teacher is often required to instruct dozens of students, making it impossible to provide immediate and personalized feedback to individual students (Hayadi et al., 2018) and may inhibit their interest in learning.

Learning content is also a factor affecting the development of spatial ability. According to the research of Bufasi et al. (2024), insufficient course duration and unreasonable course design may be obstacles to the development of students' spatial ability. Previous research has reported that inadequate course time may hinder the growth of spatial abilities in students (Collins, 2018). Some courses do not directly involve spatial ability or only include a small part of the time to tell the theory of spatial ability; students can only use the time after class to self-study or carry out practice, which increases their learning pressure.

In addition to the above factors, other factors also affect students' spatial ability development. For example, D'Urso et al. (2023) mentioned that teachers' anxiety will affect students' learning in art education. Teachers' spatial ability may be negatively affected by their low belief in spatial ability, resulting in teaching anxiety and affecting the quality of teaching, which is also one of the factors affecting student achievement and learning outcomes (Purnawati, 2022). Teachers with high spatial pressure may avoid spatial activities in the classroom, resulting in limited concepts related to spatial ability that students can acquire (Pollitt et al., 2020).

On the other hand, the different characteristics of students make interest, motivation, learning style, and many other aspects different among students, which also causes the development of spatial ability to be out of sync (Safitri et al., 2022). Moreover, there is a disconnect between what students experience before entering college and the technology used in most classes, or the teaching method is not updated in time, which will affect the teaching effect (Flynn and Frost, 2021). Overall, more profound research is needed to explore the factors and the degree of influence on the development of spatial ability.

In current art education, due to these factors, students' learning performance has also had an impact. For example, a study by Hutson and Olsen (2022) surveyed 128 art students and found that 75% believed they would prefer VR devices to learn than theoretical courses. In addition, more than half of respondents said they would like to see the technology used in other courses. Research by Hui et al. (2022) found that VR technology can help students fully develop their creativity. However, although the government has increased its investment in higher education, most schools still lack a learning environment that can use VR devices to teach (Xiao, 2022). Therefore, this study hopes to improve art students' spatial ability and learning performance by enhancing the learning environment and other factors.

1.2.3 The Application of Immersive Learning Environment in Education at an Exploratory Stage

VR has potential advantages in supporting spatial ability (Safikhani et al., 2022), which is malleable and can be developed through education and training (Lane & Sorby, 2021). The development of VR is very rapid, and it is used in various industries around the world. However, the application and research of VR in education is still in the exploratory stage, but it has the potential to generate ideas that will transform education in all walks of life (Özgen et al., 2021; Arora, 2024). Due to its potential to display data in 3D, virtual reality (VR) has been recognized as a means to support students in visualizing objects in 3D and help students improve their spatial abilities (Mårell-Olsson et al., 2019; Sarioğlu & GiRgiN, 2020). Compared with the traditional spatial ability training methods, the VR technique provides more opportunities and possibilities for improving learners' spatial ability and improving the effect of spatial learning. Some studies also show that using VR techniques properly enhances learners' spatial ability (Abich et al., 2021; Jensen & Konradsen, 2017). Higher education institutions are poised to adopt VR on a broader scale to enhance learning with virtual environments (Hutson & Olsen, 2022).

Therefore, VR-based immersive learning environments provide students with a complete representation of external processes, reducing the cognitive load they are subjected to when developing mental representation models, thus enabling them to achieve higher spatial ability and more learning benefits (Lowe & Schnotz, 2007; Lee & Wong, 2014). By improving students' spatial ability, they can have strong spatial representation ability and achieve better learning performance (Kalyuga et al., 2003; Plass et al., 2003).

However, due to various restrictions, little attention has been paid to applying VR in specific courses, and only a few classrooms have integrated modern technology into their teaching. Most of them focus on case appreciation and the use of computers. At the same time, there is less research on how various design strategies affect students' experience of spatial ability and learning outcomes, especially in the art teaching of visual communication design, with only a small part of practitioners using fully immersive VR (Wang & Mokmin, 2023). Although Microsoft has developed advanced software like Hololens, its use in general courses is relatively rare; Dominguez et al. (2020) also believed that while virtual collaborative environments are promising for science, technology, engineering, and math education, the use of this technology has not yet been applied in the field of spatial skills training.

ILE still faces great historical opportunities and considerable challenges in the tide of education informatization (Chen, 2022; Wang, 2024). From the level of education, the lack of resources, design and development technology threshold is high and difficult to master (Han et al., 2023). The teaching model and teaching evaluation are still in the exploratory stage, and there is no mature experience for reference. From the technical level, improving the portability of equipment further, the immersion of the environment, the natural nature of the interaction, and the immersion experience of learners are still necessary (Baxter & Hainey, 2023). VR technology has been preliminarily applied to the construction of learning environments (Liu et al., 2024). Still, the difficulty of ILE application in education is how to provide learners with a positive experience, which will affect whether the experience is profound and real (Yang, 2023).

1.3 Research Questions

This study focuses on the following three issues:

i. What factors affect spatial ability enhancement in an immersive learning environment?

ii. How to design and construct a conceptual model of an immersive learning environment for enhancing spatial ability based on the identified factors?

iii. How to evaluate the immersive learning environment conceptual model in art education, especially on learning performance?

1.4 Research Objectives

The core objective of this study is to evaluate the immersive learning environment constructed by VR to enhance students' spatial ability. Therefore, the research objectives of this thesis are as follows:

i. To determine the factors that enhance spatial ability through the immersive learning environment in art education,

ii. To construct a conceptual model of enhancing spatial ability through the immersive learning environment in art education based on the identified factors,

iii. To evaluate a conceptual model of enhancing spatial ability through the immersive learning environment in art education by the changes in students' learning performance.

1.5 Scope of the Research

The focus of this study is to establish a conceptual model of an immersive learning environment for the development of spatial ability in art education. The conceptual model identified the factors influencing spatial ability development through literature review and supported theories, including constructive learning theory, cognitive load theory, and empirical learning theory.

In art education, spatial ability promotes students' creativity and is the critical content of art education. However, in the current classroom teaching, the effect of spatial ability development is limited because the factors affecting the development of spatial ability have not been paid attention to, such as general learning situations, single learning activities, inappropriate learning content, etc., will lead to the limitation the degree of students' acceptance and inhibit the development of spatial ability. VR provides more opportunities and possibilities for learning effect, and the proper use of VR can help improve students' spatial ability. However, the application of VR in education is still in the exploration stage, and few people pay attention to the application of VR in specific courses, and only a few classrooms integrate modern technology into teaching. Therefore, this study used VR to construct an ILE conceptual model by enriching teaching methods to develop spatial ability and improve learning performance. In addition, participants in this study were only first-year art students. This Study selected first-year students rather than the other grade students because they did not have experience applying and studying VR design software and did not have contact with "basic" course content, which can effectively reduce the possible influence of students' prior knowledge on the research results.

1.6 Operational Definitions

There are three terminologies involved in this thesis, which are defined as follows:

1.6.1 Spatial Ability (SA)

Spatial ability refers to an individual's ability to recognize, manipulate, and transform the spatial characteristics of objects (Bruce et al., 2016). In particular, spatial ability involves three main aspects: (i) the knowledge and understanding of space itself, (ii) spatial reasoning and the presentation of spatial information through mental manipulation of the whole space shape, imaging the rotation of objects, the folding and unfolding of plane patterns, and measure the change in a relative position of an object in space (McGee, 1979), (iii) the encoding and decoding of diagrams(e.g., maps, flow charts), and the reasoning which needs solving the problem and making decisions by interpreting and processing spatial information. In this study, spatial ability mainly refers to art students' ability to design and create.

1.6.2 Immersive Learning Environment (ILE)

Immersive learning environment refers to virtual reality technology, which combines a three-dimensional graphics system and various interface devices to provide immersive effects in an interactive virtual environment (Pan et al., 2006). It provides a highly interactive, simulated environment for users to interact with various objects in a computer-generated virtual world (Burdea & Coiffet, 2017) and provides learners with an "immersive" multi-sensory experience.

The immersive learning environment allows learners to immerse themselves in virtual scenes and interact with virtual learning content, virtual scenes, and virtual characters in real-time to feel what they have learned in the experience intuitively. In addition, the immersive learning environment can break through the limitations of time and space, not be restricted by objective conditions such as venues and equipment, and support infinite repetitive operations until the ideal learning effect is achieved. It can effectively solve the difficulties faced in the current teaching links, such as experiments, practices, and internships (Wu et al., 2014). The immersive learning environment mentioned in this study mainly refers to the learning environment constructed through virtual reality technology.

1.6.3 Learning Performance

Learning performance generally refers to students' comprehensive assessment of their performance in knowledge, skills, and other aspects, which specific indicators can measure. Anvin (1965) defined learning performance as a student's course grades, credits quantified, or scores that can represent a student's learning level. Pascarella et al. (2005) used learning performance to describe test and course scores. Qureshi et al. (2021) analyzed the factors that affect the learning performance of college students and believed that learning performance is a measure of a student's performance in school, including exam results, homework, participation in activities, etc. Ricciardi et al. (2021) divide learning performance into curriculum and developmental achievement related to student learning.

In addition, Goodman et al. (2000) argued that in addition to tests and other standardized tests, learning performance should be measured by various indicators such as consciousness, personality, and skills. In other words, besides the essential measurement of knowledge and skills, the learning performance must also cover interest, attitude, and other indicators related to students' learning effect (Musengimana et al., 2021). Learning performance generally reflects students' learning ability (Gittinger & Wiesche, 2023).

Based on the above analysis of the "learning performance" concept, it is not difficult to find that learning performance is a measurable variable. Therefore, in this study, we defined it as "measurable behavioural results displayed in the course work of learning."

1.7 Structure of Thesis

The structure of this thesis was divided into seven chapters:

Chapter 1: Introduction. This chapter clarifies the research background, puts forward the problem statements that this research tries to solve, and further defines the research questions, objectives, scope, and operational definition.

Chapter 2: Literature review. The definition of spatial ability, the components of spatial ability, the research and development of spatial ability, and the theoretical framework of spatial ability measurement are summarized. The definition and conceptual connotation of virtual reality technology, the academic support of virtual reality technology application, and the related research of its application in education. The research status of immersive virtual environments in education and teaching to develop students' spatial ability is summarized. Traditional learning and ILE models were compared and analyzed to summarize the potential contribution of ILE to the development of spatial ability. This paper brings out the indicators to evaluate the change in students' learning motivation and learning performance to demonstrate the advantages of spatial ability of ILE development.

Chapter 3: Research methodology. This chapter summarizes the research methods to solve all the research questions. The conceptual model design scheme was proposed after reviewing the previous work on spatial ability, immersive learning environment, and learning performance. After that, the IVRSA learning system was designed and developed using 3D Max, UE4, and other software. Finally, aiming at using the ILE conceptual model and IVRSA learning system, the research designs teaching experiment cases for the "Composing Foundation" course from the aspects of research design, research object, experiment content, measurement tools, and experiment process.

Chapter 4: The verified conceptual model of spatial ability development in the immersive learning environment. By sorting out the design principles and elements of the ILE conceptual model, this chapter builds a conceptual model of an immersive learning environment oriented to spatial ability development based on constructive learning theory, cognitive load theory, and experiential learning theory, combined with the characteristics of immersive technology. Then, experts were invited to conduct expert reviews to verify the conceptual model.

Chapter 5: Evaluation and effect on enhancing spatial ability in immersive learning environment. First, this chapter verifies the application effect of the ILE conceptual model. Students learn relevant learning contents of spatial ability in ILE. Students' mental rotation, spatial orientation, and spatial visualization ability are tested through learning activities. One-way ANOVA and paired sample T-test are applied to summarize the changes in spatial ability, academic ability, cognitive load, flow experience, and embodiment activities of students in different learning environments. Then, this chapter discusses the results of students' learning performance after learning in ILE and analyzes the influence of different learning environments on students' spatial ability development and learning performance.

Chapter 6: Conclusion and future work. The research conclusion, research contribution, research deficiencies, and prospects of this study.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews the concepts of spatial competence and immersive learning environments. It discusses the definition and classification, development history, measurement methods of spatial ability, and the characteristics, functions, advantages, and status quo of an immersive learning environment in developing spatial ability. At the same time, this chapter also discusses the functions and limitations of the existing ILE conceptual models. In addition, this chapter compares the difference between the traditional learning mode and the ILE mode and combs out the idea of ILE construction. Finally, this chapter sorts out the evaluation methods of learning performance. The following subsections discuss each concept considered in solving the problem statement.

2.1 Definition and Classification of Spatial Ability

Spatial ability comprises a complex and interconnected processes network, which researchers describe through various concepts. For example, spatial ability is also known as "spatial reasoning," "spatial structure," "visual thinking," "spatial perception," "mental representation," "spatial cognition," "spatial intelligence," etc. These terms can be generally substituted as synonyms depending on the circumstances.

Although spatial ability has been an important research topic in psychometrics since the early 20th century, there is still no consensus on the definition of spatial ability in academic circles. Some researchers define the concept of spatial ability from different disciplines or research perspectives. For example, from the perspective of cognitive psychology, spatial ability refers to the ability of cognitive subjects to obtain, process, store, transmit, and interpret spatial information, obtain spatial knowledge, and solve relevant spatial problems (Shuang, 2010). From the perspective of educational psychology, spatial ability is the innate spatial imagination ability that individuals have before receiving formal education. The following is a review of some researchers' definitions of spatial ability.

According to Kelley (1928), spatial ability is the cognition and memory of visual forms or the psychological manipulation of visual shapes. Thurstone (1938) believed that spatial ability refers to the ability to remember a spatial image in the mind, twist, move, or rotate the image to a new position in the brain, and then compare the changed image with the image provided by the researcher. Guilford and Lacey (1947) believed that spatial ability is the ability to mentally visualize the rotation of objects and imagine an expanded plan or a folded three-dimensional figure of an object or the relational ability to understand the changing position of an object in space. Burt (1949) divided spatial ability into static and dynamic. Static spatial ability refers to observing and recognizing graphs, while active spatial ability refers to the imagination in space. According to Gardner's (2011) multiple intelligences theory, spatial ability is called spatial intelligence. He believes that spatial intelligence is the ability to form mental models of objects in the mind and effectively use and operate such models.

In addition, some researchers believe that spatial ability is not a single skill but consists of various factors (Linn & Petersen, 1985; McGee, 1979). For example, according to McGee (1979), Spatial ability includes at least two main components: Spatial visualization and Spatial orientation. Based on previous studies, Lohman (1979) applied the method of factor analysis to distinguish three spatial ability factors: spatial relations, spatial orientation, and spatial visualization; Linn and Petersen (1985) distinguished spatial ability into three components: spatial perception, mental rotation, and spatial visualization.

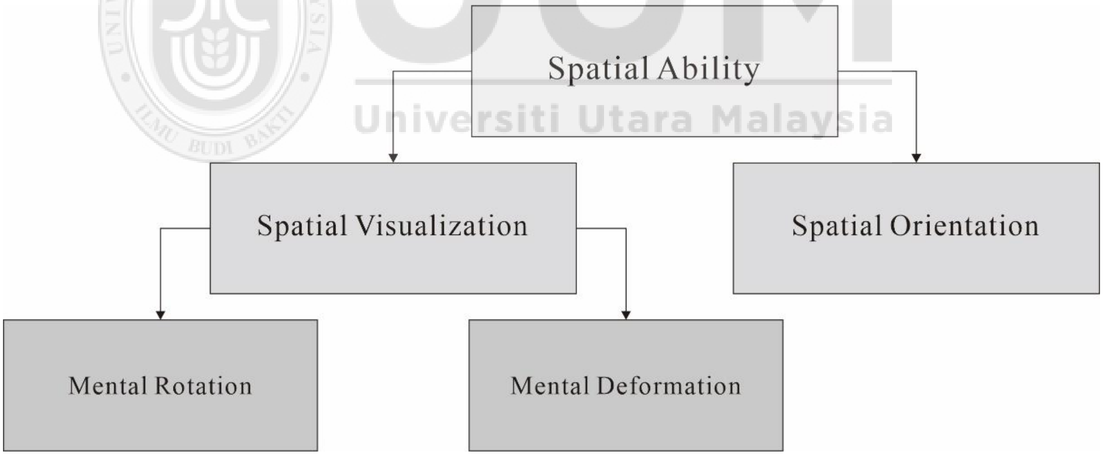

Figure 2.1. Elements of spatial ability

Tartre (1990) proposed the dimensional classification of spatial ability based on the research of McGee (1979) and the point of mental processes, as shown in Figure 2.1. Such mental processes are thought to be used in performing a given task. Tartre (1990) believes that spatial ability consists of two distinct components: spatial visualization and spatial orientation. Spatial visualization involves mentally moving objects, and spatial orientation consists of the ability of individuals to shift their perspective when objects remain mentally fixed in space. Tartre (1990) also pointed out that spatial visualization can be subdivided into mental rotation and mental deformation. Mental rotation refers to the complete rotation and deformation of an object in space, but mental metamorphosis is only parts of an object deform in a certain way. Many researchers classify the mental rotation of two-dimensional and three-dimensional stimuli as spatial orientation or relationship. At the same time, Tartre (1990) regards mental rotation as a component of spatial vision because the stimulus is moved in the mind.

Maier (1999) divided spatial ability into five factors in his research: Spatial Perception, Mental Rotation, Spatial relationship, Spatial orientation, and Spatial visualization. However, he thought those five components were interrelated and could not be altogether distinguished. Sorby (1999) agrees with his view and points out that these broad categories have overlapping elements.

Therefore, this paper summarizes the definition of spatial ability and its components according to the time axis of spatial ability research and development. Table 2.1 lists the researchers' definition of spatial ability and summarizes its component classification.

Table 2.1

Definition and Components of Spatial Ability

Names and years	Definition of Spatial ability	Components				
		SV	**SO**	**MR**	**SR**	**SP**
Kelley (1928)	The cognition and memory of visual forms or the mental manipulation of visible shapes.	✓		✓		
Thurstone (1938)	The ability to remember a spatial image in mind, twist, move, or rotate the image to a new position in the brain, and then compare the changed image with the image provided by the researcher.	✓		✓		
Guilford et al. (1947)	The ability to mentally visualize the rotation of objects and imagine an expanded plan or a folded 3D figure of an object, or the relational ability to understand the changing position of an object in space.	✓		✓	✓	
Burt (1949)	Spatial ability can be divided into static spatial ability and dynamic spatial ability.	✓				✓
French (1951)	The ability to understand objects moving in three-dimensional space.	✓		✓		
Shepard and Metzler (1971)	The ability to see through changes in an image.	✓				✓
Ekstrom and Harman (1976)	The ability to manipulate and transform spatial pattern impressions to form other spatial pattern arrangements.	✓		✓		
McGee (1979)	spatial ability refers to keeping direction as the direction of spatial structure changes in the presented spatial structure.	✓	✓			
Lohman （1979）	The ability to generate, retain, extract, and transform visual images.	✓	✓			
Eliot and Smith (1984)	Spatial ability is explored from two main dimensions: spatial visualization and spatial relationship.	✓			✓	
Linn and Petersen (1985)	The skill of expressing, translating, generating, and recalling symbolic, non-verbal information.	✓		✓		✓
Tartre (1990)	Spatial ability consists of two distinct components: spatial visualization and spatial orientation.	✓	✓			
Pellegrino and Hunt (1991)	The ability to reason about visual images.	✓				✓

Table 2.1 continued

Maier (1999)	Spatial ability, including Spatial Perception, Mental Rotation, Spatial relationship, Spatial orientation, and Spatial visualization.	✓	✓	✓	✓	✓
Sorby (1999)	Spatial ability categories have overlapping elements.	✓	✓			
Contero (2003)	Creating good-quality spatial ability requires solid visualization skills.	✓		✓		✓
Pak et al. (2006)	There is a strong relationship between spatial ability and performance on computer-based tasks.	✓	✓			
Gardner (2008)	The ability to form a mental model of an object in one's mind and to use and manipulate this model effectively.	✓		✓		
Bruce et al. (2016)	The ability to recognize and manipulate (mentally) the spatial properties of objects and the spatial relationships between objects.	✓		✓	✓	
Lowrie et al. (2019)	spatial visualization intervention program can increase student spatial ability.	✓				

SV=Spatial Visualization; SO=Spatial Orientation; MR=Mental Rotation; SR=Spatial Relations; SP=Spatial Perception

In summary, spatial ability is not a single skill. However, several elements cover most spatial abilities, including mental rotation, spatial orientation, and spatial visualization (as shown in Figure 2.2 below).

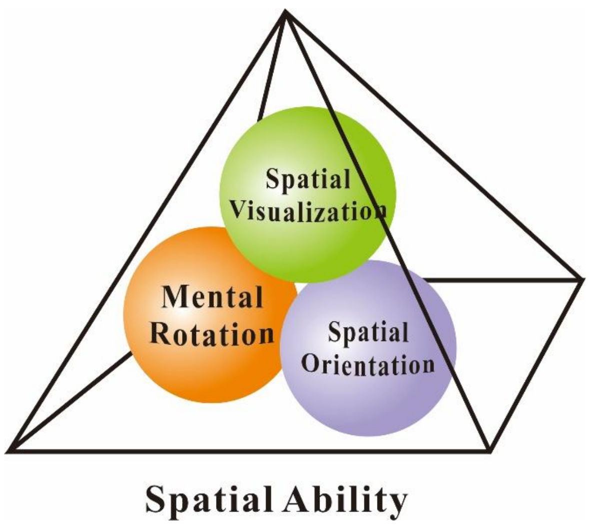

Figure 2.2. 3D framework for spatial ability

2.1.1 Mental Rotation

Mental rotation is a cognitive psychology term initially proposed by American psychologist Shepard and Metzler (1971) and introduced into experimental cognitive psychology. They thought, "Mental rotation is a form of spatial thinking that refers to the ability to mentally rotate a two-dimensional or three-dimensional figure quickly and accurately without external tools, such as constantly memorizing the correct orientation while constantly changing the orientation of objects or shapes." Other researchers have also expounded on the connotation of mental rotation. For example, Reilly et al. (2016) believe that mental rotation is a spatial skill that requires individuals to mentally rotate objects in space to verify how they look from different angles or perspectives. Frick et al. (2013) believe that mental rotation refers to the movement of imagined objects (combined objects) in two-dimensional or three-dimensional space.

At present, mental rotation has been widely discussed by psychologists. The speed effect usually measures the impact of mental rotation, that is, the speed and accuracy of learners' mental rotation process. In the experiment where Shepard and others measured mental rotation, mental rotation was described as a shape-matching activity. In this activity, learners must decide whether two elements (such as two objects or pictures) that appear simultaneously or consecutively from multiple angles are the same or different. In those simulated mental rotation tasks, the objects are often identical or mirror images and sometimes differ in orientation and rotation angles. In these tasks, all kinds of spatial skills (such as symmetric, positioning, orientation, balance, decomposition/recombination, translation, scaling, comparison, and navigation) in the form of interconnected reveals that the mental rotation process is a complex phenomenon and nested in the body movement, cognitive process, and ordinary activities of a given environment (Ottaviano et al., 2019).

2.1.2 Spatial Orientation

Spatial orientation refers to the ability to correctly understand and participate in the relationship between the position of the object and its position when the object is presented from different angles (Clements & Battista, 1992); McGee (1979) believed that spatial orientation included the ability to understand the arrangement of elements of visual stimulus patterns; Spatial orientation is mainly reflected in the individual can identify their position, and can accurately identify the direction; Newcombe and Huttenlocher (1992) believed that spatial orientation refers to "imagining the perspective from another position (not your own)," that is, imagining how the object looks from other people's perspective or position.

Spatial orientation is mainly reflected in individuals' ability to identify their position and accurately identify the direction. In general, the mental processing of spatial orientation is mainly dynamic and can be divided into object-based spatial transformation and egocentric perspective transformation (Zacks et al., 2002). For example, when manipulating objects psychologically, the observer's point of view remains fixed. However, Kozhevnikov and Hegarty (2001) argued that the mental rotation ability and the ability to reposition the image of self are two independent spatial abilities, and the selfish perspective is the movement of an object, using its body as a frame of reference to imagine the perspective of others. A self-centred perspective is the movement of an object using its body as a frame of reference to imagine someone else's perspective. It can be found that the critical difference between mental rotation and spatial orientation is the frame of reference used to explain the situation, that is, whether the frame of reference is egocentric or object-centric. In other words, the difference between mental rotation and spatial orientation relates to the relationship between the observer and the subject being manipulated.

2.1.3 Spatial Visualization

Spatial visualization refers to the ability to mentally manipulate the shape of the whole space, imagine the rotation of objects, the folding or unfolding of planar patterns, and the relative change in the position of objects (McGee, 1979). Carroll and B (1993) believe that spatial visualization refers to the "understanding, encoding, and mental transformation of three-dimensional spatial forms." Smith (2001) defined spatial visualization as the ability to retain the topological and geometric relations of problems and solve multi-stage problems, mainly using mental imagery involving the appearance and structure of objects. Smith (2001) defines spatial visualization as the ability to retain the topological and geometric relations of problems and solve multi-stage problems using mental imagery, mainly related to objects' appearance and structure. In addition, it may also involve the reasoning of additional dimensions, language, and symbols. Dennis and Tapsfield (2013) believe that spatial visualization is a specific type of spatial thinking involving imagination to "generate, retain, retrieve and transform well-structured visual images." Spatial visualization is sometimes called "eyes in the head" thinking and consists of moving objects around the mind. It involves completing a series of mental transformations, which may require the retention of intermediates in memory. It also involves the psychological manipulation of entire spatial structures, which usually require many processing steps (Lowrie et al., 2020).

To summarize, spatial visualization is an inclusive term involving a series of spatial operations. Most researchers' definitions have something in common: they emphasize the relatively complex multi-step procedures that spatial visualization may require and the execution of a series of mental transformations. In other words, spatial visualization means "engaging in the complex, multi-step manipulation of spatial presented information." It involves the processes required for spatial perception and mental rotation. It is characterized by the availability of multiple solutions, emphasizing the need for multi-step analysis procedures to solve tasks.

Spatial visualization is one of the critical components of spatial ability, and it has been widely considered by researchers in engineering, mathematics, chemistry, and art design. As Rhoades (1981) mentioned, this ability, which creates and performs mental imagery, has great significance for the study of mathematics, geometry, physics, chemistry, and other disciplines, as well as for the performance of professional techniques such as medicine, architecture, machinery, engineering, and design. Devon et al. (1994) also pointed out that spatial visualization is essential in art and design due to its direct relation to design and pattern communication. The research of Gobert (1999) shows that in the performance of architectural design, spatial visualization ability is related to the acquisition, understanding, and development of the three-dimensional representation of architectural plane information, and it, with spatial orientation ability, will also have an impact on the extraction of high-level architectural knowledge. In human-computer interaction, the difference in spatial visualization ability enables some users to query and retrieve information more effectively. This difference does not mean that users with low spatial vision ability cannot find information, but the query speed is often slower. Therefore, spatial visualization ability is considered a weathervane for the future career success of students engaged in these fields and has good predictive validity for individual growth and future achievement.

2.2 Advances in Spatial Ability Research

The research on spatial ability originated from Western scholars' research on human intelligence in the early 20th century. Eliot and Smith (1983) believed that the research and development of spatial ability tests went through about four stages: The first stage (1904-1938) is the initial research stage of spatial ability, which focuses on psychometric research to determine whether there is a spatial factor on the general intelligence factor; The second stage (1938-1961) was the study of spatial ability elements. Researchers tried to determine the different degrees of elements of spatial ability from each other through psychometric research. The third stage (1961-1982) is the research of the origin and extension of spatial ability. Researchers sought to elucidate the state of spatial ability in the context of complex factors and interaction with other abilities and to examine sources of variation affecting spatial test performance. At this stage, researchers also focus on the psychological processes of various operations to explore possible ways to improve spatial ability. The period from 1982 to the present is the fourth stage. It is the research stage of integrating spatial ability and modern technology. Researchers focus on the impact of technology in measuring, investigating, and improving spatial abilities and turn to understanding spatial abilities from the perspective of information processing. Table 2.2 briefly introduces the research overview of each stage.

Table 2.2

Research Stages of Spatial Ability

Years	Item	Details
1904-1938 Initial research	Research works	1. Spearman (1961) published an intellectual theory work -- General Intelligence Objectively Determined and Measured. 2. Binet and Simon (1904) published the first intelligence scale.
	Methodology	After an experimental investigation of mental images, psychological tests separate spatial and general intelligence factors (Mohler, 2006).
	Conclusion	Independent spatial factors are established, and spatial ability is regarded as a skill separated from general intelligence elements.
1938-1961 Elements research	Research works	1. Researchers have conducted large-scale surveys focusing on the components of spatial ability and their differences. 2. Many new spatial tests based on pen and paper are produced.
	Methodology	Researchers have studied the spatial factors of spatial ability through psychometry and used various assessment methods to assess spatial ability.
	Conclusion	The researchers ultimately concluded that spatial ability is not a single skill. At the same time, researchers have developed more spatial testing tools, leading to a better understanding of the components of spatial ability.

Table 2.2 continued

1961-1982 Research on origin and extension	Research works	1. Werdelin and Stjernberg (1971) found gender differences between boys and girls in their ability to understand, organize, and reorganize visual structures 2. Piaget (2013) mainly focused on the development of spatial ability from childhood to adulthood, which makes the study of age-related differences in spatial ability become the focus of attention 3. Guilford (1967) proposed the "three-dimensional structure of intelligence model," Indicating that spatial ability is no longer viewed as a relevant factor but can be measured through tests with different combinations of operation, content, and output. 4. Monash University and Wattanawaha (1977) proposed the Dimension, Internalization, Presentation, and Thought Process (DIPT) classification system for space tasks.
	Methodology	This period focused on studying spatial cognitive problems, spatial ability development, and gender differences.
	Conclusion	The researchers elucidated the state of spatial ability, examined the sources of variation affecting spatial test performance, and explored possible ways to improve spatial ability.
1982-Present Integration of spatial ability and modern technology	Research works	1. Previous research themes continue to be focused 2. Focus on the impact of technology on measuring, investigating, and improving spatial ability. 3. It focuses on understanding spatial ability from the information processing perspective.
	Methodology	Researchers have focused on the impact of technology in measuring, investigating, and improving spatial ability and have turned to understanding spatial ability through the lens of information processing (Mohler, 2006).

The summary of the research status in each stage shows that spatial ability is a series of complex cognitive abilities. Each research content or method has uniquely contributed to promoting spatial ability research in different research stages. However, many disputes and problems still need to be solved.

Researchers have different views on whether and how spatial ability can be developed. Although some cognitive scientists believe that spatial ability cannot be improved, much research suggests that spatial ability can be enhanced through spatial activity and training. However, researchers disagree on what type of experience and how long it takes to improve spatial ability. Sexton (1992) pointed out that it is possible to improve spatial visualization ability if appropriate teaching and training time is sufficient. Braukmann and Pedras (1993) also showed that spatial visualization ability could significantly improve after 18 hours of engineering graphics teaching. Saito (1994) believes descriptive geometry and computer graphics courses can improve students' spatial skills. Field (1999) believes using sketches in the course can improve spatial visualization skills. Smith and Taveras (2005) said that visualization is a skill that can be learned, developed, and enhanced through appropriate guidance and corresponding methods. Eliot and Smith (1983) noted that although the idea of whether spatial ability can be trained in the classroom has not been tested, there is widespread support for the idea that work experience can improve spatial ability.

In addition to the above specific training approaches, McKim (1980), an American psychologist, put forward the training method of image thinking from the perspective of thinking training. In his opinion, Image thinking is carried out through three kinds of visual images (seeing, imaging, and drawing). One is “the images that people see,” the other one is “what we imagine through our mind,” and the third is “what we draw, doodle, or paint.” He also points out that experienced visual thinkers can use all three visual images flexibly and interactively.

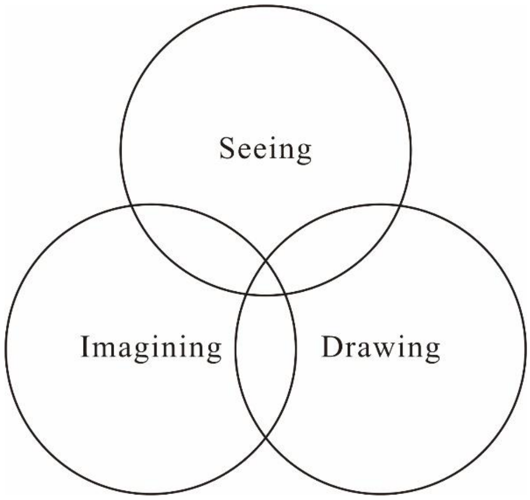

Figure 2.3. McKim image thinking model

Figure 2.3 shows the interaction of the three visual images. Among them, the optical image and the drawing image partly overlap, which reflects that the viewing can promote the construction, and the construction also strengthens the viewing. The drawing and imaging images partly overlap, reflecting that the construction can stimulate and encourage the imagination, and the imagination also provides the material for the construction. The imaging and the visual image partly overlap, reflecting that observation can provide the raw material for imagination, and imagination can provide targets for observation and filter the observed elements.

Based on the theory above, McKim (1980) suggested that image thinking training needs to consider how to effectively combine “Seeing,” “imaging,” “drawing,” and the correlation of the three to arouse learners’ intrinsic perception. In the “Creative Thinking training course” set up by Stanford University, he carried out the “imagination drawing” training, requiring students to see, think, and draw organically.

Therefore, to improve the spatial ability of art students, it is necessary to strengthen their training in image thinking.

2.3 Spatial Ability Measurement Classification

How to measure spatial ability has always been one of the research topics. The development of spatial ability measures has been accompanied by research on spatial ability. Over the past 100 years, teaching staff and researchers have developed various testing tools to assess the spatial ability of specific individuals. These tools have evolved from designed for experimental purposes to standardized testing. In 1983, Eliot and Smith published the "International Guide to Spatial Testing," which provides a basis for researchers to measure spatial ability. They systematically collected 392 pen-and-paper spatial ability tests from commercial and private sources and grouped them into 13 categories. Some are still used as a common reference standard for spatial ability tests.

According to their classification framework, these tests can be further divided into cognitive and manipulation task tests. Cognitive task tests include imitation, embedding graphics, visual memory, shape synthesis, and shape rotation, which can be regarded as tests of spatial orientation ability. The test of operation task includes building block calculation, building block rotation, origami, surface unfolding, perspective, etc., which can be regarded as the test of spatial visualization energy. The specific classification is shown in Table 2.3.

Table 2.3

Eliot and Smith Classification Framework for Single Task Spatial Ability Test

Cognitive tasks	Manipulation tasks
1. Imitation and maze tests	1. Block calculation test
2. Embedded graphics quiz	2. Block rotation test
3. Visual memory test	3. Paper folding test
4. Shape a comprehensive test	4. Surface development test
5. Figure rotation test	5. Fluoroscopy test

In art design related to education, the crucial components of spatial ability are mainly involved in mental rotation, spatial orientation, and spatial visualization. Therefore, this study analyzed the research and development status of the measuring methods of the above three factors and provided a reference for the follow-up selection and measurement of spatial ability in a teaching situation.

2.3.1 Measurement of Mental Rotation

Generally speaking, mental rotation is measured in two primary forms: chronometric mental rotation tasks (CMRT) and psychometric tests (PT). The CMRT is a computer-timed test that presents pairs of stimulus materials to the subject, usually at varying angles. Participants had to compare pairs of figures or objects as quickly and accurately as possible, and the performance of mental rotation (reaction time or error rate) was measured as participants mentally rotated to determine whether these pairs of figures or objects matched. PT is a paper-and-pencil test in which participants must solve a mental rotation task by taking a time-limited, multiple-choice test.

To effectively obtain the Mental Rotation level of learners, many psychological researchers have developed various types of scales to measure Mental Rotation ability, such as the Card Rotation Test (CRT), Mental Rotation Test (MRT), The Purdue Visualization of Rotations Test (PVRT). The following is a brief description of the various tests.

i. CRT

French et al. (1963) proposed the Card Rotation Test (CRT) using two-dimensional figures as a mental rotation test. The CRT requires the subject to determine from several presented graphs, which are rotated to be the same as the previously specified graph. The CRT, which measures an individual's ability to distinguish between images, is a six-minute, 112-item test that measures a two-dimensional figure's orientation and rotation. Each test item consists of one card to the left of the vertical line and eight cards to the right. In the test, given a two-dimensional card on the left, participants were asked to check whether the card on the right was the same (S) or different (D) from the card on the left.

ii. MRT

The MRT requires that participants compare pairs of figures or objects as quickly and accurately as possible and measure mental rotation's performance (reaction time or error rate) as participants mentally rotate to determine whether these pairs of figures or objects match.

The most typical example is the "three-dimensional cube" Mental Rotation Test developed by Shepard and Metzler (1971), also the most familiar example of CMRT. They developed a spatial pattern of 10 connected blocks in different directions, creating 1,600 pairs of these shapes. This is a spatially visualized pen-and-paper test. Each question consists of a familiar figure and four options to measure rotation, and the subject is asked to judge how long it takes. The experimental results show that the more degrees of rotation, the longer the reaction time. In Shepard and Metzler's (1971) experiments, the mental rotation test method was based on the accuracy and time spent on the mental rotation test.

In addition, Vandenberg and Kuse (1978) adapted the mental rotation test of 3D cube figures based on Shepard and Metzler's (1971) stimulus materials, the most widely used mental rotation paper-and-pencil test (PT). In this test, each figure is a two-dimensional rendering of one of five three-dimensional objects drawn by a computer and displayed on an oscilloscope. Each 3D cube is shown in a different direction. The test consists of 20 questions, each containing an authoritative figure (a three-dimensional figure made of 10 blocks), from which the subjects must judge the rotated figure of the authoritative figure. The mental rotation task required participants to choose the two correct choices from a list of four consistent with a familiar figure.

To distinguish the two MRT methods, the MRT developed by Shepard and Metzler (1971) is called SMRT, and the MRT created by Vandenberg and Kuse is called VMRT.

iii. PVRT

The PVRT test is similar to the MRT in that both tests require the mental manipulation of a mental representation of an object that is more identical to the manipulation of a three-dimensional object than the actual two-dimensional figure presented. However, PVRT differs from MRT in some ways. The object rotation in MRT is limited to the drawing plane or vertical axis running through the drawing. In contrast, the object rotation axis in PVRT corresponds to the natural axis of the object. In addition, MRT avoids the use of graphs containing hidden parts of singularities. At the same time, PVRT covers the features of hidden objects in perspective and the features of objects rotating around multiple axes.

Bodner and Guay (1997) developed the PVRT test, which uses multi-sided bodies as the content material of mental rotation. The test requires learners to be able to (1) study how the object in the top row of the question rotates and (2) Picture in their mind what the objects in the middle row would look like if they were rotated according to the same rotation rules; (3) Choose one of the five figures given in the bottom row (A, B, C, D or E) that looks like the middle object rotated in the correct position.

Overall, the mental rotation test is a spatial task involving imagining how objects might appear when rotated in two or three dimensions. The selection of measurement method of mental rotation also depends on the topic, content, and subject area of the study. For some study designs that measure individuals (e.g., precision timing studies closely related to experimental psychology, the field of psychology), CMRT may be more appropriate than PT. However, PT is more suitable for use in groups, and the effectiveness of this test is not easily affected by computer experience (Quaiser-Pohl et al., 2014).

2.3.2 Measurement of Spatial Orientation

For tests of spatial orientation, there are many typical test scales in the field of psychology. These scales include Guilford and Zimmerman's (1948) spatial orientation test, Kozhevnikov and Hegarty's (2001) spatial orientation test, etc.

Guilford and Zimmerman’s (1948) Spatial orientation test is a widely used spatial orientation test. The test asks learners to identify the location of a boat with a particular view. Participants were asked to note how the position of the bow in the second image changed from its original position in the first image. For each image, participants were asked to do the following: First, look at the top image and see the direction of the boat; Second, look at the bottom picture and notice the change in the direction of the bow; Finally, select and mark one of the five diagrams on the left to show how the ship is moving. Each chart is shown as a dot representing the old position of the bow and a dash representing the new position of the bow.

The spatial orientation test developed by Kozhevnikov and Hegarty (2001) presented participants with a two-dimensional queue of many target objects and asked them to imagine their specific orientation. Participants then indicated the poll of the target object in the queue from an imaginary perspective.

2.3.3 Measurement of Spatial Visualization

Many psychological experts have also explored ways to measure spatial visualization. Usually, the scales used to measure spatial visualization mainly include Witkin's (1971) Embedded Figure Test (EFT), the Paper Folding Test (PFT) proposed by French et al. (1963), the Surface Development test (SDT), etc.

The EFT measures the ability of individuals to find simple patterns from complex patterns. The test includes multiple complex graphics and simple graphics. According to the instructions, participants will depict the simple graphics contained in the complex graphics within the specified time.

The PFT requires participants to judge the position of these holes or marks after the origami is unfolded from the patterns with holes, truncated corners, or marks (Ekstrom & Harman, 1976). The tester observes the left side of the paper, which has been folded, and the corresponding punching position, then determines which of the five pictures on the right side is the expanded picture of the left image.

In the SDT, participants must imagine an unfolded planar figure and what three-dimensional objects will be formed by folding. At the same time, they must point out the letter edges of the folded three-dimensional objects corresponding to the numbered edges of the unfolded planar figure to determine which edges are the same.

To sum up, scholars have explored the measurement methods of each dimension from different perspectives. Table 2.4 summarizes the measurement methods of spatial ability component dimensions and provides a valuable reference for the measurement methods of spatial ability.

Table 2.4

Summary of Measurement Tools for Each Spatial Ability Component

Elements of Spatial Ability	**Test project**	**The specific way**	**The test content**
Mental rotation	SMRT	Object rotation	Determine which object is the same as a given object by imagining rotation.
	VMRT	Object rotation	Identify which object is the same as the depicted object when several objects rotate.
	CRT	Image rotation	Determine which two-dimensional picture is the same as a given picture by imagining rotation.
	PVRT	Object rotation	Identify which object is the same as the depicted object when several objects rotate.
Spatial orientation	Guilford & Zimmerman	Identify the change of direction of the ship	Notice how the position of the bow in the second picture changes from the original position in the first picture.
	Kozhevnikov & Hegarty	Methods to identify two-dimensional objects	Imagine your specific orientation in many 2D objects.
Spatial visualization	EFT	Inlay pattern	Find simple figures from complex figures.
	PFT	The paper folding	Predict the position where holes will appear on the punched paper after unfolding.
	SDT	Development of surface	Imagine how to fold the pattern into a given shape.

2.4 VR-based Immersive Learning Environment

2.4.1 The Characteristics of ILE

The learning environment built based on VR technology has the characteristics of immersion, interactivity, and imaginativeness. At the current level of technology, students mainly interact with information from the virtual world through multi-sensory channels of vision, hearing, and touch to obtain an immersive experience and sense of reality (Slater, 2017). In this study, we define an immersive learning environment (ILE) as the experience and feelings of students immersed in a virtual environment through a head-mounted display (HMD) (Limniou et al., 2008; Sharples et al., 2008). In ILE, students are rarely disturbed by the external environment, and their visual, auditory, and other senses are stripped from the real world, which provides convenience for deep immersion and experience in objective conditions.

Learners' interaction in ILE is divided into the following three parts:

i. Learner: as the interactive subject.

ii. Hardware: generally, head-mounted display, control handle, image accelerator of the host, processor, etc.

iii. Software: includes core, middleware, and user space, and hardware is used as the carrier to create an immersive learning environment.

Learners enter the learning environment through HMD and participate in the interactive process as active elements of the environment (Shudayfat & Alsalhi, 2023).

Learners consciously control handle hardware facilities, such as microphone input information such as gestures voice, and then through the processor to input information into the software part of the core space subsystem, repass middleware analysis, calculation and realization of gesture recognition, speech recognition, and learning environment, in the end, the learning environment to input information through relevant procedures for processing, with visual, listening sensory devices in the form of perception or touch are fed back to learners. Through brain thinking, learners can determine the meaning of feedback information and prepare for the following action to realize closed-loop interaction between learners and the environment.

The visual perception that ILE brings to learners is highlighted in two aspects: the borderless field of vision and the curved display space (Zhang et al., 2023). Learners turn their heads 360° to look around the learning environment and actively select the objects they are interested in. Line of sight guidance and comfort are the issues that need attention in ILE application and design. Visual comfort refers to learners' subjective experience when viewing objects in a virtual space (Yunitsyna & Toska, 2023). If the object is directly in front of the learner, it is easiest to produce visual comfort without looking up, overlooking, and strabismus (Wang et al., 2018). Head-up is the primary viewing mode in the virtual environment. The frequency of looking up and down is less than that of head-ups, and the comfort level of head-ups is 30 degrees above and below the horizontal line of sight (Wallmyr et al., 2018).

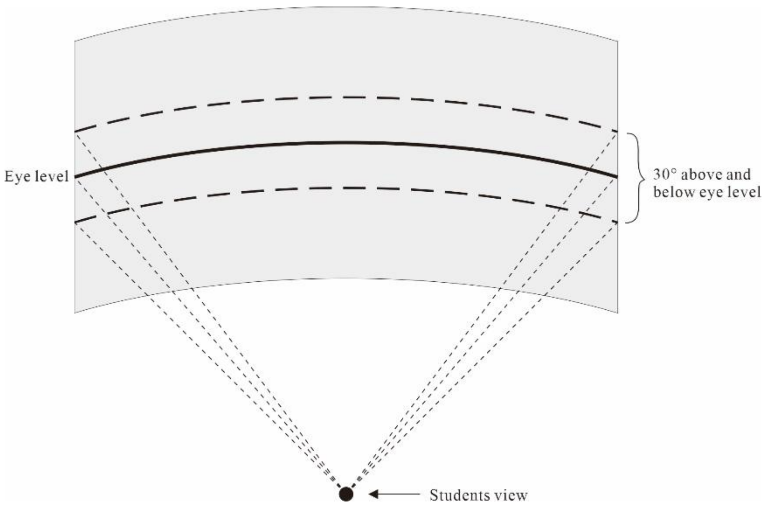

Figure 2.4. The comfort range of the Head-up area

As shown in Figure 2.4, in the arc field of view, the red line represents the horizontal line in the head-up view, and between the dashed lines is the comfort range of the head-up area. The learning content and things observed can be arranged in this area to generate visual comfort.

The following are the characteristics of ILE:

i. It shows learners an utterly virtual learning space; what they see and hear is the simulation and reproduction of the natural or imaginary world (Mulders et al., 2020; H. Huang et al., 2010).

ii. It provides deep immersion (Beck et al., 2020). Learners can look around the environment 360° by wearing head-mounted displays and other devices, and the presentation effect of virtual things is more realistic and natural.

iii. Multi-sensory integration and interaction between learners and the environment can be achieved by coordinating sensory channels such as vision, hearing, and touch. Learners have a strong sense of presence and integrate with the environment (Kovtoniuk et al., 2022; Sarafanuk, 2005).

iv. In the learning process, learners are always in a closed and immersive space. This vivid learning environment provides a new learning experience and plays an important role (Elmqaddem, 2019; Stavroulia & Lanitis, 2019).

2.4.2 The Role of ILE

ILE is a new type of virtual learning environment created by VR technology. Its main feature is the ability to create an immersive environment by providing a wider range and a higher degree of synthetic sensory stimulation (Daniel et al., 2006; Sherman and Craig, 2003), whose concept can be defined as a virtual learning environment with deep immersion and 360° panorama built based on VR technology, to serve teaching and learning, integrate multi-sensory channels such as sight, hearing and touch as one, with vivid situations and natural and efficient interaction ways, to support students to carry out a variety of learning activities to obtain a positive learning experience.

Immersion and interaction are frequently discussed in ILE, which realizes human-computer interaction through various interaction methods such as vision, voice, and gesture, thus bringing students a strong sense of immersion and improving their learning experience. Previous research has found that ILE has potential advantages in the field of art. ILE's role in the field of education and learning is manifested in the following aspects:

(i) ILE is conducive to improving students' academic ability and learning experience. The immersion and interactivity provided by ILE can promote students' visual presentation and mental rotation ability (Yeh. et al., 2013) and realise human-computer interaction through various interaction methods such as vision, voice, and gesture, thus bringing students a strong sense of immersion and improving their sense of embodiment. Ahmed Abdel Rahman (2021) enables students and teachers to carry out experiential learning in ILE, which enhances their creativity and productivity. Another study used ILE for arts education to achieve good results for students and teachers regarding immersion, interactivity, and imagination (Paatela-Nieminen, 2021). These results suggest that creating artistic design can benefit from using ILE.

(ii) ILE is conducive to expanding the learning space. ILE has no physical entity; it is a completely digital world, and all things are represented digitally (Sá & Serpa, 2023; Knox, 2022). All kinds of learning information of ILE are contained in the context, simulating, re-producing, and surpassing people's working, living, and learning environment. Visualisation is a prominent characteristic. Simulating various things can significantly expand the learning space and provide new cognitive ways and places for learning and teaching.

Figure 2.5. Virtual situation English learning scene

Figure 2.5 shows the English learning scenario in virtual situations, where learners are immersed in the virtual environment to stimulate their intrinsic motivation for language learning (Liu et al., 2016).

(iii) ILE can promote the occurrence of intuitive teaching and meaningful learning (Power et al.,2022). Intuitive and vivid displays can leave a deep visual memory and impression on students, which is conducive to meaningful learning. Using ILE to explore unknown areas can play an important supporting role in the learning environment, thus promoting the occurrence of meaningful learning (Van Schaik, et al., 2012).

Figure 2.6. The VR technique supports intuitive learning

Figure 2.6 shows the scene of learners learning human bone structure through the VR technique, which enables learners to understand more thoroughly, memorize more firmly, and learn more interesting (CWRU links. 2015).

(iv) ILE is conducive to creating new learning styles and teaching methods. Students will achieve the best learning effect When they devote themselves entirely to ILE and fully interact with it (Xu, 2018). The immersion of ILE is conducive to creating a new student-centred teaching model and carrying out virtual practical teaching and immersive teaching, etc. According to new research by Rong et al. (2022), introducing VR technology into art education can encourage students to engage in deep learning. Figure 2.7 shows an immersive teaching scenario in a VR classroom.

Figure 2.7. Immersive teaching scenario (originate from the author)

2.4.3 The Advantage of ILE for Spatial Ability Development

In recent years, researchers' research on VR has focused on an "immersive" experience, exploring the positive effect of an immersive learning environment (ILE) supported by VR on improving spatial ability. VR can be a potential tool and offer unique advantages to assess, train, and restore spatial abilities in individuals (e.g., navigation searching and cognitive rehabilitation). For example, the VR spatial rotation system was used to help individuals solve Shepard & Metzler's mental rotation task, which was also directly used in 3D mental rotation tests (Rizzo et al., 1998). Participants use an HMD or large screen, where they can be seen manipulating virtual 3D objects using interactive devices. Participants ' mental rotation performance improved after VR spatial rotation system training. Passig and Eden (2001) investigated using VR to train the mental rotation ability of deaf and hard-of-hearing children. The results showed that the training positively affected children's mental rotation. In addition, VR can also be used to enhance people's spatial behaviour in the real world, such as helping disabled children solve the difficulties of finding new environments. Alternatively, after exploring a 3D simulated environment (reconstruction), children with disabilities can acquire a considerable degree of spatial ability and perform spatial orientation in a natural environment (Foreman et al., 1997).

In addition to VR, other technologies such as augmented reality, pervasive computing, holography, and collaborative environments are also involved in studying spatial abilities. Although the research on these aspects is still limited, they have good application prospects, which can assist spatial learning and benefit students' learning motivation, social interaction, and collaboration. Therefore, the goal of using VR in education is to provide a more engaging, stimulating, and exciting learning experience for future students. Researchers want to see novel, immersive, sensory stimulating, and exploratory technologies that encourage students to move from passive to active learning, and virtual reality technology, in particular, can support the creation of collaborative learning environments.

2.4.4 The Application Status of ILE

In recent years, the application of VR in education has become more widespread, and many researchers have tried to apply VR in science, language, history, physics, mathematics, and other diverse disciplines. Moreover, created based on the VR immersion learning environment, it can improve students' engagement and presence, allow the empathy experience, has the ability of knowledge visualization, concrete to an abstract concept, can give learners can see and touch the three-dimensional image, promote cooperation and sharing, enhance learning motivation, promote a change of education ideas and modes (Zhang & Wu, 2018).

Education departments worldwide hope to play a role in the potential of VR, create ILE suitable for learning activities, and bring about changes in classrooms and teaching. Therefore, schools at all levels and of all kinds have conducted preliminary application and exploration and achieved specific experiences and results in ILE design and educational application. For example, Dominguez et al. (2020) believe that VR can be a powerful tool for training spatial capabilities.; The Washington Leadership Institute has used VR techniques to create an immersive virtual chemistry laboratory where learners can conduct virtual chemistry experiments using hazardous chemicals such as sulfuric acid and mercury without risk and at a meagre cost (Michael, 2019).

The application fields include English language teaching, medical simulation technology, safety education, physical training, etc. A critical supporting condition in language teaching is to create appropriate context. Visual and interactive context helps learners to master language application ability.

In English teaching, immersive VR can be used to build a variety of virtual environments and carry out a variety of task-based teachings, such as ordering food, asking for directions, buying tickets, etc., so that learners can communicate and learn in a realistic cultural environment, which is beneficial to the cultivation of learners' intercultural communicative competence, pragmatic competence and language competence (Lin & Yu, 2015);

In medical education, using immersive VR and force feedback technology, Pan (2017) constructed ILE for spinal surgery training. This environment is visually authentic and reliable, and the force tactile feedback is stable and rapid, which can accurately simulate the force tactile sensation of a bone drilling operation in actual surgery and effectively transform the training effect into the surgical experience.

In fire safety education, Rossler et al. (2019) mentioned that immersive VR technique-based simulation can realistically reproduce the fire scene by setting different points of view, such as observers, followers, or experience perspective. Learners will be able, as it were, to experience the dangers of fire and ruthlessness, to fully understand and master the knowledge of the fire escape.

Concerning physical education teaching, Gómez-García et al. (2018) used the lightweight immersive VR technique Krpano to construct the leisure sports teaching environment. The application practice showed that it could achieve better results in leisure sports teaching. To sum up, ILE can improve learners' understanding and knowledge mastery to a large extent.

Figure 2.8. ILE teaching application system

From the literature related to ILE application in education, "learning performance" and "motivation" are often studied in the articles. For example, Amri et al. explored the effectiveness of A 3D VR learning environment (3D-VRLE) on the learning performance and motivation of eighth-grade students in physics (Amri et al., 2020). The study results showed that students using 3D-VRLE significantly improved their learning performance in physics compared to the traditional learning environment. In addition, 3D-VRLE has a positive effect on physics learning motivation. Garzón et al. (2020) developed augmented ILE educational resources based on AR technology to promote ecological agrotourism and explored the impact of this method on learning performance and motivation.

The results show that the ILE educational resources based on AR have a moderate impact on learning benefits while significantly impacting knowledge retention and motivation. Bhagat et al. (2018) explored the effectiveness of using ILE's formative evaluation system to improve the learning performance and motivation of primary school students in the unit teaching about butterflies. The results show that ILE's formative assessment can effectively enhance students' learning performance and learning motivation compared with traditional formative assessment methods.

In addition, exploring learners' attitudes towards learning in the ILE has also received attention. For example, Cai et al. (2019) studied the influence of the ILE application based on VR technique on the attitude of high school students to use AR technology in mathematics learning. The research showed that students' willingness and attitude to learn in ILE were cheerful. Similarly, the survey results of Sahin and Yilmaz (2020) also found that learning materials developed using VR techniques positively impact learners' attitudes towards learning science courses and ILE applications.

2.5 Existing Conceptual Model for Immersive Learning Environment in Spatial Ability

The application of virtual reality technology in studying spatial ability is more scattered and distributed in disciplines such as machinery, civil engineering, art, mathematics, architecture, medicine, chemistry, geography, aerospace, and so on. An immersive learning environment with VR technology as the main means of learning is also widely used in the field of education. According to Osberg (1992), the positive impact of using virtual reality technology in an educational environment includes three aspects: (i) the similarity with the psychological process in the real environment, (ii) allowing students to control and interact with the learning object; (iii) Improve activity and learning motivation. Some researchers apply virtual reality technology to train students' spatial ability and focus on providing better technical support for spatial learning. The following is a summary of the virtual reality technology and immersive learning environment in the field of teaching and learning in some cases.

Mengshoel et al. (1996) developed an instructional software system composed of the Visual Sweeper and the Visual Teacher, cultivating students' visual reasoning ability by exploring the problem of missing views. This exploration requires students to apply the opposite step of orthogonal projection to solve a problem by creating a three-dimensional entity with two two-dimensional projections.

Contero et al. (2003) developed an instructional research tool called "CIGRO," which provides a model environment based on the incremental sketch, in which students can draw lines in the axonometric projection map, and the system can automatically optimize and connect the current drawing elements. Based on the axonometric inflation method, the line plot is transformed into a 3D model in real-time through reconstruction. The system implements smooth transitions between 2D sketches and 3D view visualization and also provides shadow views and normalized orthogonal projection diagrams.

Company et al. (2004) developed a teaching system called "REFER," in which students could hand apply a virtual pen and paper sketch. When the sketch was completed, the system automatically created a three-dimensional model that matched the previous sketch by clicking the function key. Students can also change the point of view to produce a shaded view or a normalized orthogonal projection. However, the system only accepts some polyhedral models conforming to geometric constraints, which has some limitations compared with commercial CAD applications.

Christou et al. (2007) developed a 3D dynamic geometry software to promote students' 3D geometry understanding and spatial thinking ability. Through the interaction with geometric objects, such as the folding, expansion, and construction of different geometric forms, students intuitively understand the relationship between two and three dimensions and the shape formation process. The primary purpose of this system application is to enable students to construct, observe, and manipulate objects in virtual space and to study the structural relationship of different objects. It can improve the spatial visualization ability of students through the process of building dynamic visual images.

Luh and Chen (2011) developed a perspective sketch training system to enable beginners to correctly express the spatial structure and perspective effect of the basic volume in the conceptual sketch stage. They argue that the design process is slowed down and deviates from the normal visual experience due to the misproportion caused by the incorrect spatial structure. Especially when the sketch is converted into an orthographic map, the weak spatial cognition makes learners face more expressive problems. Based on the drawing principle of two-point perspective, the system provides learners with correct feedback after drawing the cube so that students can find and improve the problems existing in the drawing in practice. The research shows that after a series of teaching practices, the students' accuracy of cube sketching is increased by 19%, and the learning effect and efficiency of teaching resources are improved.

Roca-González et al. (2016) studied the impact of AR and VR applications on college students' spatial skills. Students in the experimental group received AR training in the first week and VR games about maps and navigation in the second week. The results showed that the spatial ability scores of the experimental group increased significantly in all dimensions (spatial visualization, rotation, orientation). However, there was no significant change in the control group.

Gün and Atasoy (2017) investigated the effect of VR applications on students' spatial ability and learning performance. The study was designed around the course theme "Geometric Objects and Measuring Volumes" and was conducted by 88 sixth-grade students. The results showed that VR applications significantly improved the spatial ability of participants.

Molina-Carmona et al. (2018) designed VR learning activities to help students develop spatial abilities. The learning activity consists of an immersive virtual environment and presents simple polyhedral shapes that the learner manipulates by moving, rotating, and scaling. After four weeks of practice, the spatial visualization ability of the experimental group has significantly improved.

Chiu et al. (2024) developed DL-ALS(deep Learning-based art learning system) to overcome the obstacles of traditional teaching. This study conducted a group experiment on 46 art students, and the results showed that DL-ALS learning can effectively improve students' learning efficiency and art appreciation ability.

Table 2.5 describes the strengths and limitations of existing conceptual models of spatial ability. With the development of science and technology, the construction of ILE is being optimized step by step. The input of new technologies solves the shortcomings in previous cases and provides a better learning environment for developing spatial ability.

Table 2.5

The Strengths and Limitations of Existing Conceptual Models for Spatial Ability

Researchers	Name	Function and Strengths	Limitations
Mengshoel et al. (1996)	Visual Sweeper and visual teacher	Provide feedback to students on partial solutions to the missing view problem.	The calculations are rough, and several solutions may have equal or nearly equal matching values.
Contero et al., (2003)	CIGRO	Smooth transitions between 2D sketches and 3D view visualization are implemented, providing shadow views and normalized orthogonal projections.	Lack of immersion
Company et al., (2004)	REFER	Automatically create 3D models that match the previous sketches.	The system only accepts some polyhedral models that meet the geometric constraints and cannot perform complex calculations.
Christou, et al., (2007)	DALEST	Constructed a dynamic visual image.	It has not been used in practical teaching.
Luh and Chen. (2011)	CAI	The system provides students with the correct feedback after drawing the cube.	The system only provides a cube model and lacks the use of other geometric figures.
Roca-González et al. (2016)	Spatial Skill Test System	Transferred plane images to three-dimensional	The cognitive overload required by the application may affect students' concentration.
Gün and Atasoy (2017)	Geometric Objects and Measuring Volumes	Convert 2D graphics to 3D objects	The ability of the operator (teacher or student) to use the equipment is highly required.
Molina-Carmona et al. (2018)	Manipulating polyhedral blocks	Students' spatial abilities are trained by moving, rotating, and scaling polyhedral shapes.	The use of low-cost technology provides less immersion.
Chiu et al. (2024)	DL-ALS	After the students complete the work using the graphics software, the teacher can give real-time feedback on the students' work.	Lack of three-dimensional display effect

However, ILE still faces great historical opportunities and considerable challenges in the tide of education informatization. In terms of education, there is a lack of resources, a high threshold of design and development technology, and not easy to master. The teaching model and teaching evaluation are still in the exploratory stage, and there is no mature experience to learn from. From a technical point of view, further improving the portability of devices, the immersion of the environment, the naturalness of interaction, and the immersion experience of learners is still necessary. VR technique has been preliminarily applied to construct a learning environment. However, the difficulty of ILE application in education is in providing learners with a positive experience, which will affect whether the experience is profound or fundamental. Therefore, effectively improving learners' experience is one of the focuses of this paper.

2.6 Traditional Learning Mode and Immersive Learning Environment Mode

2.6.1 Spatial Ability Training Methods in Art Education

There are no special courses for developing spatial ability in art and design education. However, they are scattered in courses such as sketch, three-dimensional composition, display design basis, visual marketing, etc. From the analysis of training methods, sketch and effect drawing, computer-aided design, and 3D entity modelling are the primary means to make students master spatial knowledge theory and develop spatial ability. These methods play different roles in different stages of the design process and promote the development of students' spatial abilities to a certain extent. The main training methods are summarized as follows:

2.6.1.1 Sketch and Rendering Drawing

In art and design education, a sketch is a brief concept diagram drawn by freehand, which generally does not require in-depth depiction or is confined to the performance of details. In the design conception stage, students need to present the space layout in the form of sketches, which can be the overall layout diagram in perspective form. Plans and elevations can also be made based on the parallel projection method. As a standard expression mode in the early stage of creative work, hand-drawn sketch training aims not only to enable students to master the skills of drawing expression but also to develop spatial visualization ability to transfer design ideas and promote creative thinking in students (Avoti Lina et al., 2023). As Gedenryd (1998) points out, drawing the perimeter is fundamental to the cognitive process of design. The process reflects the designer's visualization thinking and analysis process. The designer presents the graphics on paper and other media through the abstract thinking activities of the brain and gradually refines and concretizes them so that the relevant practitioners can intuitively discover, analyze, and solve problems through visual graphics (Santos, 2020). Many shreds of evidence also show that sketch training is essential in developing spatial performance.

Figure 2.9. Sketching by students

Effect drawing refers to applying the perspective principle to simulate the spatial form of the object and realistic painting techniques in two-dimensional space to create three-dimensional visual effects (Haryanto & De Haan, 2022). Compared with the sketch, the effect drawing is usually a more complete and three-dimensional two-dimensional space picture to express and convey the design idea and can express the design intention more intuitively so that the concrete implementation and production of the process can be smooth and orderly achieve the expected design scheme, is an essential part of the design process (Venkatesh et al., 2021; Pieczara, 2020). Its function mainly embodies three aspects: (1) is used to convey the design principle and design connotation, reflects the design scheme of the artistic conception, as well as the space created by thought, and (2) in the form of three-dimensional visualization of colour, texture, and light and shadow rendering design content, intuitive performance design object space relation, space, atmosphere, make the project implement smoothly. (3) Directly recommend and introduce design intention to users, participate in project bidding, design competition, and other activities, and have a decisive role in demonstrating results.

Figure 2.10. Student's hand-drawn renderings

With the popularity of 3D Max, CAD, and other software, hand-painted renderings have gradually been replaced by digital storage-stained renderings. However, they are still an essential means of basic training.

2.6.1.2 Computer-aided Design

In addition to the freehand drawing of sketches and renderings, drawing spatial renderings using two-dimensional aided design software is also a standard training method. In practice, the pen input device is generally used to draw sketches directly on the computer. For instance, the Free2CAD system demonstrates how pen input can make CAD more accessible to novices by directly converting sketches into CAD commands (Li et al., 2022).

There are two main kinds of sketch drawing software commonly used. One is a dot-matrix drawing tool, such as Painter and Photoshop image processing software, which can produce a vivid sketch effect. However, the drawn image is a bitmap, which cannot be transformed into a vector map and used as a structural line for 3D modelling. It is only a reference map for 2D vision. However, these tools are instrumental in producing precise design outlines and facilitating workflows from concept sketches to final CAD models (Willis et al., 2021).

The other is vector graphics production tools, such as CorelDraw, Illustrator, etc. This commonly used software is not only used to draw design sketches and contour curves, structure lines, etc., but can also be converted into CDR. AI and other formats are directly used after input to CAD software. This method has explored combining 2D freehand sketches with CAD tools, emphasizing the critical role of freehand drawing in design cognition (Budiman et al., 2021). At the same time, this software can also output BMP, JPEG, and TIFF format bitmap.

However, it is still controversial whether training to draw plane sketches by computer can improve students' spatial ability. Some researchers believe that although two-dimensional design software is an essential tool for design, creation, and production, it lacks the education of three-dimensional thinking (Machuca et al., 2019).

With the increasing power of PC configuration and graphic design software, more and more students are using 3D Max and CAD software to create display scenes. Compared with hand-painted form, using the advantage of digital modelling not only can quickly create and modify 3D models but also can add texture, material objects, and lights, which produce high-quality still images or animation. Slag dyed after the image can conform to the physical characteristics of the actual effect, make the students and teachers more intuitively feel the visual impact of the exhibition space, and assess the layout and ambience of the space.

In addition to the realistic presentation of design ideas, 3D modelling software can, more importantly, use 3D entity modelling technology to strengthen students' ability to configure, analyze, and read 3D shapes to improve students' spatial visualization ability. This is mainly because 3D Max and CAD software can provide a three-dimensional environment for presenting objects. Smallman. et al. (2001) believe that users' interest in the 3D perspective view lies in its ability to convey the shape of complex objects in a natural and integrated way. It can also appear in the process of 2D and 3D graphics configuration engineering knowledge. The software provides the tools, line, face, body and stretching, lofting, chamfering, Boolean operations such as operations that can build complex 3D forms, help students to understand from the plane to the three-dimensional, from simple to the complex modelling process, training students' ability of fast imagine stereo space shape.

Figure 2.11. Student computer software renderings

In addition, software such as 3D Max and CAD can provide a variety of display modes of models, which is convenient for learners to observe the effects of models. For example, the wire-frame mode can simplify the creation of object structure and scene spatial effect and help students improve the concept of contour modelling and "stereoscopic." Therefore, 3D modelling software is a drawing tool that assists designers in spatial thinking.

2.6.1.3 3D Physical Model Making

The 3D physical model reduces the actual state of the display space in a relatively accurate proportion according to the design drawings and selects similar materials to show the overall conception of the display space and the method of segmentation and combination. This three-dimensional space representation method can make up for the limitations of drawing to a certain extent. However, as a model of presentation skills, it cannot wholly replace the design drawing. In art design education, model making can help students master the essential design content of space, get familiar with the spatial scale, proportion, form, structure, overall colour relationship, and visual effect, and help students gradually establish space awareness.

From the above analysis, it can be seen that the purpose of applying freehand drawing, computer-aided training method, or physical model making is mainly in two aspects: first, to enable students to have the ability to transform the design ideas in the brain into visual graphic language at any time; The second is to train students' spatial expression and spatial transformation ability. In graphically expressing ideas, students should pay attention to the size, proportion, size of objects, spatial relationship between objects, and transform between the plane and three-dimensional or three-dimensional graphics.

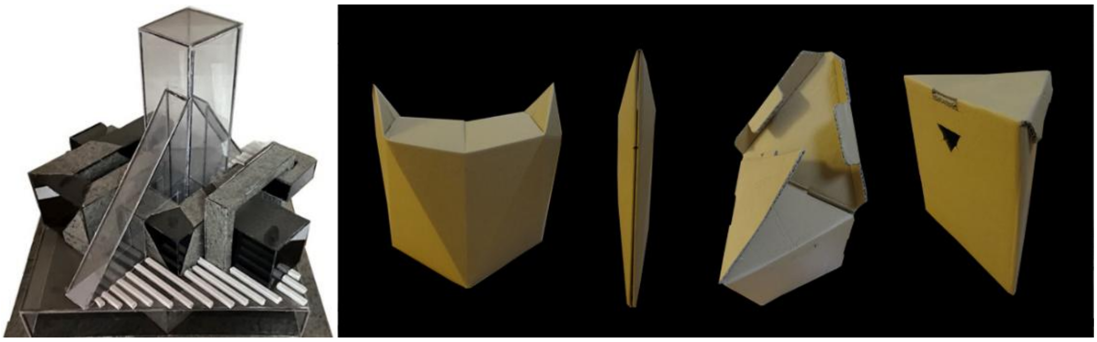

Figure 2.12. Students make product models

2.6.2 The Traditional Learning Model of Spatial Ability

i. The Learning Mode is Closely Linked with the Teaching Model

In the current learning mode of art design courses, teachers generally dominate the learning content, learning time, and learning schedule (Zheng, 2022). For example, in the link of theme design, teachers set one or several creative themes in advance and require students to complete the corresponding effect plan according to the design theme and requirements. In the concrete implementation process, the teacher explains the theme meaning or concept conveyed by the design theme and guides the students to design and create through case analysis. The students complete the specified learning content according to the requirements.

ii. The Learning Mode is Closely Linked to the Textbook

Learning materials assist students in designing, creating, and mastering spatial knowledge (Ridha et al., 2020). Currently, textbooks and design magazines are the primary sources for art students to learn related expertise in the classroom teaching environment. Their content and form are relatively single and limited. Although students can also use network resources to consult relevant knowledge and information, online self-directed learning lacks supervision. Moreover, it is necessary to provide learning resources matching spatial knowledge and the ability to cultivate spatial ability. Generally, the network resources based on text and pictures are complex to improve learners' spatial ability.

iii. The Learning Mode is Closely Related to Knowledge Structure and Critical Points

In the classroom teaching environment, students' learning is closely related to unit knowledge and structure, and they learn through unit knowledge points. However, in the design and creation activities, students generally need to be involved in many aspects of knowledge, such as training in modelling artistic works (Tsui et al., 2023). Students must be guided by the principle of perspective to express the modelling accurately. Although some students have good modelling ability, the expression is inaccurate because they have not mastered the principle of perspective. The content of the unit knowledge does not necessarily solve the relevant concepts or principles involved in the current problem.

iv. The Learning Mode is Simple, and the Feedback is Simple

Teachers mainly study art design according to the teaching units, and the knowledge is transmitted to students through the demonstration of teaching media (Yang, 2024). Students carry out design exercises according to the learning tasks assigned by teachers. In the learning process, teachers assist and guide students in completing the learning tasks and supervise the whole process of learning activities. A linear learning mode dominates the learning process. Teachers are active teachers, teaching media are demonstration tools to assist teachers in teaching, and students are the objects of knowledge imparting and passive recipients of external stimuli.

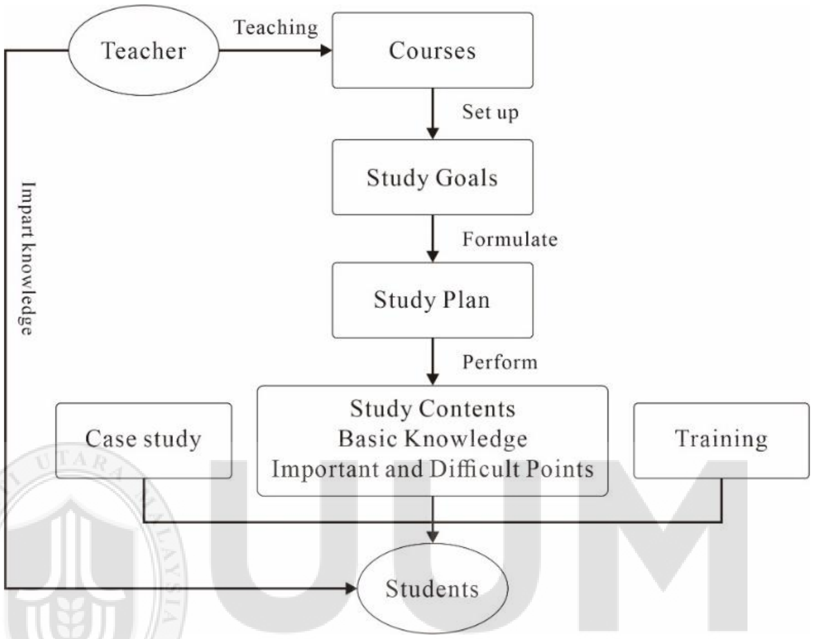

Figure 2.13. The learning model in the traditional classroom environment

Figure 2.13 summarizes the learning model of students in a traditional classroom teaching environment, reflecting the interaction sequence and relationship among teachers, students, and learning content.

In the traditional learning model, the cultivation of spatial ability is mainly through teaching methods such as explanation and drawing training so that students can acquire "how to read pictures" and "how to draw pictures." From the analysis of the current teaching status of spatial ability in art and design courses, although most students have excellent spatial ability or their interest in spatial knowledge and their acceptance of relevant knowledge may be more potent than students of other majors, there are still differences in spatial ability among them (Palmiero & Srinivasan, 2015). Moreover, some teachers point out that although a student with good spatial ability faces fewer difficulties in learning 3D design software and creating 3D models, he may not be a good designer. Therefore, there is still a need to improve their spatial performance through related courses and training to enhance their professional competitiveness.

According to the current teaching status and learning model of developing students' spatial ability, the traditional spatial ability learning model mainly has the following characteristics:

i. In the traditional learning model, teachers show teaching units to students according to the teaching plan. These teaching units include content, questions, cases, exercises, etc. Learners' learning content is related to their knowledge domain.

ii. Teachers carry out teaching activities using strategies, present knowledge and respond to students' behaviours.

iii. Students obtain the content of course units according to the learning plan made by teachers, and the learning content of students is related to the order of teaching knowledge points and plans.

iv. The traditional learning model emphasizes the structure of professional knowledge. Teaching is mainly implemented in two stages: one is content planning, which makes clear the concept and order of learning according to teaching objectives and students' characteristics; The second is the implementation of the plan, the learning of each concept according to the situation of students to determine a series of teaching behaviour.

v. The traditional learning model is based on the objective learning model, which is based on the origin of knowledge and how to obtain it. Students' knowledge construction comes from their own correct or incorrect knowledge in a major.

2.6.3 Immersive Learning Environment Model for Spatial Ability Development

The development of spatial ability generally refers to the representation of spatial information, which reflects spatial concepts such as the size, shape and orientation of objects and spatial relationships in the human brain. The emergence and development of ILE enable school education to use a virtual 3D learning environment as a research tool, and spatial creation means bringing students into a realistic 3D environment, which significantly promotes the convenience of spatial ability development.

3D images are more effective in measuring spatial skills (Huk, 2006). However, the 3D virtual learning environment created by ILE has a strong sense of space, realistic 3D effect, and fascinating immersion, which makes it easy to arouse students' spatial awareness, promote the generation of spatial experience and three-dimensional feeling, and create favourable conditions for the development of spatial ability.

Ghani et al. (1994) believe immersion enables people to concentrate on learning without external interference. ILE has a strong sense of immersion because it can genuinely simulate objects, scenes or real-world phenomena and render graphics with realistic visual effects. Through immersive experience and perception of the existence of space in ILE, students generate spatial consciousness and cause spatial control behaviour, thus improving spatial ability.

ILE built on VR is very different from the traditional 2D learning environment. It can enhance students' sense of participation and presence, allow empathic experience, visualise concretely abstract concepts, provide learners with three-dimensional images that can be viewed and touched, promote collaboration and sharing, and enhance learning motivation. To encourage the change of educational concepts and models.

Each object in ILE has a position and direction and can be moved, rotated, scaled, etc., which makes it convenient for students to construct complex scene effects in 3D space and evaluate the aesthetic characteristics of the design. In particular, the rotation function can assist students in observing the shape of 3D objects, feeling the performance of colours and materials in an all-around way, and deciding how to present the processed information or whether it has been well presented. According to Sweller et al. (2011), if various information resources are integrated as required, working memory will be reduced, thus reducing students' cognitive load and improving learning efficiency.

To sum up, the immersive learning environment for spatial ability development can be summarized as follows: a learning environment that aims at developing spatial ability takes virtual reality technology as the medium, combines experiential learning theory, and integrates students, learning situations, learning contents, and learning activities. Its characteristics include:

i. The construction of professional knowledge is obtained from the learning context rather than the structural knowledge. Therefore, this learning model focuses more on the perspective and interpretation related to the knowledge construction in the learning process. The learning opportunities are derived from the provided context rather than based on teaching.

ii. Learning is mainly the interaction between students and ILE, “learning by doing.” Teachers guide students’ interaction and knowledge construction. This process mainly emphasizes students’ behaviour, cognitive structure, and interaction between students and ILE.

iii. In the ILE model, the learning process not only focuses on knowledge acquisition but also on knowledge construction. In this model, students complete knowledge construction through interaction with ILE under the support and guidance of teachers.

iv. The learning order in the ILE model is determined by the interaction between students and the 3D virtual environment, which depends on comprehensive factors such as students' opportunities in the interactive environment and previous experience.

v. The role of teaching strategy is not to determine teaching events but to provide students with the possibility of interaction.

2.6.4 Comparative Analysis of Traditional Learning Mode and ILE Mode

Compared with the traditional learning mode, the innovation of the ILE mode is mainly reflected in the following four aspects:

i. The ILE mode emphasizes the student-centred teaching concept, and its teaching process pays more attention to the characteristics of students, the environment, and the interactive relationship between students and the three-dimensional virtual environment (Raykova et al., 2023).

ii. In the ILE mode, the role of the teacher is changed to that of a guide and supporter of learning. The role of the teacher is mainly to create a problem-based situation for students and provide support for students to analyze and solve problems (Suryani et al., 2024).

iii. Students in the ILE mode acquire and construct knowledge mainly through interacting with the environment. Compared with the traditional learning model, it can better explain how students construct knowledge based on problems in terms of cognitive state, interactive characteristics, and interactive state (Schott et al., 2024).

iv. The ILE mode is more extensive and flexible than the traditional learning model in terms of learning, and it is more suitable for a 3D virtual environment in which to carry out learning (Deniz & Alıcı, 2024).

According to the characteristics of the two learning modes mentioned above, Table 2.6 summarizes the differences between the two learning modes in terms of the theoretical basis and learning basis.

Table 2.6

Comparison Between the Traditional Learning Mode and the ILE Mode

Items \ Learning mode	**Traditional mode**	**ILE mode**
Basic Theory	Theory of objectivism	Theory of constructivism
Learning Foundation	Structured knowledge	Construct knowledge situation
Sources of Learning Opportunities	Teaching strategy	Learning situations
Learning Feedback Characteristics	Unidirectional, non-real-time	Interactive, real-time
Role of students	Passive to accept	Take the initiative to constitute
Students Tasks	Accept knowledge	Construct knowledge
Role of Teachers	Teach knowledge	Support to explore
Teachers Tasks	Carry out teaching activities according to the teaching plan	provide a possibility for interactive learning
Learning Evaluation Object	Learning result	Learning process

2.7 ILE Construction

2.7.1 Elements of Immersive Learning Environment Design

The practical design of a learning environment requires scientific overall planning and planning of its constituent elements and clarifying the relationship between each element. ILE requires that the design process be centred around conducive to experience, and the design results should meet experiential learning needs. Therefore, ILE oriented to spatial ability development should pay attention to the construction of four elements: student (WHO), learning situation (WHERE), learning activity (HOW), and learning content (WHAT), to promote the generation of positive learning motivation.

2.7.1.1 students' individual characteristics

In the ILE design process, students play a significant core role (Kim and Irizarry, 2021). Because everything is designed to develop students' spatial abilities (Dowker, 2019), before the course, students should first have a basic understanding of their prior background, such as their gender, age, style preference, prior knowledge background, spatial ability foundation background, familiarity with virtual reality technology, and acceptance of virtual reality technology in the classroom. Then, the avatar and perspective of students in ILE are designed reasonably and effectively to enhance students' sense of identity with the learning environment, promote the generation of deep immersion, enhance students' experience and feelings, and enhance students' learning motivation and interest.

2.7.1.2 Learning Situations

Learning situation refers to the environment or context in which learning occurs and is influenced by external factors that affect the sustainability of internal activities (Asvio, 2017). Specifically, a learning situation can be any real or simulated environment that helps students understand, experience, and explore knowledge (Isba & Walsh. 2013). Its core is to set the learning content in a real or simulated specific environment so that students can learn and apply knowledge and skills in this environment.

Hamilton et al. (2021) believe learning situations are important for developing spatial ability. Whether students can get good learning performance is directly related to the problem. Natural and perceptible situations can improve students' learning motivation and learning experience and provide solid material guarantees for the development of contextualized learning (Zhang et al., 2020).

Effective learning situations should have a degree of suspense or activity to stimulate students' curiosity and desire to explore, attract their attention, and encourage them to participate actively in the learning process (Xiao et al., 2023). At the same time, the process of creating learning situations also needs to consider the individual differences and developmental stages of students to ensure that the situation is practical and effective (Tan et al., 2023).

Therefore, the ILE learning mode attaches great importance to the initiative of students, participatory and intuitive feeling, and experience through specific experiences and activities to master the knowledge and skills. Its significance lies in the current school education in the shared knowledge and skills with the real world, learning to such problems as contextualization, provide significant reference value. Because the ILE learning mode has the advantages of episodic memory, emotional memory, semantic memory, etc., it is very conducive to retaining and retrieving memory, which is conducive to learning.

Each situation can be concretized into different scenarios, the basic units that make up the situation, and the learning environment. The scene refers to various three-dimensional panoramic pictures presented to students visually, which is an essential part of ILE. Different scenarios form the same scenario, forming the learning environment. Figure 2.14 shows the relationship between scenarios and ILE.

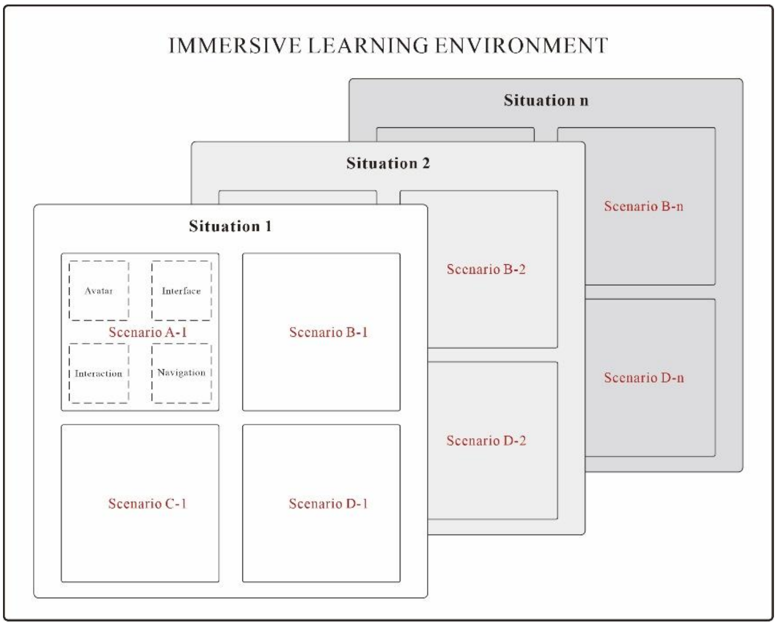

Figure 2.14. Relationship between situation and scenario

2.7.1.3 Learning Activities

Learning activities are a series of behaviours and tasks that students perform during the teaching process, designed to help them acquire new knowledge and skills or enhance their existing knowledge and skills (Khurma et al., 2022). These activities usually involve language practice, which can be observed, perceived, and experienced. Learning activities include not only the process of the activity but also its result (Mertha & Mahfud, 2022). This is because learning is a relatively consistent process of change in an individual's behaviour or behavioural potential acquired through experience. In other words, in learning activities, students should not only participate but also think and understand what they have learned to achieve the goal of learning (Wekerle et al., 2020).

In addition, the former Soviet psychologists Leontiev, Gariperin, and Tarykina put forward the "activity theory," which emphasizes the comprehensively of learning activities and holds that learning is "the activity of transmitting - mastering social, cultural and historical experience, which transforms external to internal." This means that students should absorb knowledge in the activities process and internalize it to make it their ability and quality (Winiharti & Chairiyani, 2018).

In general, learning activity is a kind of active participation of students in the teaching process, which is the process of obtaining their knowledge needs and changing the external environment (Pranoto & Suprayogi, 2021).

2.7.1.4 Learning Content

Learning content refers to information, materials, resources, and pedagogical elements provided to students to facilitate the acquisition of knowledge, skills, or understanding in an educational setting (Al-Samarraie et al., 2013; Chen & Chen, 2022). It includes a wide range of materials and resources designed to support the learning goals and outcomes of a course, training program, or educational module (Faridi et al., 2020).

Selecting appropriate learning content is the key to cultivating students' spatial ability, which can be achieved through learning content in learning activities (Wang et al., 2020; Connolly, 2009). First, select the learning content that can be developed into an immersive curriculum based on the features of virtual reality technology. For example, the macro world (such as the universe, stars, mountains, rivers, and seas); Microscopic domains (e.g., molecular and atomic structures); Some historical events that have occurred in the past (e.g., the destruction of the Old Summer Palace); Restricted content in the real world (e.g., body construction, weapon construction); As well as those that change quickly and are difficult to detect (such as physical and chemical changes), these learning contents can be used as school courses or operational courses to train professional skills.

On this basis, the learning content that can integrate the development elements of spatial ability is further selected, for example, making geometric figures, model making, 3D printing, 3D object design, map learning, etc.

Therefore, the learning content should also have a certain epochal and forward-looking. The design and selection of learning content should consider students' age, gender, interests, learning ability, and other factors to meet the needs of social and individual development.

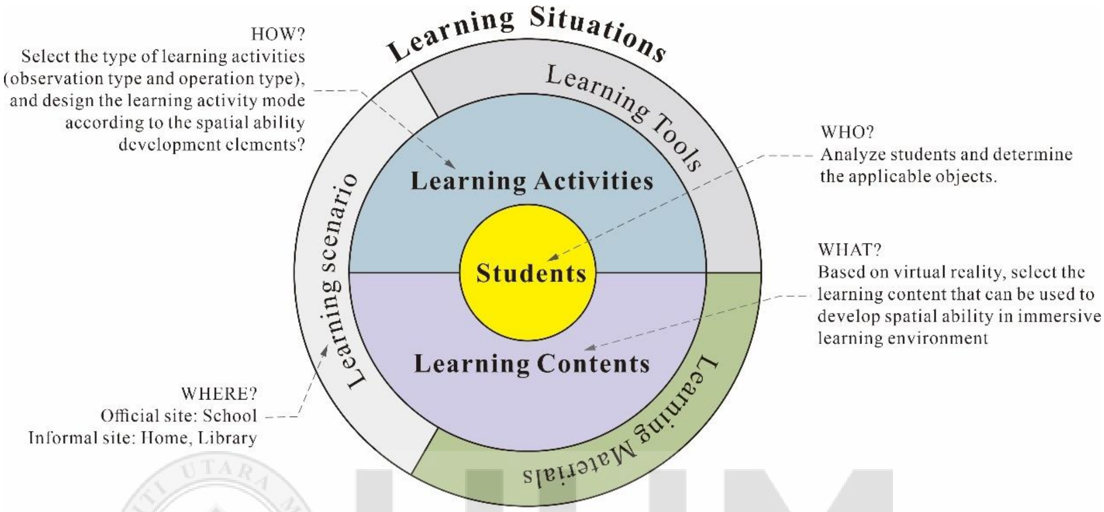

Figure 2.15. ILE components and their relationships

To sum up, Figure 2.15 shows the relationship between the four elements in ILE design: Students are the core of learning, and the development of spatial ability can be achieved by using learning content to carry out learning activities in the learning context. This relationship also provides the basis for constructing the ILE model.

2.7.2 Design Process and Framework

Based on the theoretical basis of constructivism, cognitive conformity theory, and experiential learning theory mentioned above, as well as the relationship between ILE design elements, the learning process of spatial ability can be summarized as follows: students learn spatial ability and its elements (learning content) in the learning situation, and the learning activity process is related to the experiential learning theory. Through four learning stages, the elements of spatial ability are systematically learned. Therefore, this paper proposes the following design ideas and methods:

2.7.2.1 Design Process

ILE needs continuous improvement, finding and solving problems in the use process and gradually improving its functions with the help of design-based research methods. Design-based research methods need to find a breakthrough to solve problems in practice, characterized by measuring the value of educational intervention based on students' experience. The design process includes iteration, design, implementation, and redesign, which has certain practicability, intervention, iteration, and integration (Wang et al., 2018). The design-based research method is used to gradually improve the experience function of the environment through continuous iterative design. In the gradual iteration process, the virtual environment's immersion and interactivity are improved, and various situations required for learning under ILE mode are realized.

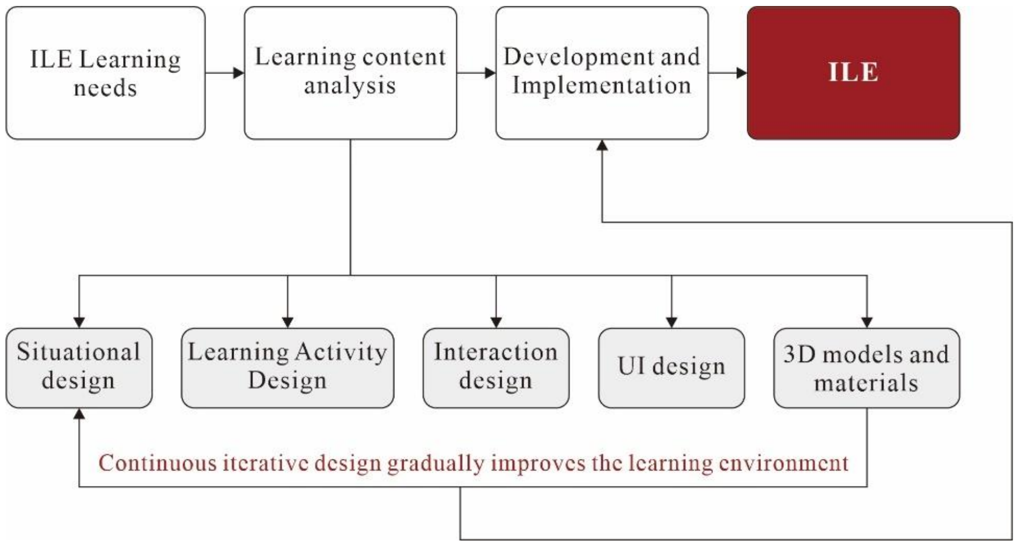

Figure 2.16. The design process of ILE

Figure 2.16 shows the ILE design process. First of all, analyze the ILE learning needs. Then, the learning content of visual thinking method analysis, turning it into specific situations, and types of learning activity design, interaction, interface, 3D model, and material, adopting the method of design iteration process each link design and prototype environment, gradually improve its functionality, finally realizes the ILE.

2.7.2.2 Design the Learning Situation

Learning situation is the basic unit of ILE. This design combines the four stages of experiential learning. It divides the situation design into four steps: "existing experience situation," "reflection observation situation," "concept formation situation," and "active verification situation," respectively. At the same time, necessary auxiliary tools such as cognition, cooperation, and communication are provided for each situation. Students can enter the situation in order or randomly enter a situation to carry out learning, as shown in Figure 2.17.

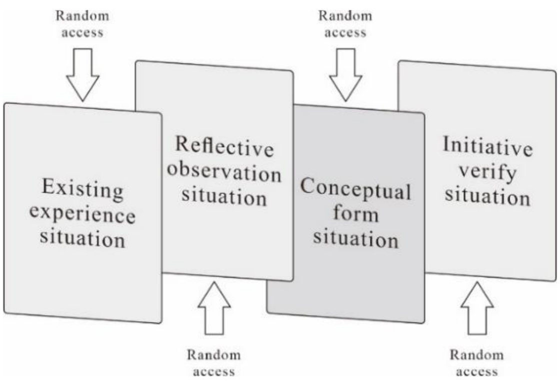

Figure 2.17. Four situations of ILE

The designed situation enables students to discover problems in the exploration process, generate problems, propose hypotheses, and obtain various resources to support them in solving real problems. It can provide other rich examples and similar problems for students to conceptualize and transfer.

2.7.2.3 Design Learning Activities

Generally speaking, activities are the efforts and actions of the subject for a specific goal. The design of learning activities should consider learning subjects, activity objectives, activity content, activity tasks, activity organization, activity rules, and other elements (Li et al., 2013). Only by organizing these elements reasonably can we carry out learning activities effectively. ILE learning activities should be based on relevant learning theories, fully consider the objectives, tasks, and other elements, and support different learning stages. The experiential learning theory divides learning into four stages: existing experience, observation and reflection, abstract concept, and active verification of concept in a new situation. The related learning activities can also be decomposed into four corresponding types: existing experience, observation and reflection, abstraction and conceptualization, and active detection. According to the abstract degree of students' experience, the order from concrete to abstract forms different activity stages: design specific tasks and goals for each activity phase.

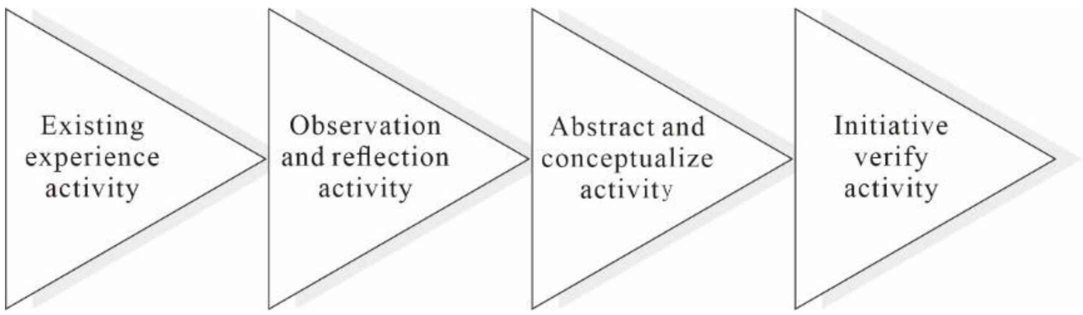

Figure 2.18. Learning activity design

According to the relevant guidance and help, students can explore the environment, investigate the structure of things, and master the operation rules according to the design steps, which is conducive to completing learning tasks and improves learning motivation and effectiveness. For example, when students master the operation method of virtual machining machine tools, they can clearly understand the equipment's structure, composition, and operation method through the combination of voice, indicator arrow, and text. According to the instructions for operating the virtual machine tools, after completing a particular operation, give the corresponding feedback results and guidance information for the next step until the students complete the operation task and obtain a positive experience.

2.8 Evaluation of Learning Performance

Learning performance assessment mainly includes spatial cognitive engagement and spatial ability improvement.

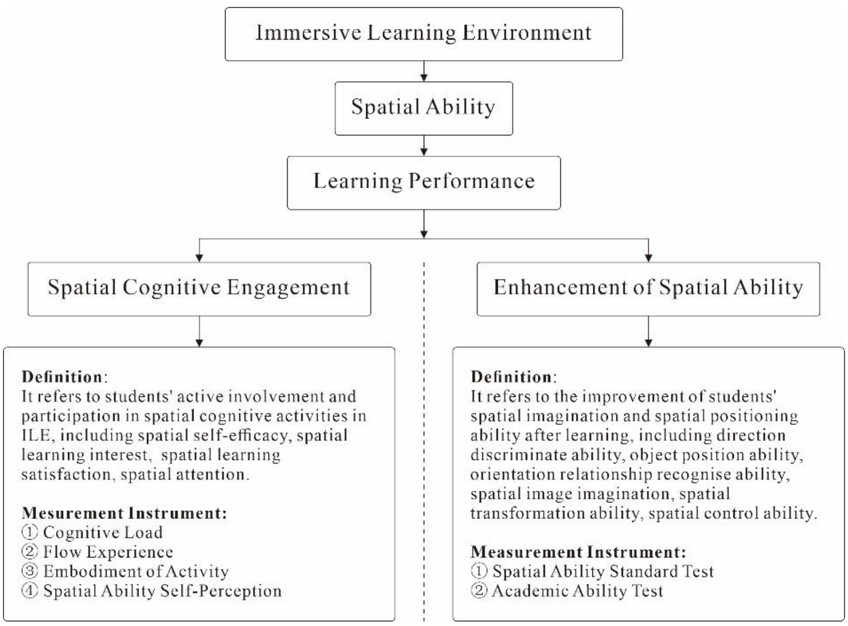

Figure 2.19. Evaluation of learning performance

Figure 2.19 shows the process and content of the assessment of learning performance. Students learn spatial ability in ILE and evaluate their learning performance to verify the effectiveness of the ILE model in cultivating students' spatial ability.

2.8.1 Spatial Cognitive Engagement

Spatial cognitive engagement refers to students' active involvement and participation in spatial mental activities in ILE (Krukar & Dalton, 2020). Spatial cognitive participation, such as interaction and learning duration, can be measured objectively and investigated subjectively. The measurement methods include cognitive load, flow experience, activity embodiment, and spatial ability self-perception. Learners in learning participation and involvement have the most experience and speak. Spatial cognitive engagement can reflect learners' learning behaviour and learning process to a large extent, and its specific indicators are as follows:

i. Spatial self-efficacy

Reflect students' confidence level in completing spatial learning tasks. In ILE, self-efficacy can improve the expectation of spatial cognition and help students complete spatial cognitive tasks.

ii. Interest in spatial learning

Spatial learning interest can reflect students' learning involvement and participation in ILE, and it is an essential indicator of learning involvement.

iii. Spatial learning satisfaction

Spatial learning satisfaction reflects students' satisfaction with the learning process and results of spatial cognition, which can explain the effect of spatial awareness to a large extent.

iv. Spatial attention:

It indicates the concentration degree of students in ILE and whether they focus on learning content in a virtual space.

2.8.2 Enhancement of Spatial Ability

Improving spatial ability refers to advancing students' spatial imagination and spatial positioning ability after learning. The specific measurement includes spatial ability standardized tests and academic ability tests. Spatial cognitive ability is a skill; the ability improvement is reflected in the following indicators.

i. Direction discrimination ability

It mainly refers to the accuracy of students' orientation identification in ILE. The direction of east, west, south, and north can be inferred according to the recommendations suggested in the environment.

ii. Object localization ability

In addition, students should be able to quickly discover the location of virtual objects and accurately locate the area.

iii. Identification ability of azimuth relation

In ILE, students can clearly define the position relationship between objects, such as the relationship between objects, front, back, left, and right.

iv. Spatial image imagination

Students can imagine the overall image of the space and the location of each virtual object, which requires imagination and visual thinking.

v. Spatial conversion ability

It is a kind of mental rotation ability, a continuous spatial transformation cognitive ability, which enables learners to imagine the shape of objects after rotation at a certain Angle. For example, after viewing a three-dimensional skull model, students can imagine how the model would look if rotated at an Angle.

vii. Spatial control ability

In ILE, according to learning requirements, students have proficiency in manipulating objects in displacement and rotation and other spatial control abilities.

2.9 Summary

By sorting out the conceptual definition and development process of spatial ability, this chapter finds that the study of spatial ability has experienced a development process based on theoretical development, psychological measurement and evaluation, gender difference research, and the impact of technology on spatial ability, which indicates that spatial ability, as a component of individual intelligence or skill elements, has received much attention from researchers. Mental rotation, spatial orientation, and spatial visualization are the core elements of art students' development of spatial ability. Then, this study discusses the characteristics and functions of an immersive learning environment based on VR. By analyzing the research results of existing teaching methods on spatial ability training, it is found that the ILE mode has certain advantages in developing spatial ability. However, there is relatively little research on art education, and some practical cases are lacking. Finally, this study summarised the innovation points by comparing the ILE mode with the traditional learning mode. It sorted out the operation mode and learning evaluation points of the ILE mode. It provided indicators for demonstrating the advantages of developing the spatial ability of the ILE.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter describes the ways to achieve the goal of this study. Based on the in-depth analysis of the relevant literature on spatial ability, immersive learning environment, and their relationship, this study analyzes the advantages of immersive learning environments in promoting spatial ability development. It extracts the key factors affecting spatial ability development in the school education environment and constructs a conceptual model. Then, the model is applied to teaching cases, and empirical research is carried out to verify the effect of an immersive learning environment oriented to spatial ability development by evaluating students' learning performance. Finally, the research conclusion is drawn.

3.1 Research Roadmap

This study collected, identified, and sorted out the current research status of spatial ability and immersive learning environments by literature review. It summarized the relevant research to grasp its theoretical basis and focus. Then, summarizing the definition and components of spatial energy provides the basis for constructing an immersive learning environment and empirical research design for spatial ability development. For the literature review, the content analysis method is used to analyze and summarize the current published literature on the application of immersive technology in education and spatial ability in the immersive technology environment.

The design-based research method has attracted researchers' attention in the field of education, which focuses on the design of an effective learning environment and adopts the "gradual improvement" method to realize both theoretical and practical development (Han & Wang, 2021). From the experience perspective, this study adopted the design-based research method combined with the characteristics of VR to design the ILE conceptual model oriented to spatial ability and develop the corresponding teaching cases.

Finally, this study conducted experimental research on ILE learning evaluation, measured and calculated the results of spatial ability development, and further discussed the educational value of spatial ability in an immersive virtual environment.

Therefore, this study is divided into three phases. The first phase is the theoretical part, which includes “Identify Problem & Motivation” and “Proposed Solution”. This stage identifies the problem domain and provides the corresponding solution. The second phase is the empirical part, which includes “Design & Develop Conceptual Model,” “Experimental Tools Development,” “Expert Review,” and “Pilot Test.” In this stage, a conceptual model is designed and developed for the solution proposed in the first phase, and experts are invited to verify it. The pilot test verified the usability of the VR prototype and questionnaires. The third phase is the evaluation part, which includes “Experiment” and “Evidence.” By setting up the control group and the experimental group, this study analyzed the changes in spatial ability, academic ability, cognitive load, flow experience and activity embodiment of students in different learning environments, and verified the effectiveness of ILE in developing students' spatial ability. The specific research roadmap is shown in Figure 3.1.

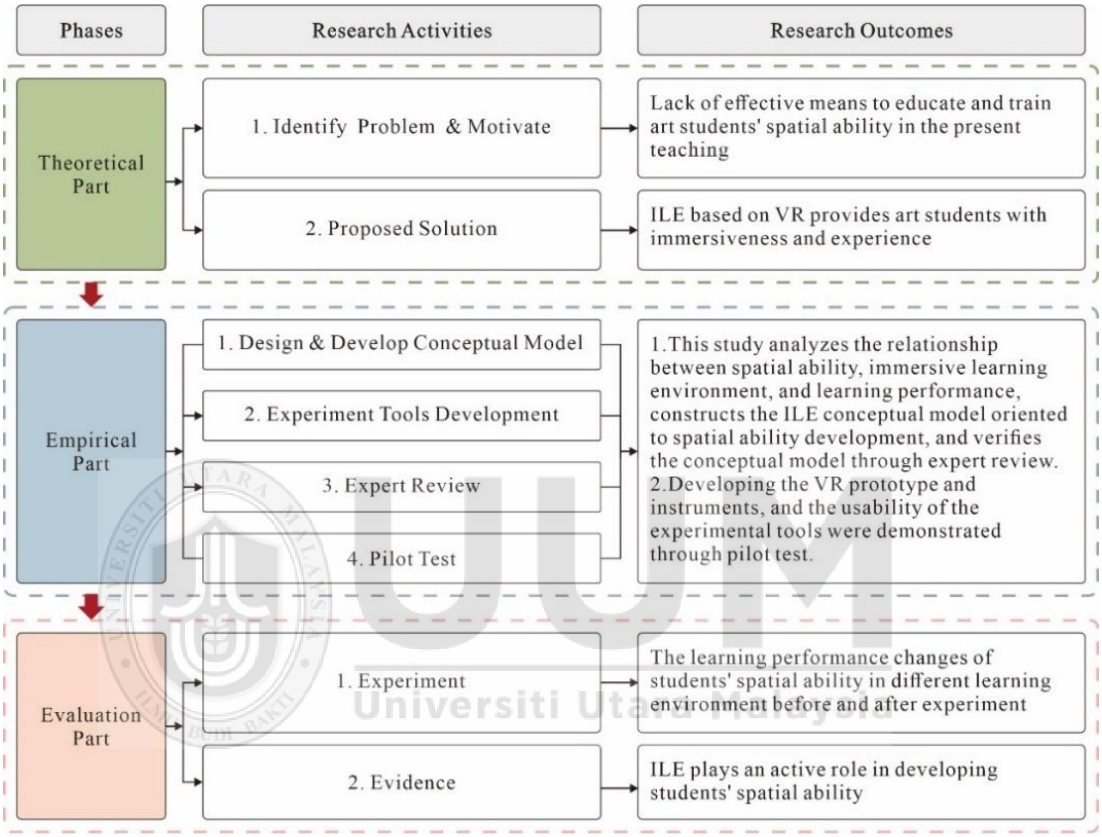

Figure 3.1. Research roadmap

The theoretical part (phase 1) has already been discussed in Chapters 1 and 2, and the ideas provide theoretical support for this chapter. The empirical part (phase 2) is covered in this chapter, while the results, evaluation, and conclusion (phase 3) are covered in subsequent chapters.

3.1.1 Phase 1: Theoretical Part

The theoretical part includes "Identify Problem & Motivation" and "Proposed solutions". This stage identifies the problem domain and provides the corresponding solution.

3.1.1.1 Part One: Identify Problem & Motivation

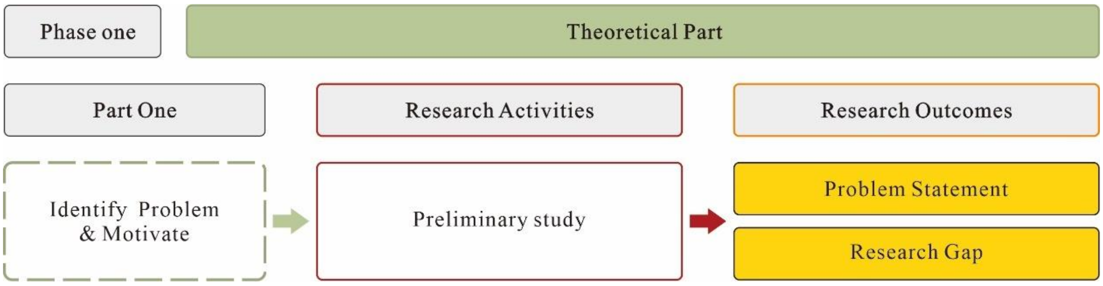

Figure 3.2. Problem identification

Figure 3.2 describes the specific contents of part one in phase one, including the identified problems and motivations, gaps, research scope, and goals. By referring to relevant literature, this study sorted out the problems existing in the current teaching of spatial ability, the existing achievements and the limitations of conditions, etc., and further reviewed the relevant information and accumulated all the knowledge to understand the process in this field. The search includes a variety of online resources such as books, conference proceedings, journals, articles, and web pages.

The problem statement of this study is taken from the literature review. We conducted a preliminary study to determine students' and teachers' perceptions and requirements of traditional ways of teaching spatial ability for learning. The study surveyed 437 first-year students majoring in art and asked students questions about VR (Appendix A) to identify their previous experiences. The results found that 92.47% of students want to experience 3D or immersive environments, and 89.88% are interested in adding VR technology to the classroom and are willing to try it.

Although VR technology has gradually been applied to education, it has not been established in professional art courses, especially fully through a course. The core of art design is creativity, through practical operation, to form visual works to cultivate students' creativity in an all-round way. However, in current art education, the primary learning materials are the theoretical and practical textbooks the Ministry of Education in China provides, namely 2D texts, images, and videos. This single teaching method is limited by time, space, materials, and equipment, which limits students' thinking to a large extent and inhibits the occurrence of creativity.

By reviewing the literature on VR and ILE in existing courses and education based on VR technology, this study determined the research problems, research gaps, and research scope. This study also collected relevant data on students' views on applying VR technology and ILE model teaching in the curriculum. The research was carried out among art students at a university in Chongqing, China.

3.1.1.2 Part Two: Proposed Solution

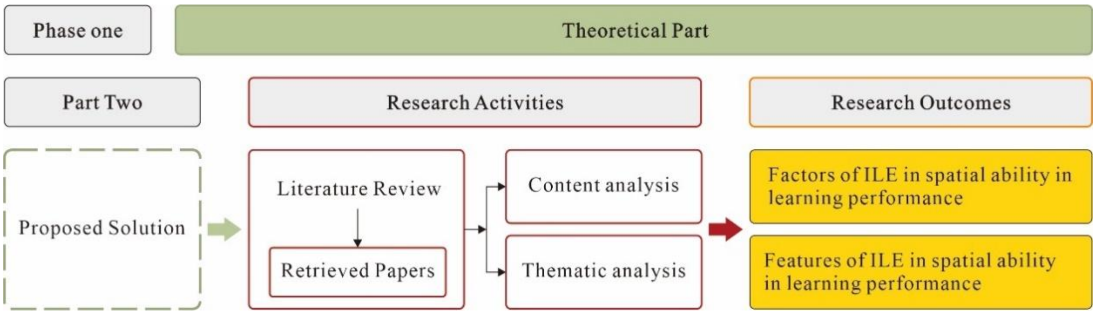

Figure 3.3. Proposed solution

Figure 3.3 shows the solution proposed in Part 2 to the problem identified in Part 1, supported by preliminary research. The results of the first part of the study confirmed the absence of the ILE conceptual model in the cultivation of spatial ability. Therefore, this study conducts a literature review of articles from the past 5-10 years and uses content analysis and thematic analysis as research methods to identify the factors and features of ILE affecting students' learning performance in art course teaching. The factors of ILE in spatial ability in learning performance include learning situation, learning activity and learning content. The features of ILE in spatial ability in learning performance include the user interface, learning scenario, materials, and tools. This part is discussed in detail in Chapter 2.

3.1.2 Phase 2: Empirical Part

Based on the problems and research gaps identified in the theoretical part and proposed solutions, the empirical part (phase 2) developed and designed the ILE conceptual model and invited experts to verify it. Then, the research developed VR prototypes and instruments and verified their usability through a pilot test.

3.1.2.1 Part One: Design and Develop the Conceptual Model

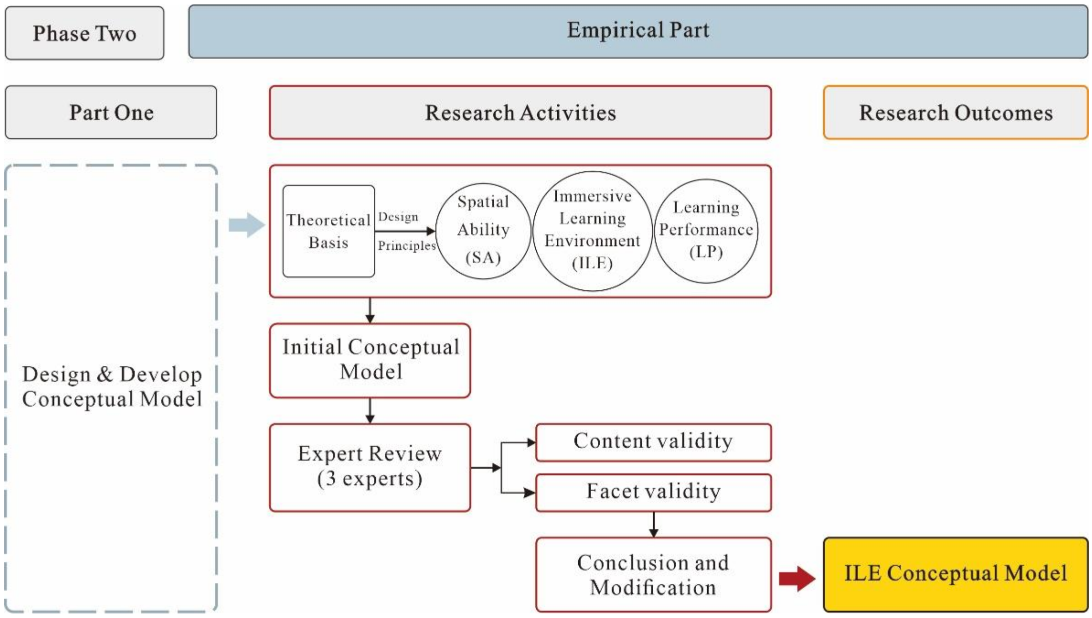

Figure 3.4. Design and develop the conceptual model

Figure 3.4 depicts the design and development conceptual model process and the number of experts and users involved in the design and development process. Joy (2013) describes conceptual models as graphical portrayals that "show the core components of their respective systems and the theorized relationships between them, " meaning that the conceptual model visualizes the flow of applications supported by tables and graphical symbols. By analyzing the relationship between spatial ability, immersive learning environment and learning performance, this study forms a conceptual model of an immersive learning environment oriented to spatial ability development. The comprehensive details of this conceptual model are discussed in Chapter 4.

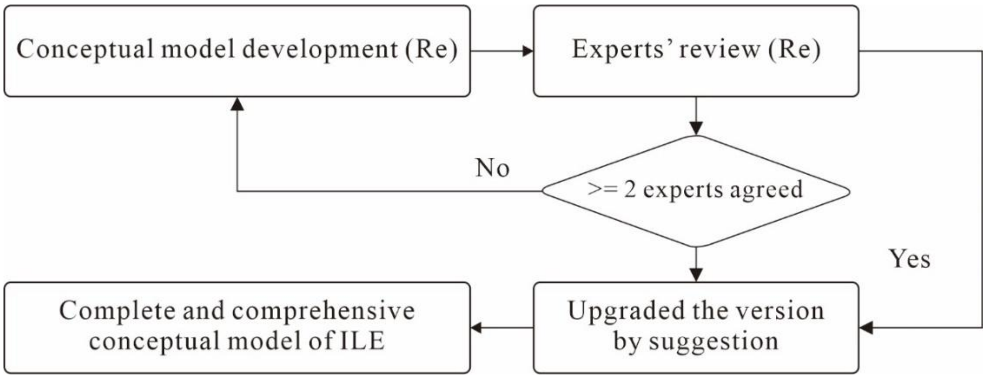

Figure 3.5. The repetition process in the conceptual model development stage

As shown in Figure 3.5, the model development process goes through a repetitive process to verify the validity of the proposed ILE conceptual model. The process begins with developing an initial conceptual model based on a literature review output and existing models, followed by an expert review of the conceptual model. The specific expert review process and feedback are described in detail in Section 4.5.

The process is repeated between the development phase and the expert review assessment phase until saturation is reached and a conceptual model of an immersive learning environment (ILE) for spatial ability development is finalized. This process aims to obtain valuable and critical feedback that helps improve the validity and robustness of the proposed conceptual model. The researchers analyzed the experts' feedback and made changes based on their comments. The ILE conceptual model aims to design and develop a practical and helpful model for art students and to provide appropriate guidance for developing spatial abilities. At the same time, this serves as an example for those who want to design and build projects or those who wish to take this concept to the next level.

3.1.2.2 Part Two: Experiment Tools Development

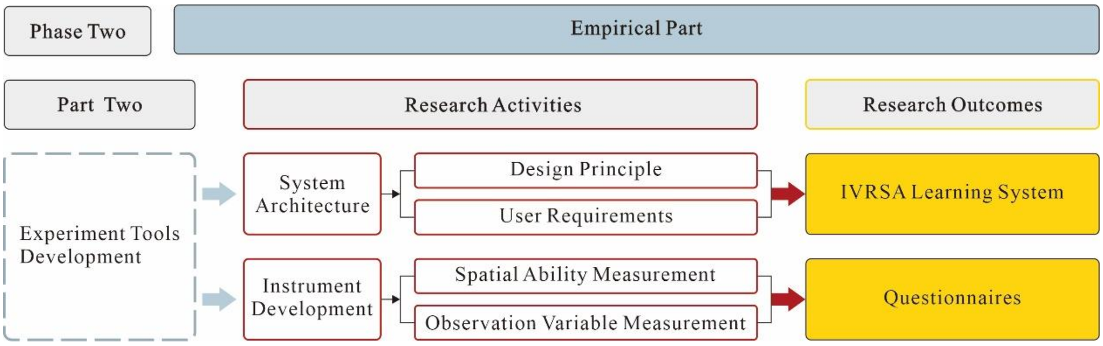

Figure 3.6. Experiment tools development

Figure 3.6 illustrates the process and content of experimental tool development. VR prototype development uses VR development technology to build virtual learning spaces that include learning scenarios, tools, materials, etc. VR prototype proves that VR technology can produce a relatively high degree of visual realism. The whole development process of the VR prototype adopts typical VR development technology, and the development of content files, including composition theory and VR equipment information, adopts multimedia production technology. The immersive virtual reality spatial ability (IVRSA) learning system is designed and developed according to the design principle by analyzing user requirements. The developed questionnaires included a spatial ability standard test, academic ability test, spatial ability self-statement report, cognitive load scale, flow experience Scale and activity embodiment scale. The specific development process of VR prototypes is discussed in detail in Section 3.2.

In this study, spatial ability is the core element. In order to obtain a more comprehensive and complete understanding of spatial ability for art students, this study adopted the data collection method of "data triangulation mutual verification" to verify the impact of an immersive learning environment on spatial ability. The observed variables came from students' learning performance. Based on the analysis of existing test questionnaires and the content of this subject, a questionnaire for the "Composing Foundation" course is formed to analyze the changes in students' spatial ability, academic ability, self-perception, cognitive load, flow experience and activity embodiment before and after learning. The specific questionnaire development process and contents are discussed in detail in Section 3.3.

3.1.2.3 Part Three: Expert Review

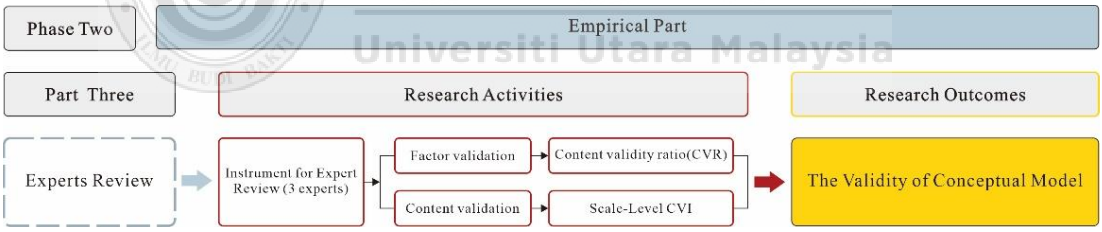

Figure 3.7. The process of expert review

The expert review validated the factors influencing the development of spatial ability. Factor validation is based on the content validity ratio (CVR), and the findings are reported. Figure 3.7 shows the process of expert review, including factor and content validation, which mainly measures the validity of the item and scale. The steps and contents of the expert review are discussed in depth in Section 3.4.

3.1.2.4 Part Four: Pilot Test

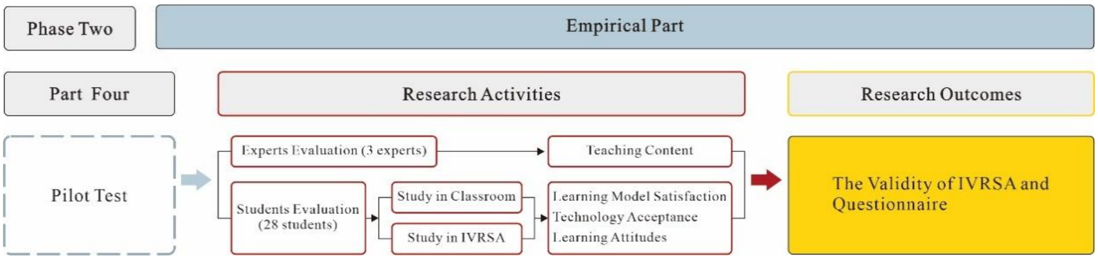

Figure 3.8. Process of the pilot test

Figure 3.8 shows the pilot test process, which includes expert evaluation of the contents of the IVRSA learning system, as well as students' experience and feelings after learning spatial ability in ILE mode and traditional mode. The Pilot test aims to verify and evaluate the effectiveness of the IVRSA learning system and questionnaire and to gather feedback throughout the evaluation process. The steps and contents of the pilot test are discussed in Section 3.5, and the results are detailed in Section 5.1

3.1.3 Phase 3: Evaluation part

The third and final phase includes the "Experiment" and "Evidence." This study verifies the effectiveness of ILE in developing students' spatial ability by analyzing the changes in spatial ability, academic ability, cognitive load, flow experience, and activity embodiment in different learning environments.

3.1.3.1 Part One: Experiment

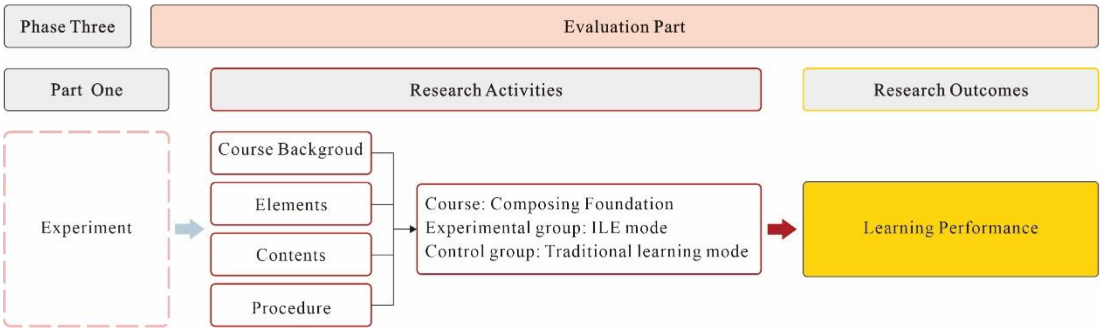

Figure 3.9. The process of experiment

Figure 3.9 describes the application and demonstration process of the VR prototype in the ILE conceptual model. Students use the VR prototype to learn spatial ability in ILE and evaluate whether ILE has advantages in cultivating spatial ability through learning performance feedback. According to the characteristics of art education, this study selected specific courses, purposefully sampled test subjects, combined with the IVRSA learning system to form teaching content, and finally observed students' learning performance through group teaching.

Given the above ideas, this study adopts mixed methods to carry out experiments, including quantitative and qualitative methods.

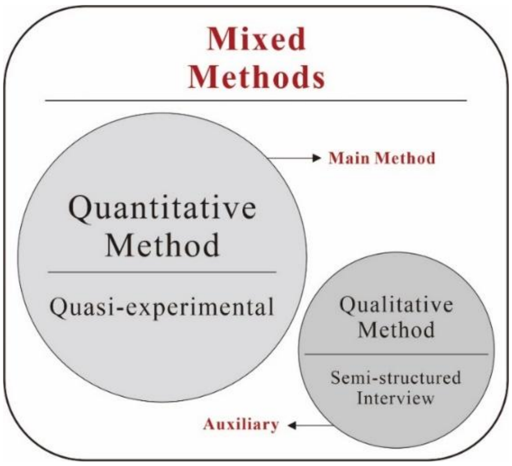

Figure 3.10. Mixed methods

As shown in Figure 3.10, the quantitative method is tested through quasi-experimental research, collecting data on students' spatial learning ability in ILE and traditional classrooms and conducting the qualitative method through semi-structured interviews to obtain students' psychological feedback on spatial learning.

The independent variable of this study is the immersive learning environment, the dependent variable is the spatial ability (including mental rotation, spatial orientation, and spatial visualization) and academic ability, and the observed variable is students' spatial ability self-perception, cognitive load, flow experience, and activity embodiment after learning the "Composing Foundation" course. The research design was as follows: Before the teaching began, all students were randomly divided into experimental and control groups according to the class. Before the beginning of the course, all the classes were pre-tested, and then the course "Composing Foundation" was taught. Among them, the experimental group learned the course knowledge in an immersive learning environment, while the control group adopted the traditional classroom teaching style and learned the same course content. At the end of the course, all groups of students were given a post-test. Finally, students in the experimental group were selected for semi-structured interviews to explain and support the quantitative research results from the qualitative research perspective. The content and process of the experiment are specifically discussed in section 3.6.

3.1.3.2 Part Two: Evidence

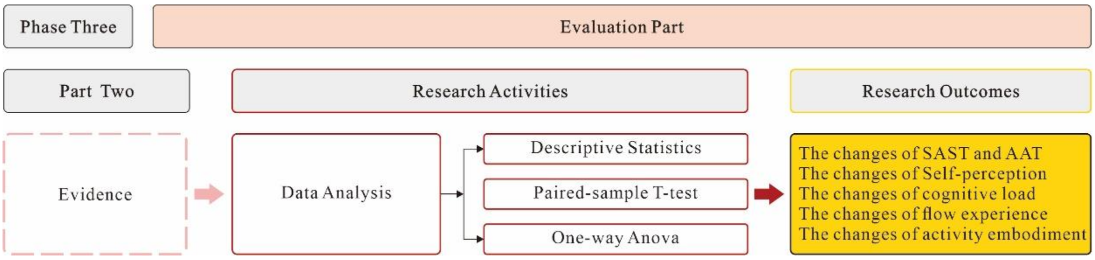

Figure 3.11. Evidence

The Evidence part analyses the test data and discusses the research results (Figure 3.11): students use the VR prototype to learn spatial ability in ILE and evaluate whether ILE has an advantage in developing spatial ability through the feedback of learning performance. Students carried out spatial ability learning in traditional learning mode and the ILE model, respectively, and completed the questionnaire developed in this study. IBM SPSS 23 software was used for variance and correlation analysis. The methods of data collection and analysis are discussed in Section 3.7, and the detailed analysis and results are discussed in Chapter 5.

3.2 VR Prototype Construction

In this study, we developed an IVRSA learning system. The IVRSA is an e-learning application created by combining virtual reality and multimedia technology, such as model combination, decomposition, reconstruction, colour matching, and other real-time interactive exercises, which is an innovative tool for cultivating and training art students' spatial ability. The development process includes storyboard development, floor plans, 3D modelling, optimization models, texture mapping and lighting, rendering and animation, and virtual reality scripting. The application utilizes 3D models in a virtual space to generate non-interactive and interactive visualizations.

3.2.1 Design Principle

i. IVRSA should focus on the authenticity of learning situations

Context is one of the supporting conditions for experiential learning and the basic unit of IVRSA. The real and sensible situation provides a solid organizational guarantee for improving students' experience and developing contextualized learning. According to the experiential learning model and theory, design the experience situation, the reflection situation, the concept formation situation and the detection situation, as well as the corresponding specific scenes, to create a real, vivid, dynamic, three-dimensional panoramic picture and increase the sense of the reality of the situation.

The production of positive experience depends on the concrete perceptual process of students' experience and participation in the situation and scene. The authenticity and three-dimensional characteristics of the situation can stimulate learning enthusiasm, encourage the students to devote themselves to the learning environment and facilitate the continuous development of learning activities. Especially in generating spatial experience, it is necessary to build a virtual three-dimensional situation so that students can perceive space, generate corresponding consciousness, trigger spatial operation behaviour, and promote spatial learning and ability development.

ii. IVRSA should focus on the naturalness of interaction

The naturalness of interaction can lead to the generation of positive experiences and improve the efficiency of interaction between people and the learning environment. Various natural interaction methods should be actively adopted, such as control handles, spatial positioning, position tracking, voice interaction, etc., to integrate their functions into the learning environment, and students can flexibly choose and use them according to their needs and learning hobbies.

The typical interaction mode of IVRSA is to use the ray interaction generated by the control handle. Objects can be selected remotely through the handle ray to achieve accurate selection and function stimulation, and the current position can be moved instantaneously in the virtual space to improve the roaming efficiency of three-dimensional space and enhance students' perception of three-dimensional space. Spatial positioning and position tracking interaction allow students to move freely within a certain space, and its natural interaction mode is very close to the daily behaviour mode. By overcoming the limitations of sitting posture and fixed position, students can participate in physical and mental learning activities and further promote the generation of experience.

iii. IVRSA should focus on the decomposition of learning activities and the design of help information

According to the experiential learning model, IVRSA should decompose learning activities into experiential activities, reflective activities, concept-forming activities, and other stages, as well as design specific tasks and goals for each stage of activities. Under the guidance of the experience goal, it ensures that students can complete various tasks step by step and enhance the process experience of learning activities to promote their successful completion.

To enhance the learning experience, in addition to breaking down learning activities into specific tasks, some guidance and help should be designed to assist learners in completing the tasks. The types of help information include task instructions, path guides, and operation guides. The help information should be integrated and designed as voice, text, and graphic help information. Especially in exploration learning activities, providing necessary help information and operation instructions can improve the learning experience, reduce students' loss of three-dimensional space, reduce cognitive load, and help them focus on learning content.

iv. IVRSA should focus on the construction of 3D space

Three-dimensional space is one of the important features of immersive IVRSA, which can enhance the authenticity of the learning environment. When designing the relevant learning environment, students should be shown its three-dimensional characteristics as much as possible, and a three-dimensional panoramic space should be built to enhance students' sense of identity and affinity for the environment and promote the generation of learners' positive experiences.

The construction of three-dimensional space creates convenient conditions for spatial learning, and students can see the panoramic picture effect through the head-mounted display, which is conducive to generating an immersive experience. Three-dimensional space can create a profound and three-dimensional situation for students, promote the formation of spatial awareness, and make them feel the environment is real and credible and the learning process is closer to the real environment. When creating three-dimensional space, reasonable navigation methods and avatars should also be designed according to needs to facilitate students' roaming and movement and enhance social interaction experience and spatial ability.

In a word, the design of IVRSA should build a realistic three-dimensional learning environment and space, allowing students to integrate into the virtual environment to feel, experience, and operate to their heart's content, reflecting the authenticity, interactivity, and three-dimensional characteristics of the environment, and providing appropriate learning activities, which facilitate the development of investigational learning, observational learning, and other learning styles.

3.2.2 User Requirements

Before the development of the application, the study surveyed 437 first-year students majoring in art about their situation, including questions such as "Have they used VR-related software or devices," "How do you feel about using 3D or immersive environments," "What do you think about using VR technology in the classroom," and so on. Appendix A shows all the items in the questionnaire. By collecting questionnaires and statistics, this study found that 92.47% of students want to experience 3D or immersive environments, and 89.88% are interested in adding VR technology to the classroom and are willing to try it.

The study also involved a series of discussions with VR program development professionals on possible user needs. The following are the suggestions of experts for VR prototypes:

i. Add some functions to enhance students' interest, such as adding complex shapes, enriching operation tools, or increasing the introduction of VR equipment and the interaction of using methods.

ii. The vision system of the VR prototype needs to meet the preferences of young students.

iii. Try to accommodate the needs of different types of students, from those unfamiliar with the operation of electronic devices to those skilled in using electronic devices.

iv. Release VR and PC versions to meet the needs of students who can use them in class and after class.

These suggestions are used to design user interfaces and draft storylines and storyboards for content.

3.2.3. Design Framework

The framework of the IVRSA learning system is designed around the teaching content of the "Composing Foundation" course. The Ministry of Education uniformly formulates the curriculum standards, and professional teachers with rich teaching experience review the specific teaching contents and plans. Table 3.1 shows the combing process of the IVRSA learning system.

Table 3.1

The IVRSA Design Framework

Content and target of course standard	Critical points	IVRSA
Learning task 1. Understand the basis and principle of three-dimensional composition and colour. 2. Understand three-dimensional composition methods, study composition aesthetics, and establish rational thinking methods and modern aesthetic thoughts. Master the basic ways and methods of three-dimensional modelling, broaden or change its inherent and rigid stylized thinking, and improve the aesthetic realm of modelling and creative ability.	1. Overview and history of composing 2. Basic form of composing 3. Case presentation	Learning Hall
3. Master the expression concept of colour composition. Using the principle of science and the law of the combination of art form beauty, give play to people's subjective initiative and abstract thinking, and create aesthetic design works by the ideal.	1. Basic elements of 3D composing 2. The formal beauty of 3D composing 3. 3D composing plane modelling 4. Surface, line, and block 3D composing 5. Combination of 3D space modeling	Moulding Studio
Goals: 1. Have correct rational artistic thinking method; 2. Rich means of artistic expression; 3. Master the principles of formal beauty; 4. Have the ability to image thinking and abstract thinking 5. Have the ability to design and create artistic thinking. 6. Excellent quality of meticulousness and patience.	1. Color expression 2. Visual psychology of colour 3. Contrast and harmony of colours 4. The principles and basic methods of formal beauty of colour	Dyeing Room

The corresponding teaching points are sorted out by extracting the core content from the curriculum standards of the "Composing Foundation" course. Finally, three parts are formed in IVRSA: a learning hall, a moulding studio, and a dyeing room.

i. Learning hall

The learning hall is a vast learning area that simulates a real learning scenario. There is a study area, an equipment display area, and a leisure area for students to study the related contents of the "Composing Foundation" (Figure 3.12).

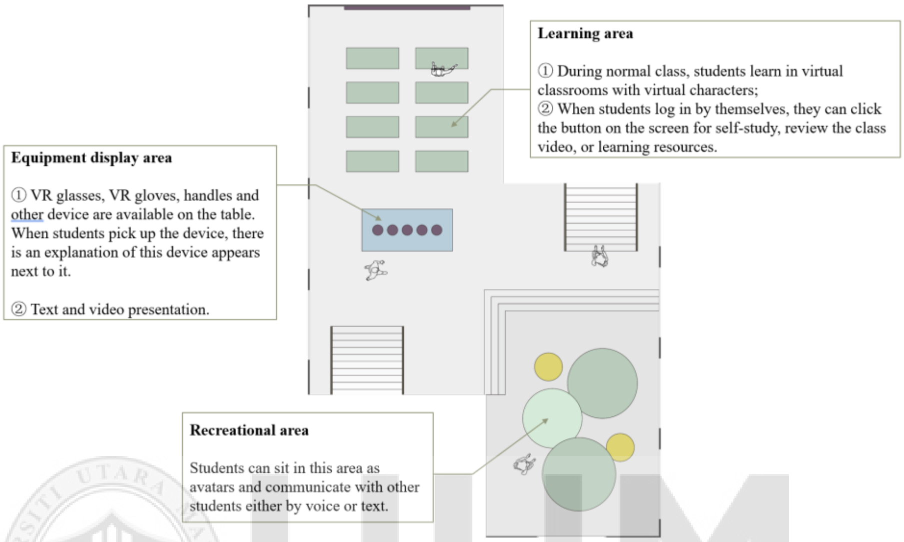

Figure 3.12. The layout of the learning hall

The study area mainly carries out theoretical learning. In a regular classroom, students and teachers learn using avatars in a virtual classroom. When students learn independently, they can click the "select" button to select the class playback or select the course chapter and then play the theoretical knowledge of the chapter through video to provide a theoretical basis for subsequent students to carry out practical operations.

In the device display area, devices such as HMD helmets, VR glasses, VR gloves, and joysticks are placed on a table. When the student picks up the device, the instruction video appears next to it, explaining its principle and operation method to the student.

The leisure area provides a space for students to talk with others in a virtual environment. Before entering the virtual environment, students can create a personal image and nickname. Students can communicate and discuss with other students virtually in the leisure area. Instead of finding the right time and place to discuss with each other, virtual communication space can facilitate students to discuss at any time and improve learning efficiency more effectively. At the same time, virtual space can solve the problem of students with communication difficulties because they cannot communicate with others in the natural environment.

ii. Moulding studio

The moulding studio has a material area, a tooling area, and a moulding area where students mould their 3D moulding creations (Figure 3.13).

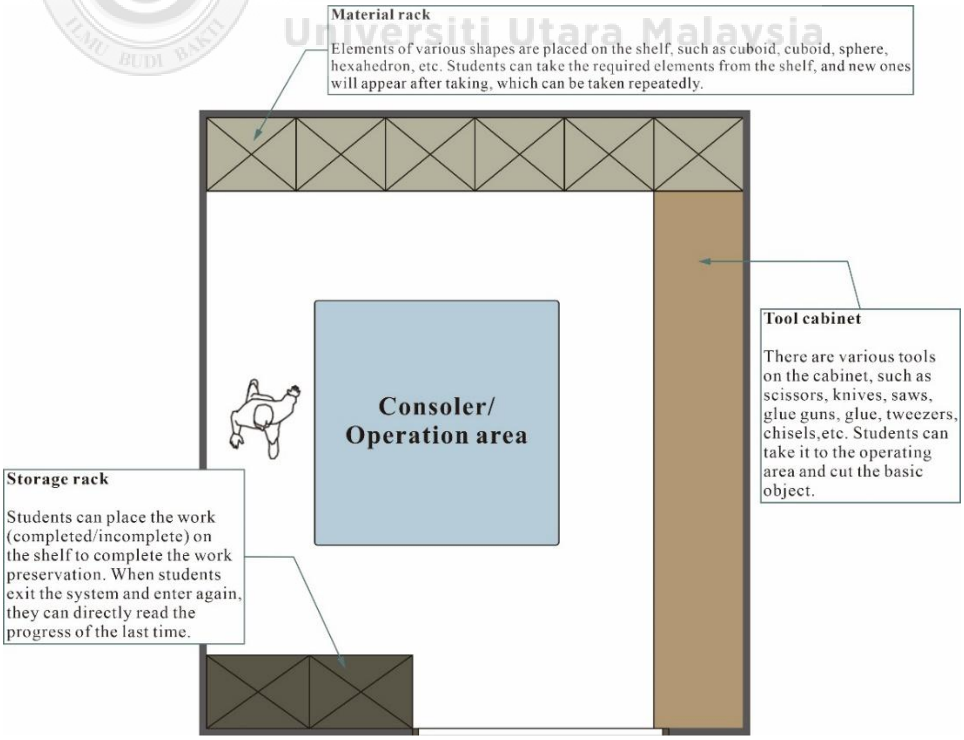

Figure 3.13. The layout of the moulding studio

The materials area has various learning materials, such as spheres, cubes, cylinders, and other basic geometric modelling blocks, which are the essential elements of 3D modelling design. Students can repeatedly take the required elements from the shelf.

The tools area provides scissors, knives, saws, glue, glue guns, spray paint, and other tools. The middle of the room is the operation area, where students place the materials and tools taken on the operation table for modelling (cutting, splicing, deformation, etc.).

There is also a storage rack within the moulding studio where students can place their finished/unfinished work onto the frame for preservation. When students enter the system next time, they can directly read the learning content, ensuring the course's continuity.

iii. Dyeing room

The visual psychology of colour is also an essential part of the composition, and the emotion of colour can reflect the designer's psychological feelings or the emotion he wants to convey. Therefore, in the dyeing room, students can use different tools in the tool cabinet to make various colour adjustments to the 3D model of the design to convey the emotion of the work more comprehensively.

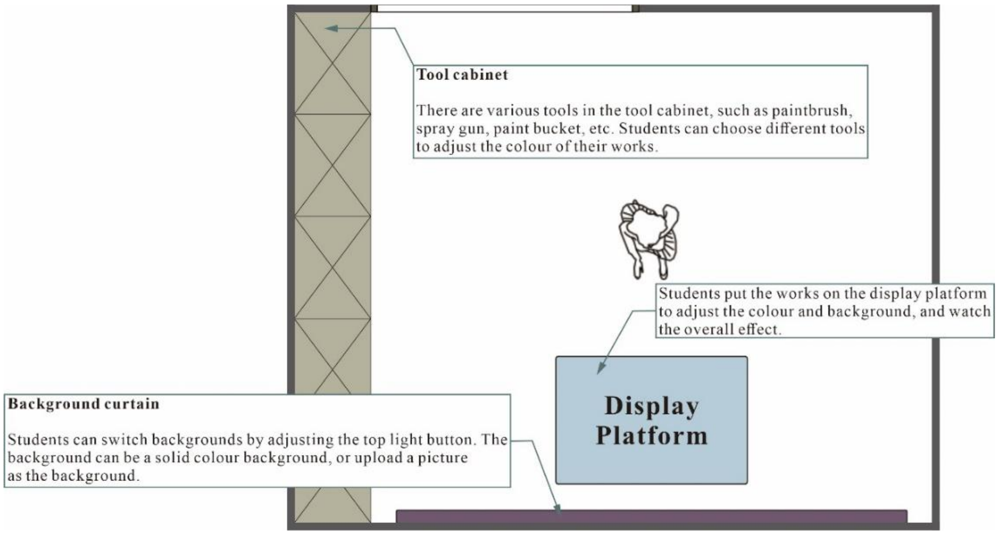

Figure 3.14. The layout of the dyeing room

As shown in Figure 3.14, the student can place the 3D model designed in the moulding studio on the display table and take the tool from the moulding shelf to colour it. At the same time, there is a background curtain on the room's front wall. Students can choose a suitable background for the 3D model to match the integrity of the three-dimensional work. The background can be a solid colour background or a picture you uploaded.

3.2.4 Procedure

IVRSA is an e-learning application that combines virtual reality and multimedia technologies. It aims to develop students' spatial ability to navigate a virtual environment and acquire basic spatial ability skills by interacting with ICONS and labels. The IVRSA learning system includes real-time interactive practice functions such as model composition, decomposition, reconstruction, colour matching, etc. It is an innovative tool for cultivating and training art students' spatial ability.

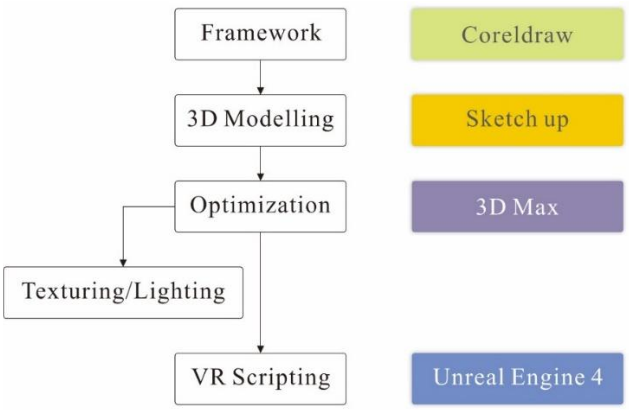

Figure 3.15. VR Development Process

Figure 3.15 depicts the development process of the IVRSA learning system, including framework design, floor plans, 3D modelling, optimization models, texture mapping and lighting, rendering and animation, and virtual reality scripting. The application leverages 3D models in virtual Spaces to generate non-interactive and interactive visualizations.

IVRSA uses interactive means to show students the relevant knowledge of the "Composing Foundation" course. Theoretical concepts and related resources are added to the IVRSA in the form of a video, the content of which is displayed only when the student triggers the icon. Typical video production consists of three processes: pre-production, production, and post-production (Vaughan, 2014). In pre-production, you need to write the lesson plan and the course content, but you also need to determine the presentation (character recording or animation effects), time, lines, etc., which can help the designer or developer smoothly handle the project. During the production phase, all recording work is done to provide a wide range of materials for post-production. Editing, effects, and rendering are the activities involved in the post-production process until the product is finally ready to be included in the VR application. VR scripts are then used to embed the final video file into the VR application.

Authenticity is an important aspect to consider when constructing visual representations of virtual environments, as proposed by previous studies (Mosaker, 2001; Shadiev et al., 2020). Therefore, the scene design of IVRSA is derived from real teaching scenes. Before modelling, field measurements were carried out in multimedia classrooms, equipment classrooms, laboratories, and other places in the school, followed by two-dimensional measurement drawings drawn using AutoCAD software. After ensuring the data is correct, import the 2D measurement map into the SketchUp software for 3D modelling.

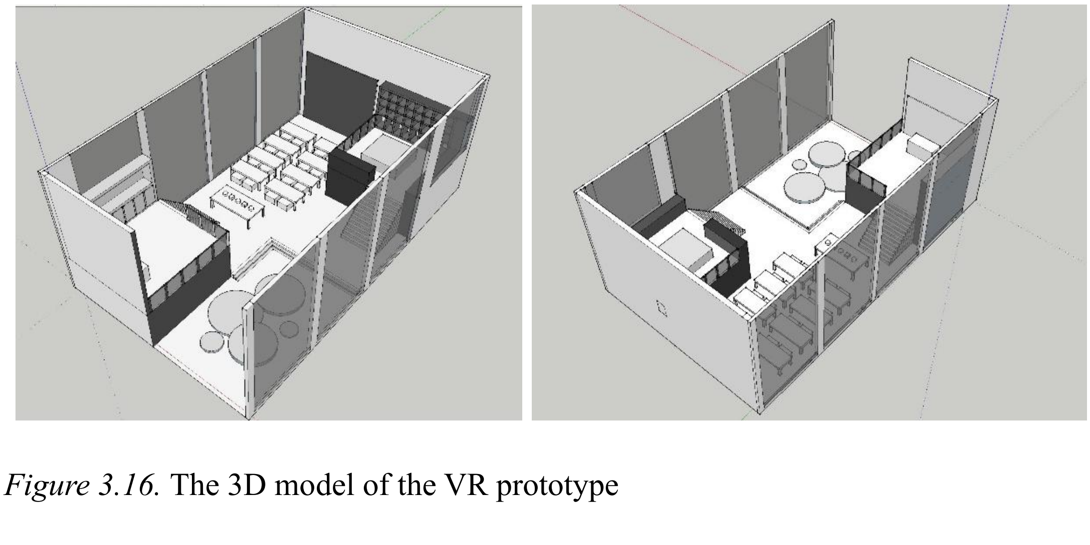

Figure 3.16. The 3D model of the VR prototype

Figure 3.16 shows the spatial layout and the specific orientation of the three rooms. The scene in IVRSA is composed of multiple actual scenes. In model building, many details need to be created and planned reasonably. For this reason, we invited teachers majoring in interior design to give guidance on the design of more information.

Fidelity is another factor we consider during the design process. Fidelity refers to the ability of the system to function in ways that match real-world counterparts (Torrens & Kim, 2024). Previous studies have shown that high and low-fidelity visual representations are effective for virtual environments (Flint et al., 2018; Al-Jundi & Tanbour, 2022), but for students to have a more immersive experience, ILE requires higher fidelity.

Developing 3D models in SketchUp has a relatively large amount of geometry, which results in harsh and unreal effects, so the 3D models need to be optimized, and texture mapping and lighting are necessary to provide a degree of realism to the virtual environment (VE). Therefore, we use 3D Max software to optimize materials and lighting to achieve significant visual realism. Since the number of textures and lighting increases the file size of the VE, the use of textures and lighting is selective to have enough realism.

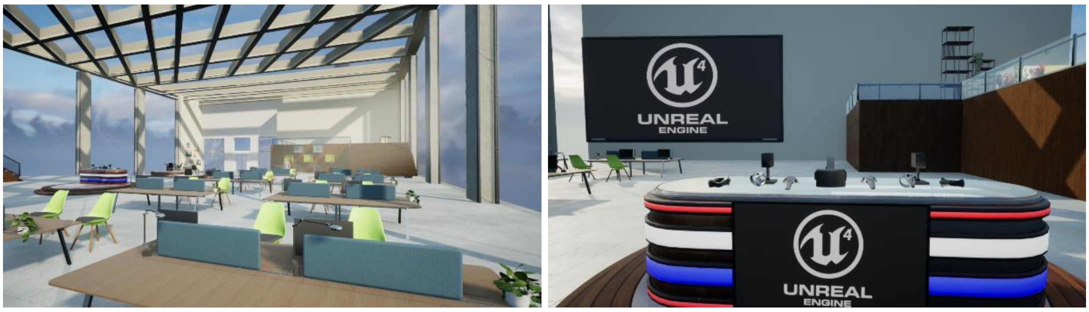

Figure 3.17. The texture and lighting effect of the VR prototype

Figure 3.17 shows the effect of the learning hall. The scene is closer to the real environment by mapping effect processing for desks, chairs, and floors and adding light sources to form shadows. It appears more authentic, providing a sense of immersion in the virtual learning environment.

The final 3D model is exported from 3DS Max to the virtual reality software Unreal Engine 4 to generate the virtual reality environment in the .uasset file format. Once the 3D model is transferred to the VR software, students can enter the virtual learning space through external HMD helmets, VR glasses, and other devices and perform actions such as taking, moving segmentation, and rotation. After the 3D model is transferred, the environment mapping is applied to the background to add visual realism.

In addition, a good interface can enhance students' visual experience so that students can enter the learning state more happily and effectively, improving students' learning concentration. The user interface design of IVRSA is derived from the learning objectives of the "Composing Foundation" course. The details of the interface design of the IVRSA learning system are discussed in detail in Appendix N.

3.3 Instrument Development

The questionnaire method is the primary research tool to evaluate the cognitive load proposed in this study. A questionnaire is a research tool consisting of questions or statements designed to gather statistical data from respondents. In this study, several guidelines were followed to build the tools, which were that (i) the tools should be nice looking and clear, (ii) only consider things that are relevant to the objectives of the study, (iii) use regular and understandable language, and (iv) prevent boot or loading problems (Zikmund et al., 2013). Therefore, the Measuring tools used in this experiment include a spatial ability standardized test, academic ability test, spatial ability self-statement report, cognitive load scale, flow experience scale, activity embodiment scale, and semi-structured interview outline. The selection of those scales involved in this research is described in Table 3.2.

Table 3.2

Classification of measuring tools

Variable	Measuring tools
Dependent variable-spatial ability	1. Spatial Ability Standardized Test (SAST) 2. Spatial Ability Self-statement Report 3. Semi-structured Interview
Observed variables-learning performance	1. Academic Ability Test 2. Cognitive Load Scale 3. Flow Experience Scale 4. Activity Embodiment Scale

3.3.1 Dependent Variable Measurement

To obtain a comprehensive understanding of spatial ability, the data collection method of "data triangulation mutual verification " was adopted in this study to verify the influence of an immersive learning environment on spatial ability. " data triangulation mutual verification " refers to using data from multiple sources in research. The mutual verification of data makes the research conclusion more reliable. In this study, the data sources of spatial ability include three aspects: the standardized test of spatial ability, self-report of spatial ability, and semi-structured interview. Figure 3.18 shows this study's mutual triangulation method for collecting spatial ability data.

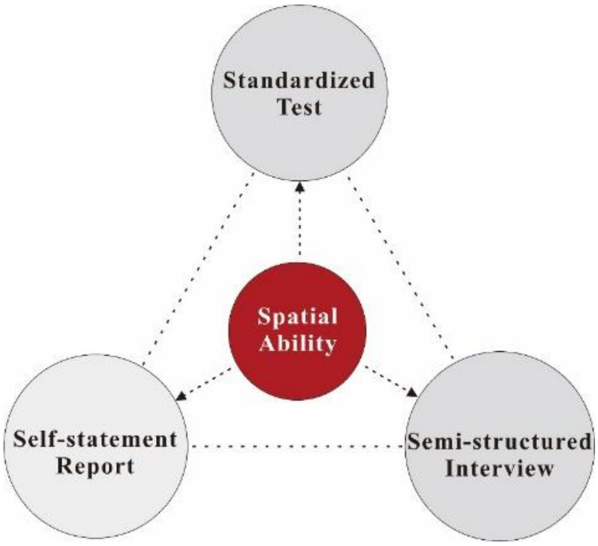

Figure 3.18. Data triangle mutual verification

3.3.1.1 Spatial Ability Standardized Test

Selecting a comprehensive spatial ability test tool with excellent reliability and validity is necessary to measure spatial ability accurately and effectively. It covers three dimensions: mental rotation, spatial visualization, and spatial orientation. Considering that this study focuses on education and targets college students, it adopts the comprehensive version of the spatial ability measurement tool developed by Ramful et al. (2017), which includes three dimensions: mental rotation, spatial orientation, and spatial visualization. The measurement tool measures students' spatial ability from the perspective of spatial thinking and is suitable for related disciplines, mainly for educational purposes. The specific measurement dimension framework and content description are shown in Table 3.3.

Table 3.3

Ramful's Spatial Skills Measurement Framework

Component dimension	**Problem description**	**Problem characteristics**
Mental rotation	Rotate 2D and 3D objects clockwise or counterclockwise	1. Determine the rotation results of 2D and 3D objects. 2. Distinguish between reflection and rotation.
Spatial orientation	1. Position yourself in space 2. Read the map 3. The relationship between cardinal points 4. Front, top, or side view	1. Determines the position of the object relative to the observer. 2. Read the map from different perspectives. 3. The cardinality of a point whose north is not in the vertical direction. 4. Recognize orthogonal views of objects.
Spatial Visualization	1. Symmetry 2. Pattern 3. Two and three-dimensional shapes and their relationship 4. Local-whole relationship 5. Reflection	1. Visualize the results of folding/expanding a particular shape. 2. Construct entities from a given network and vice versa. 3. Matching parts and parts subparts. 4. Find the symmetry of objects. 5. Object reflection.

Among them, the mental rotation dimension requires learners to rotate two-dimensional and three-dimensional objects clockwise and counterclockwise. The spatial orientation dimension requires learners to locate their own position in space, read maps, determine the relationship between base points, and identify objects from different perspectives (front, above, or side). Spatial visualization dimensions require learners to recognize patterns, two-dimensional and three-dimensional shapes, and their relationships (e.g. symmetry, mirroring, etc.). All the items related to the spatial ability standardized test (SAST) are described in detail in Appendix B.

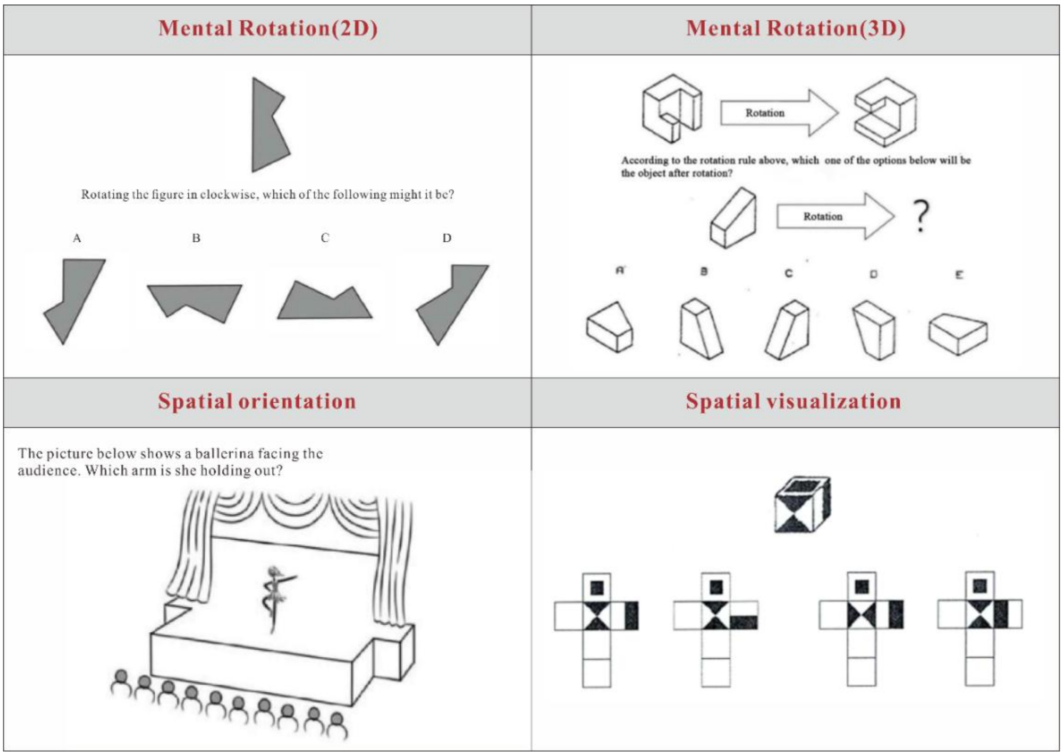

Figure 3.19. Test sample

Figure 3.19 shows an example of the standardized spatial ability test questions. Each question has a description and is accompanied by a corresponding picture. The questions are in increasing order of difficulty. The test consists of 30 single-choice questions, including three sub-dimensions: mental rotation, spatial orientation, and spatial visualization.

For mental rotation, the quiz includes sample questions for 2D and 3D cognitive courses and requires students to perform mental rotation operations (clockwise or counterclockwise) on 2D and 3D objects, respectively. For spatial orientation, the test requires students to judge the direction of things from different perspectives. For spatial visualization, the test requires students to restore a cube grid unfolded on a two-dimensional plane. Each dimension of the spatial ability standardized test contains ten questions. The correct score for each question is 1 point, and the total score for each size was 10 points. The sum of all project scores was the total score of spatial ability (30 points in total). The higher the total score is, the stronger the spatial ability is.

3.3.1.2 Spatial Ability Self-statement Report

A spatial ability self-statement report is a meaningful tool for measuring students' spatial ability and self-perception. The spatial ability standardized test mentioned above plays a vital role in objectively understanding students' spatial ability levels. Still, whether students have experienced spatial reasoning and calculation processes from a subjective perspective is unknown. Therefore, based on the standardized spatial ability test tool, this study also adopted the spatial ability self-statement report, which aims to understand the student's spatial ability self-perception.

This study selected the spatial ability self-statement report developed by Turgut (2014). As shown in Table 3.4, those items include two dimensions: the object manipulation ability and the spatial navigation ability. Among them, the object manipulation ability corresponds to the mental rotation and spatial visualization sub-dimensions of spatial ability. The spatial navigation ability corresponds to the spatial orientation sub-dimensions of spatial ability.

Table 3.4

Component Dimension of Spatial Ability Self-statement Report

Component dimension of Spatial ability	Dimension
Mental Rotation	The Object Manipulation Ability
Spatial Visualization	The Object Manipulation Ability
Spatial Orientation	The Spatial Navigation Ability

Object manipulation ability refers to the ability to manipulate two-dimensional or three-dimensional objects in space, corresponding to the mental rotation and spatial visualization dimension of spatial ability. There are eleven items in total. Spatial navigation ability is essential for finding one's route and orientation in complex environments and planning long-distance routes. It can be described as several keywords: course, direction, cognitive map, map reading, environmental geometry, and spatial information about the location of objects in the surrounding environment. These spatial skills constitute spatial navigation ability, corresponding to the spatial orientation dimension of spatial ability and including four items. A Likert 5-point scale was used, and all the items related to the spatial ability Self-statement report are described in detail in Appendix D.

3.3.1.3 Semi-structured interview

Interviews allow the researcher to penetrate the inner world of individual students and understand their views and ideas. Therefore, to obtain students' feedback on spatial ability and course learning experience, a semi-structured interview was used in this study to explore students' overall feelings after the course. The interview questions in this study mainly investigated students' thoughts and feelings when they conducted three-dimensional composition design and production activities in an immersive learning environment. The specific questions are described in Appendix H.

The study only conducted one-on-one semi-structured interviews in the experimental group, which lasted about 15 minutes. The data were collected and recorded in pen and paper during the interview. These record data were converted into electronic text and encoded, which was divided into different topics according to the similar characteristics of the coding. Then, the frequency table related to the research question is created, and the data is evaluated using qualitative analysis methods.

3.3.2 Observation Variable Measurement

3.3.2.1 Academic Ability Test

In this study, the questions for the professional ability test were designed and developed by the researchers and the teachers in the school for the teaching content and assessed by art experts based on the aspects of difficulty, logic, content coverage, etc. Finally, they formed a set of professional ability test questions suitable for first-year students majoring in art. All the items related to the academic ability test (AAT) are described in detail in Appendix C.

Before and after the experiment, all students were required to complete the academic ability test. The pre and post-tests of the academic ability test are mainly designed by the researchers and the teachers in the school for the teaching content. There are six questions in the professional ability test: two 3D-2D conversion questions, two 2D-3D conversion questions, one three-dimensional packaging expansion drawing question, and one spatial environment construction drawing question. The total score is 100 points. The questions before and after the professional ability test are the same. The purpose of the pre-test is to check whether the students' prior knowledge background is different, and the purpose of the post-test is to check the students' comprehensive grasp of spatial knowledge after the course study.

To ensure the validity of the test, the teacher in charge of the course and the expert group evaluated the learning performance before and after the test and modified the questions in question. The pre-and post-test of learning performance is issued and taken back in paper form.

3.3.2.2 Cognitive Load

Cognitive load refers to the mental activity exerted on working memory while processing information. This study adopts the cognitive load scale developed by G. Hwang et al. (2013), including mental workload and effort. The scale consists of eight items and adopts a five-point scale.

Mental workload refers to the influence of the interaction between learning tasks and subject features on students' memory capacity, which includes five items. Mental effort refers to the cognitive capacity allocated to accommodate the demands imposed by the task. There are three items in this dimension. Appendix E describes all the items related to cognitive load in detail.

3.3.2.3 Flow Experience

Flow is described as a cognitive state in which an individual is intensely engaged in an activity. The flow experience items developed by Pearce et al. (2005) are adopted in this study. The items are used to measure students' overall perceived flow state. The items consist of eleven items. A Likert five-point scale is used, and all the items related to flow experience are described in detail in Appendix F.

3.3.2.4 Activity Embodiment

Activity embodiment refers to the overall experience effect of the course during the learning process. This study selects the experiential activity items that Abdullah (2014) and Huang et al. (2016) developed. The items contain four sub-dimensions: engagement, challenge, interest, and ability. The items consist of thirteen items and adopted a five-point Likert scale format.

Involvement refers to students' learning involvement in course activities with three questions. Ability refers to a student's learning ability when participating in course activities, and there are six items in this dimension. Challenge refers to students' perception of the difficulty of the course activity process and includes two items. Interest relates to students' learning attitude towards participating in course activities. This dimension has two items. All the items related to activity embodiment are described in detail in Appendix G.

3.4 Expert Review

Expert review is a simple, instant evaluation method (Wiegers, 2002) that involves only experts and not actual users. Expert review is an effective way to control product quality improvement in other types of product testing. This study focuses on the factors that affect the development of spatial ability. Factor validation is based on the content validity ratio (CVR), and the findings are reported. This study adopts the measurement methods proposed by Lawshe (1975) and Polit and Beck (2006), which are widely used to measure items and scale validity. Content validity is an important quality index to measure instrument validity. The study results were verified by calculating the evaluation results from three relevant industry experts. The three experts have more than ten years of experience in spatial abilities, virtual reality, photography, film, and television animation. Finally, based on the rating obtained, it is decided whether to uphold or waive the judgment of any sub-factor (Raji et al., 2018).

Table 3.5 describes the experts' profile in validating the ILE conceptual model. The researchers contacted qualified experts by email and phone, met with the experts after the appointment, and briefed them on the proposed hypothetical conceptual model. After they agreed to participate in the assessment, the researchers handed them the assessment form and made an appointment to collect the assessment forms.

Table 3.5

Experts' Profile of Conceptual Model Verification

ID	Gender	Position	Years of Experience	Expertise	Locations
Expert A	Female	Professor	>15 years	Spatial Ability Virtual Reality Animation	China
Expert B	Male	Professor	>20 years	Spatial Ability Virtual Reality Photograph	China
Expert C	Female	Senior Lecturer	>10 years	Spatial Ability Virtual Reality HCI	Malaysia

The assessment forms are available in English and Chinese. The instrument provides experts with conceptual definitions of research objectives and measured variables. The experts were asked to rate the relevance and clarity of the project based on the structure in which it was located. Experts were given a Scale with three options: "Essential," "Useful but not essential," and "Not necessary." Then, two types of comment boxes were provided for experts to provide additional comments on the item and the overall Scale. In addition, to make the Scale more accurate, the Scale Content Validity Index (S-CVI) was also examined. CVR relates to the validity of items, while S-CVI represents the Scale's validity. In addition, to make the scale more accurate, the scale level CVI was also examined. CVR relates to the validity of an item, while scale-level CVI represents the validity of a scale. The instrument of expert review is shown in Appendix I.

3.4.1 Measurement Method of CVR

The results of CVR calculations are significant for their impact on the validity of the contents of the instrument and are used to remove items rated as irrelevant. According to Lawshe (1975), CVR is calculated as follows:

$$CVR = \frac{\mathrm{Ne} - \mathrm{N}/2}{\mathrm{N}/2}$$

Ne represents the number of experts who consider the project essential.

N represents the total number of experts involved in the test.

CVR is calculated as a ratio ranging from -1 to 1. Items with a positive CVR value indicate a consensus among experts that these items are significant for measuring the structure. Items with low or negative CVR values may need to be modified or removed to improve the content effectiveness of INSTRUMENT. Therefore, after discussion and evaluation by experts, this study divides the results of CVR into the following three categories and defines that as long as the value of CVR is greater than 0, the ITEM is considered valid.

CVR=1: All experts agree that this project is essential.

0 < CVR < 1: Experts disagree on the necessity of this project. However, after modifying the content of the item, it can be considered essential.

CVR≤0: Most experts believe this item is unnecessary and must be removed from the Scale.

To facilitate the calculation of the project content validity ratio (CVR), the three options of "Essential," "Useful but not essential," and "Not necessary" were marked as numbers to calculate. The expert chose "Essential," denoted as 1, for calculating Ne. The choices "Useful but not essential" and "Not necessary" are marked as 0.

3.4.2 Measurement Method of S-CVI

In this research, the validity of each Scale was examined using the scale-level CVI suggested by Polit and Beck (2006) and Polit et al. (2007). There are two methods for calculating the scale-level CVI: the Average Method (S-CVI/Ave) and the Sum Method (S-CVI/Sum). This study adopted the Sum Method for verification, and its calculation formula is as follows:

$$S - CVI/Sum = \frac{\text{Number of items with values meeting the criterion}}{\text{Total number of items}}$$

Polit and Beck (2006) state that an acceptable scale-level CVI is S-CVI≥0.8. The review expert identified the item with a CVR greater than 0 as valid in the previous article. The specific findings are discussed in detail in Section 4.5.

3.5 Pilot Test

This study conducted a pilot test to verify students' acceptance of the IVRSA learning system and the feasibility of cultivating spatial ability in ILE. Figure 3.20 shows the content of the pilot test, including the expert evaluation of the IVRSA learning system content and the experience and feelings of students after learning spatial ability in ILE mode and traditional mode. The Pilot test aims to validate and evaluate the effectiveness of the IVRSA learning system and questionnaire and collect feedback throughout the assessment process.

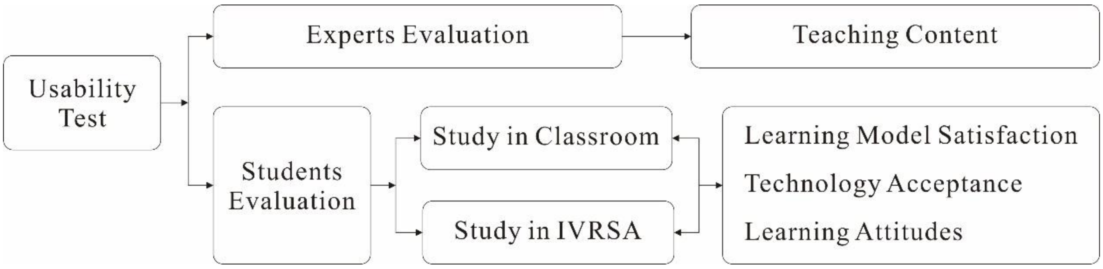

Figure 3.20. Test framework

3.5.1 Expert Evaluation

The pilot test was conducted by three experts with more than ten years of experience in virtual reality technology and spatial abilities. Table 3.6 describes the experts' profile in validating the ILE conceptual model.

Table 3.6

Experts' Profile of Pilot Test

ID	Gender	Position	Years of Experience	Expertise	Locations
Expert D	Male	Professor	>20 years	Graphic Design	China
Expert E	Male	Associate professor	>15 years	Interior Design	China
Expert F	Female	Senior Lecturer	>5 years	Animation	China

Experts evaluate the teaching content of the IVRSA learning system to verify whether it covers the relevant knowledge of the course "Composing Foundation" and evaluate the correctness and logic of the content. Then, they evaluate the questionnaire's content according to the availability of the IVRSA learning system.

3.5.2 Student Evaluation

The student test mainly tests the usability of the IVRSA learning system and the validity and reliability of the questionnaire. The test was conducted on a targeted sample of 28 students (14 males and 14 females between 18 and 19 years).

Before the practical operation, both teachers and students were trained in the operation. Teachers conduct IVRSA learning system training to ensure that there are no mistakes due to improper teacher operation. Students are trained in using VR equipment, which can reduce the impact on the experiment caused by students' inability to operate the equipment.

The content of the experiment is divided into two aspects: theoretical knowledge and practical operation. In theoretical knowledge, students learn in an ordinary classroom, and the teacher adopts traditional teaching mode and uses slides and videos to show the critical points of spatial ability knowledge. In the practical operation part, the teacher adopts ILE mode and uses the IVRSA learning system to carry out three-dimensional modelling spatial teaching. Students wear HMD helmets and touch gloves to create an immersive learning experience. The specific contents of the test are shown in Table 3.7.

Table 3.7

Teaching content for tradition and ILE mode

Tasks	Mode	Content and procedure	Time
Theoretical knowledge	Tradition teaching Mode	The teacher explained the theoretical knowledge of three views, then played related videos to present the case, showing the effect of simple and complex structures of three views.	40
Practical operation	ILE Mode	Under the teacher's guidance, students move, rotate, and view the object 360 degrees and then decompose and combine the object to view the expansion effect of three views of various structures.	40

3.5.3 Instruments

After learning theoretical knowledge (traditional mode) and practical operation (ILE mode), students need to fill out the learning mode satisfaction questionnaire, technical acceptance questionnaire, and learning attitude questionnaire to evaluate the two learning modes, respectively.

The learning mode satisfaction questionnaire, recomposed from the research of Chu et al. (2010), includes nine questions, such as: "This learning mode is beneficial for me to learn how to recognise the characteristics of the target learning object" and "I have tried new learning methods or ways of thinking because of using this learning mode", etc. This questionnaire aims to collect students' experiences and feelings after participating in different learning modes and their evaluation of different learning modes. The details are shown in Appendix K.

The technology acceptance questionnaire comes from the questionnaire developed by Hwang et al. (2013). It consists of nine items, such as "This learning method enriches learning activities" and "This learning method helps me learn better." etc. The purpose of this scale is to collect students' acceptance of teaching means and methods such as slides, video and VR technology to evaluate the influence of different modes on students' spatial ability learning. The details are shown in Appendix L.

Adapted from a survey conducted by Chu et al. (2010), the learning attitude questionnaire consists of seven questions, such as "I am more interested in observing and exploring spatial relationships", "I will actively try to observe 3D features of various objects", etc. The purpose of these items is to collect students' learning motivation, learning performance and learning state in different modes to evaluate the influence of different learning modes on students' learning attitudes. The details are shown in Appendix M.

This research used Cronbach's alpha to test the reliability of the questionnaires. According to George and Mallery (2002), the scale of Cronbach's alpha value is >0.9 excellent, >0.8 good, >0.7 acceptable, >0.6 questionable, and >0.5 poor.

As shown in Table 3.8, the Cronbach's alpha values of each scale were 0.91, 0.94, and 0.89. These values indicate sufficient reliability in assessing students' satisfaction and acceptance of different learning modes and their attitudes towards spatial ability.

Table 3.8

The Cronbach's alpha Results of Questionnaires

	Learning model satisfaction	Technology acceptance	Learning attitude
Cronbach's alpha	0.91	0.94	0.89

The test results are used to improve the IVRSA learning system and optimize the questionnaire content. The results of the questionnaire will help us understand the potential application of VR in education and reveal the advantages of an immersive learning environment for cultivating students' spatial ability. The specific findings are discussed in detail in Section 5.1.

3.6 Experiment

3.6.1 Course Background

This study chooses the course "Composing Foundation" as a case study to develop spatial ability learning due to several reasons:

Firstly, in art and design majors, Basic design is considered a foundational course because it first introduces basic design principles in design education (Denel, 1998), and students are exposed to theory and practice to help them develop the skills needed later in their design education. As one of the introductory courses, "Composing Foundation" is a compulsory course for all art students and a forerunner for all professional courses (Talent Training Program 2020). Whether environmental art design or advertising art design requires students to have spatial ability (Cho & Suh, 2023), the "Composing Foundation" course is ideal for improving spatial ability. Because students can construct three-dimensional objects (modelling works) in an immersive learning environment, during the construction process, students can manipulate them (such as moving, rotating, breaking down, composing, etc.) and observe their appearance and structural features from different perspectives. It also lays a foundation for the study of later professional courses.

Secondly, most schools use traditional teaching modes to teach the "Composing Foundation" course, which adopts slides or requires students to practice (Ma, 2023). However, the conventional hands-on practice is limited by many practical problems, such as a long production cycle, large consumables, strong professionalism, high cost, physical space constraints, and many production errors (Brinson, 2015). These limitations highlight the demands on materials, time, and physical space for art courses. The emergence of an immersive learning environment solves the above needs well (Fleischmann, 2020). In an immersive learning environment, students can create three-dimensional modelling works instantly. At the same time, they can do unique modelling work with small supplies and no professional manual experience.

3.6.2 Design Elements

3.6.2.1 Participants

This course is taught to first-year students majoring in art who have changed from a general content learning stage to a professional content learning stage and have had a significant change in learning thinking and content. Students have not studied systematically and are interested and fantasizing about the professional range. Therefore, practical learning activities should be adopted to satisfy the interest and enthusiasm of students and lay the foundation for the subsequent study of core courses.

In this experiment, the participants were 58 first-year art majors at a university in Chongqing, China. Because of the purposeful sampling, all students are selected from the art classes in one semester. At the same time, to reduce the influence of other factors (gender, age, prior knowledge, etc.) on this experiment, 28 men and 30 women were selected according to sex, and the age was controlled between 18 and 19 years old.

Subsequently, according to the requirements of the experiment, the students participating in the experiment were divided into the control group and the experimental group, which had an equal number of genders, with 29 people in each group, including 14 male students and 15 female students. Those students had no experience applying and learning VR design software but had a certain art foundation. They had received professional sketch and colour training, so it could be considered that there was no difference in spatial ability between the groups.

Before experimenting, the instructor describes all the characteristics of the experiment to the students participating in the study to ensure that the study process is ethical and ethical, and finally, obtain the written consent of the students. None of the students had been exposed to the content of the Composing Foundation course before teaching, nor had they taken the course using VR technology.

3.6.2.2 Learning Situation

In this experiment, the learning venue is mainly an immersive classroom in a school. The immersive classroom is a physical classroom of about 200 square meters and integrates the hardware equipment and software system of the immersive teaching system. The following is an introduction to the immersive classroom.

The immersive classroom hardware includes an interactive electronic screen and 40 immersive devices (each device contains a high-performance touch-screen computer, a VR controller, VR glasses, and a stylus). According to the different teaching functions, the immersive classroom space is divided into a theoretical teaching area and a practical experience area. The theoretical teaching area is equivalent to a traditional classroom, consisting of interactive electronic screens, desks, and chairs teachers and students use. It is mainly used to teach intellectual content, such as teacher-student interaction, arranging learning activities, and displaying works.

The primary function of the practical experience area is to provide virtual space learning tools and carry out three-dimensional modelling design teaching activities. Students create three-dimensional shapes according to the teacher's explanation.

Students can use the stylus to draw plane plans and a mouse or VR handle to rotate, move, and navigate objects in 3D virtual space. In this desktop VR environment, teachers can observe students and help them navigate the virtual environment. Therefore, with this virtual reality model, the experience can be guided through interaction between teachers and students, and the learning content can be supported through real-time interaction.

3.6.2.3 Learning Activities

Based on the teaching objectives of the "Composing Foundation" course and the purposes of this study, this study designs an operational learning activity oriented to spatial ability development and an immersive learning environment built based on VR. The description of learning activities and corresponding spatial ability development elements are shown in Table 3.9.

Table 3.9

Elements of Spatial Ability Corresponding to Learning Activities

Course	Constitute dimensions	Elements of Development	Learning Activity
Composing Fundament	Spatial visualization	Visual presentation	Observe three-dimensional modelling from different angles.
	Mental rotation	Navigation, mental rotation, and transformation	Locate the position of 3D modelling in ILE, take it to different places, and rotate it at various angles simultaneously.
	Spatial orientation	Identification, composition, and decomposition	Recognition, composition, and decomposition: VR equipment is used to construct a 3D model in the virtual environment, and the shape and appearance of the 3D model are set.

In addition, only one teacher is responsible for all the learning activities in this experiment, which can ensure the consistency of teaching form, teaching progress, teaching content, and teaching difficulty. This method ensures that the control group and the experimental group have the same influence factors except for different learning environments during the experiment, thus reducing the possibility of other factors affecting the experimental results.

The teacher in charge of this experiment has more than five years of teaching experience. The teacher received teaching-related training before the experiment, including VR equipment use training and simulated teaching. Through training, teachers can minimize the impact of improper operation on the test results when using VR equipment. At the same time, simulation teaching can also enhance teachers' information and reduce possible mistakes in the teaching process. The specific training content is shown in Table 3.10.

Table 3.10

The Experimental Content and Procedure of Teacher's Training

Time	Two weeks before the experiment	One week before the experiment
Training Content	**1. VR equipment use training** Under the guidance of the engineer, the teacher mastered how to operate the VR equipment, including the wearing of the handle, the function of the button, and the sensitivity test.	**2. Simulation teaching** Teachers conduct teaching rehearsals in ILE and simulate real class scenes according to the teaching content.
Evaluation and Results	VR professional engineers give guidance, and teachers can only carry out experimental teaching after passing the use test.	The art teacher evaluates the teaching plan, content, and steps and gives opinions on the teacher's teaching style and rhythm.

3.6.2.4 Learning Contents

IVRSA Learning system is an upgrade and innovation of the traditional "Composing Foundation" course. The basic course of immersive composition requires students to complete the learning task of three-dimensional modelling design and production in an immersive learning scene. The learning task is divided into four steps: "Plan drawing", "cutting", "combination", and "colour matching". The four steps are as follows:

i. Plan drawing. The process requires students to use a stylus to draw a three-dimensional shape in the learning hall.

ii. Combination. The process requires students to use VR touch gloves to "move" virtual characters to the modelling room, "take" basic shapes, and combine them according to the plan drawing.

iii. Adjustments. In this process, students need to "rotate" the three-dimensional shape, observe it from different angles, and adjust the differences with the plan.

iv. Match colours. Students "take" the completed three-dimensional shape to the colour-matching room, choose different tools and colours, and match the three-dimensional shape with colours to form an emotional expression suitable for the shape.

In three-dimensional modelling design and production, students can use a VR gamepad or mouse to control the modelling in virtual space and freely interact with various tools. For example, students can maintain the three-dimensional model, "pick up," "move," "rotate," "stick accessories," and other operations. In addition, students can also observe the appearance, characteristics, and structure of three-dimensional modelling from different angles. All these interactive behaviours can cause the movement of three-dimensional modelling in virtual space.

3.6.3 Experiment Content

The course content and teaching methods have been redesigned based on the school's original curriculum. After the redesign, the total number of class hours is 48; the teaching progress is eight weekly, and six weeks of teaching experiments are carried out. Among them, a 3-week course used a built VR prototype to conduct teaching activities. Specific teaching arrangements are shown in Table 3.11.

Table 3.11

The Whole Implementation Process of "Composing Foundation"

week	Class hour	Learning stage	Learning content and method	Target
1st week	4	Data collection	Pre-class related test of spatial ability.	Master the basic situation of students.
	4	Embodied experience	1. Teacher demonstrates using VR equipment. 2. Students experience and are familiar with those devices.	Familiarize students with VR equipment and prepare for subsequent experiments.
2nd week	4	Knowledge mastery	The teacher teaches the basic principles of composition: the regulations and rules of formal beauty, the essential elements of modelling, the design of the image, and the primary form rules of plane composition.	Enable students to master the basic knowledge of composition and have a basic cognition of composition.

Table 3.11 continued

	4	Knowledge extends	The teacher teaches related theories of 3D composition: basic concepts of 3D composition, modelling elements, and form elements.	
3rd week	4	Active practice	Students design a "3D model of **line**" plan in the "Learning Hall" of the VR prototype.	Make students' spatial thinking from 2D to 3D and form spatial skills.
	4		Students combined the plan to carry out the 3D design and produce a "3D model of the **line**" in the VR prototype.	
4th week	4	Active practice	Students design a "3D model of **surface**" plan in the "Learning Hall" of the VR prototype.	
	4		Students combined the plan to carry out the 3D design and produce a "3D model of **surface**" in the VR prototype.	
5th week	4	Active practice	Students design a "3D model of **point, line, face, and block**" plan in the "Learning Hall" of the VR prototype.	
	4		Students combined the plan to carry out the 3D design and produce a "3D model of **point, line, surface and block**" in the VR prototype.	
6th week	4	Abstract concept	1. Students show their 3D design works 2. The teacher comments and summarizes students' work.	Learn from each other's strengths and weaknesses in spatial ability.
	4	Data collection	Post-class related test of spatial ability.	Grasp the spatial skills of students after learning the course.
			Total 48 Class hours	

Since immersive devices are not included in every section of the "Composing Foundation" course, only the section on 3D modelling design in Weeks 3-5 above has been designed for instruction (Table 3.12). The primary purpose of the design is to develop students' spatial ability in ILE by using VR prototypes to carry out learning activities. The teaching objectives of this part are:

i. Through 3D modelling design and production activities, students can build complete 3D modelling and cultivate the ability to visualize two-dimensional objects into 3D objects.

ii. Through interaction with 3-D models in the virtual environment and combined with practical operation, students can build 3D works with unique shapes and cultivate their ability to operate 3-D objects.

iii. By integrating experiential learning and VR techniques, students can develop their spatial and orientation perceptions of 3D objects from different perspectives.

Table 3.12

The 3-5 Weeks Implementation Process of "Composing Foundation"

Learning contents	Teacher's activities	Students activities	Design intention
Create a situation	**[TEACH]** The teacher briefly introduced the main points of 3D modelling design.	**[REVIEW, LISTEN]** Students review the relevant theoretical knowledge based on the composition taught in the previous period.	Improve students' knowledge structure.
Part one Complete the drawing plan task of 3D modelling design in the "learning hall" of the VR prototype	**[ASSIGN TASK]** The teacher arranges the 3D modelling design requirements: 1. 3D modelling design of a line 2. 3D modelling design of surface 3. 3D modelling design of point, line, surface, and block	**[LISTEN, THINKING]** 1. After obtaining the task, students apply the theoretical knowledge to 3D modelling design. 2. Draw a plane design	Realize the transformation from theory to practice.

Table 3.12 continued

Part two Complete the creating task of 3D modelling design in the "modelling room" of the VR prototype.	**[GUIDE]** The teacher guides the students on the key points and points in 3D modelling design.	**EXPERIENCE, PRACTICE]** Students use the primary forms and tools in the VR prototype to design and make various 3D models.	1. Develop students' ability to present or visualization 2D objects into 3D objects 2. Develop students' ability to build and manipulate 3D objects
		[EXPERIENCE, OBSERVE] Students rotate 3D objects and observe whether the model from various angles conforms to the intended design.	Develop students' ability to view 3D objects from different perspectives.
Part Three Complete the colour-matching task of 3D modelling design in the "dyeing room" of the VR prototype	**[TEACH]** The teacher explained the theoretical knowledge about colour: 1. Basic theory of colour 2. Colour emotion	**[EXPERIENCE, PRACTICE]** Students fill the 3D model with colours	Cultivate students' cognitive ability of colour emotion
	[GUIDE] The teacher guides the students in carrying out the overall modelling according to the principles of formal beauty.	**[EXPERIENCE, PERCEPTION]** With the background pattern, students move the 3D model to different positions.	Cultivate students' ability to recognize the position and orientation of 3D objects in virtual space.

Based on the above teaching content, this study used the teaching design of the control and experimental groups, respectively.

The experimental group learned constitutive knowledge in the computer room and then designed a three-dimensional modelling device using sphere, cube, and cuboid geometry blocks in an immersive learning environment developed based on VR. After the design was completed, the students in the experimental group showed the completed modelling device in class and shared and exchanged their work with their peers.

The control group studied in a traditional classroom, combined with multimedia applications (slides, video, etc.) to learn the same basic knowledge of composition, and then designed a modelling device on a two-dimensional plane based on paper and pen. After the design was completed, the students in the control group displayed the completed works in class and shared and exchanged their works with their peers.

3.6.4 Experimental Process

The whole experiment lasts for six weeks, with 48 class hours.

In the first week, all students took a pre-test related to the course, including a spatial ability standardized test and academic ability test, to assess the student's background. Before the test, the researchers provided the test instructions orally to the learners and instructed them to pay attention to accuracy.

The researchers then tested the VR prototype and the corresponding component of the primary course content to achieve best practices in the classroom. The teacher introduced the experiment to the students of the experimental group. The main content includes the immersive course content and the class form, and the VR prototype's operation mode and corresponding functions have been explained. Students in the experimental group should be familiar with the method used and the related operation of the VR prototype, which helps to reduce the novelty impact of new technology on students' learning effect.

From the 2nd to the 5th week, the group used VR prototypes in the immersive classroom for essential course learning. In contrast, the control group learn the same content in the traditional classroom environment with the help of slides, video, and other forms. Only the immersive learning environment differed between the experimental and control groups.

During 6th week, all students take post-tests related to the course, including spatial ability standardized tests, academic ability tests, spatial ability self-report, cognitive load, flow experience, and activity embodiment scales. In addition, a one-to-one semi-structured interview was conducted with students in the experimental group. The whole experiment process is shown in Figure 3.21.

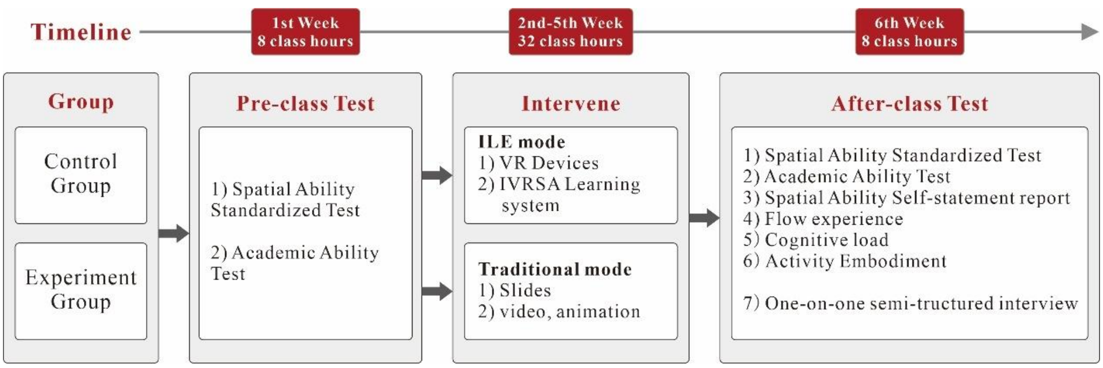

Figure 3.21. Experiment process

3.7 Data Collection and Analysis

The experimental data of this quantitative study included Spatial Ability Standardized Test (SAST), academic ability test (AAT), spatial ability self-perception, cognitive load, flow experience, and activity embodiment.

In the AAT, except for those answers that are completely correct (100 scores) or not answered (0 scores), other answers may have some details wrong or a few correct cases. Since the scoring of such questions is subjective to a certain extent, the three experts score according to the actual situation, and the average score of the three experts was taken as the final score to avoid the difference in scores caused by cognitive differences among experts, which will affect the final result. For the results, the independent sample T-test was used to compare the differences in the pre-test of AAT. Covariance analysis was used to compare the differences in the AAT post-test.

For the SAST, one-way ANOVA was used to compare the differences in the pre-test between the experimental and control groups, and covariance was used to compare the differences in the post-test between the two groups. For spatial ability self-perception, one-way ANOVA was used to compare the differences between the experimental and the control groups. For cognitive load, flow experience, and activity embodiment, nonparametric tests of two independent samples were used to analyze the differences between the experimental and control groups.

The scale provides numbers as a scale for scoring rather than semantic space or verbal clarification to classify feedback positions. Thus, responses to each item in the questionnaire were measured on a five-point Likert scale, labelled "strongly disagree," "disagree," "Neither agree nor disagree," "agree," and "strongly agree," respectively, indicating the extent to which participants agreed or disagreed with the statement.

The questionnaire was conducted in a controlled environment to avoid bias issues such as influence from classmates and reference to other learning materials, and no positive feedback was provided. Therefore, students fill out questionnaires in the classroom, with the teacher present to observe but not interfere with the student's responses. This enables students to pay attention to the questionnaire and provide honest feedback.

The qualitative method of this study includes students' classroom performance and one-on-one interviews after class. The teacher grades students' classroom performance according to their participation, activity, and enthusiasm in the class process. For one-on-one interviews, the teacher converted paper notes of recorded interview questions into typed electronic text after the interview, and the transcribed qualitative data was evaluated using content analysis methods. The specific steps are: First, the transcribed electronic text is encoded. Then, coding is divided into themes according to similar characteristics of coding. A topic and frequency table related to the research question is then created.

After the test results were processed using Microsoft Excel software, IBM SPSS 22 software was used for variance analysis and correlation analysis. The significance level of $p<0.05$ is significant, $p<0.01$ is extremely significant, and Mean±SEM expressed the test results.

3.8 Summary

This chapter mainly discusses the research method used in this paper. The final result of ILE design is to create a suitable learning environment for spatial ability learning in art education. By analyzing the core content and teaching points of the course "Composing Foundation", this chapter forms a fully functional VR prototype that can train spatial ability. It provides a platform for the experimental stage to obtain an effective proof of concept. The user requirements were obtained through a questionnaire survey of many students and a series of discussions with professional teachers. Based on these requirements, the IVRSA learning system is designed and developed. The specific framework of the IVRSA learning system is sorted out through the curriculum standards and teaching points of the course "Composing Foundation". The 3D teaching environment model is developed based on the actual teaching environment. Make the virtual world as realistic as possible by texturing and lighting it before importing it into the virtual environment. The instructional videos are recorded by professional teachers, according to which all the theoretical knowledge that constitutes the foundation is included. These video files were later embedded in the virtual environment to integrate the navigation experience and interactivity by executing a large number of VR scripts. Finally, this chapter describes the evaluation method of the IVRSA learning system after use. Questionnaires and interviews complement the quasi-experimental method. Quantitative data were collected through a questionnaire survey, and qualitative data were collected through observation and interviews.

CHAPTER FOUR

THE VERIFIED CONCEPTUAL MODEL OF SPATIAL ABILITY DEVELOPMENT IN IMMERSIVE LEARNING ENVIRONMENT

This chapter discusses a conceptual model of spatial ability development in an immersive learning environment. By combining the cases of developing spatial ability in ILE, it is found that spatial ability can be cultivated through visual presentation, navigation, mental rotation and transformation, recognition, composition and decomposition, etc. At the same time, the earlier the spatial ability training is carried out, the easier it is for students to understand and master the subsequent professional teaching content and obtain higher academic results. In addition, practical courses, including operation, interaction, discussion, and other learning activities, enrich the learning content, and students are more active in class. Therefore, the conceptual model in this study focuses on enhancing students' enthusiasm for courses and improving learning performance. The solution proposed in this study is to enhance students' sense of embodiment in the course by reasonably constructing the learning situations, learning activities, and learning content to maintain students' participation and achieve better learning performance.

4.1 Spatial Ability in ILE

Spatial ability learning in the virtual world begins with spatial awareness. That is, people must first realize that the body is in a three-dimensional space, and on this basis, they can carry out spatial ability learning, such as spatial direction judgment and object positioning. Consciousness often comes from the real experience of the heart, and the learning process of spatial ability is experiential, emphasizing students' perceptual participation in the learning process. ILE, on the other hand, provides a virtual learning space from which students perceive the existence of space, generate spatial awareness, cause spatial control behaviour, and thus improve spatial ability.

In recent years, researchers have focused on the "immersion" experience in VR and explored the positive effects of ILE supported by VR on improving spatial ability. From the perspective of teaching practice, it is helpful to understand how to develop spatial ability from a more specific level by refining the elements of spatial ability development that match students' cognitive activities. Therefore, the following four teaching cases illustrate the ILE process promoting spatial ability development.

Case 1: Constructing 3D Objects (Hwang et al., 2008)

This learning activity requires students to build "three-dimensional objects" in a virtual environment called Second Life. The completion of the activity requires students to "see" first (visualization) the object, and then find out (recognize) the "3D objects", and then need them from different perspectives to locate and observe the object (navigation), construct various shape of three-dimensional objects, and carries on the move, rotate, deformation, decomposition, combination operation (identification, composition, and decomposition; mental rotation and transformation). From a comprehensive analysis, the main elements related to the development of spatial ability in this learning activity include spatial visual presentation, navigation, mental rotation, transformation, recognition, composition, and decomposition.

Case 2: Mental rotation training (Yeh et al., 2014)

This activity uses virtual reality techniques to perform mental rotation training in an immersive learning environment. As shown in Figure 4.1, students control the emitter to rotate the managed object in the virtual space to make it consistent with the target object. The completion of this activity requires students not only to be able to "see" (visually present) 3D cube blocks in an immersive learning environment but also to be able to rotate and move 3D cube blocks using electromagnetic motion controllers (visualization and presentation, mental rotation, and transformation). From a comprehensive analysis, the main elements related to the development of spatial ability in this learning activity include visual presentation, mental rotation, transformation, recognition, composition, and decomposition.

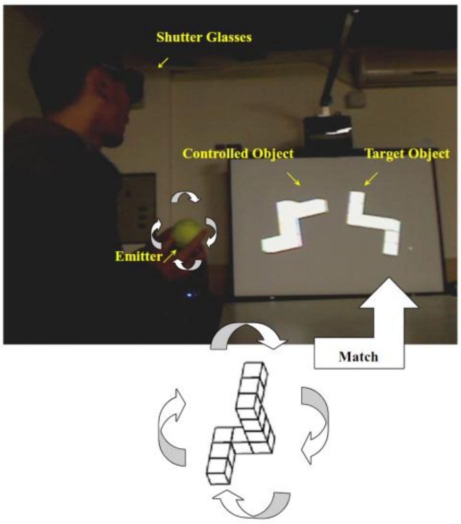

Figure 4.1. Mental rotation training

Case 3: Spatial Orientation Test (Carrera & Saorin, 2017)

The learning environment displays the urban environment through a smartphone mounted in VR glasses, with a joystick controlling the direction of movement (Figure 4.2). In the virtual environment, students must use VR glasses for orientation (visualization and navigation). From a comprehensive analysis, this learning activity mainly involves the following elements related to the development of spatial ability: navigation.

Figure 4.2. Spatial orientation test

Case 4: Manipulating polyhedral blocks (Molina-Carmona et al., 2018)

The activity requires students are required to be able to "see" (visualize) the polyhedral shape, which they are then required to manipulate by moving, rotating, and scaling (identification, composition and decomposition, mental rotation and transformation). In the teaching activities, students use a gyroscope to rotate and interact with those Polyhedral models (Figure 4.3). From a comprehensive analysis, the main elements related to the development of spatial ability in this learning activity include visual presentation, mental rotation, transformation, recognition, composition, and decomposition.

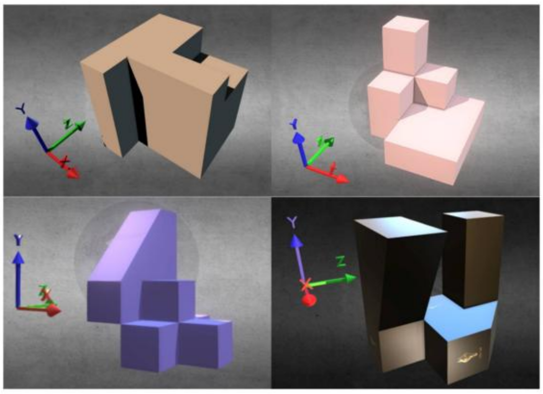

Figure 4.3. The polyhedral models

Table 4.1 summarizes the core elements of spatial ability development in each case and the spatial skills employed.

Table 4.1

The Teaching Cases of ILE

Researchers	Project	Function and Advantage	Spatial Ability	skills
Hwang et al. (2008)	Constructing 3D Objects	The learning activities require students to build "three-dimensional objects" in a virtual environment. It requires students from different perspectives to locate and observe the object, construct various shapes of three-dimensional objects, and carry on the movement, rotation, deformation, decomposition, and combination operation.	Spatial Visualisation Mental Rotation	Visual presentation Composition and decomposition
Yeh, et al. (2014)	Mental Rotation Training	The software uses virtual reality technology to perform mental rotation training in an immersive learning environment. It makes students rotate and move 3D cube blocks using electromagnetic motion controllers.	Mental Rotation Spatial Visualisation	Mental rotation Transformation Identification
Carbonell-Carrera et. al. (2017)	Spatial Orientation Test	The learning environment displays the urban environment through a smartphone mounted in VR glasses, with a joystick controlling the direction of movement. In the virtual environment, students must use VR glasses for orientation.	Spatial Visualisation Spatial Orientation	Visual presentation Navigation
Molina-Carmona, et al. (2018)	Manipulating Polyhedral blocks	The activity requires students to be able to "see" polyhedral shapes and then directs them to manipulate them by moving, rotating, and scaling.	Spatial Visualisation Mental Rotation	Mental rotation Transformation Composition and decomposition

To sum up the above teaching cases, spatial ability is not a single skill or process, and it contains many cross-cutting concepts, methods, and tools that present relevant spatial information and spatial relationships. From the conceptual level of spatial ability, spatial ability refers to recognizing and manipulating (psychologically) objects' spatial characteristics and relationships between objects. From the perspective of its component dimension, spatial ability includes three sub-dimensions: mental rotation, spatial orientation, and spatial visualization. However, in an immersive learning environment, spatial ability can be developed through specific elements such as (1) visual presentation, (2) Navigation, (3) Mental rotation and transformation, and (4) Identification, composition, and decomposition (Davis, 2015).

4.2 Spatial Ability and Learning Performance

Spatial ability is a necessary skill for art students, and "Composing Foundation" is the first lesson for students to contact spatial ability. It is also a forerunner for all professional courses. Students enter professional courses after studying this course. Therefore, this study investigated the learning performance of third-year art students, looking at the same student's learning performance in the Composing Foundation course and their learning performance in subsequent courses related to spatial ability. The specific course arrangement is as follows: First-year course: " Composing Foundation "; Second-year courses: "Production of 3D Rendering", "Panoramic Living Space”; Third-year courses: "VR Construction experience," "Building model Production." Table 4.2 illustrates the data of some students.

Table 4.2

Learning Performance of Art Students in Grade Three

Name	Gender	Basic course (First year)	Specialized course (Second year)		Major core course (Third year)	
		Composing Foundation	**Production of 3D renderings**	**Panoramic living space**	**VR construction experience**	**Building model production**
Student A	Female	95	90	93	88	94
Student B	Female	94	92	90	95	87
Student C	Male	89	90	94	83	95
Student D	Female	87	83	79	90	86
Student E	Female	83	83	80	87	86
Student F	Male	82	85	75	78	83
Student G	Female	78	88	78	71	72
Student H	Male	75	83	71	75	72
Student I	Male	72	69	68	73	66
Student J	Male	70	65	75	66	70
Student K	Male	69	72	68	60	69
Student L	Female	64	74	65	63	70

As seen from Table 4.2, most students with higher learning performance in the course "Composing Foundation" have relatively higher scores in subsequent professional courses. It can be seen that after the initial learning of spatial ability, the level of spatial ability may affect the subsequent learning of professional courses.

4.3 Learning Content and Learning Performance

The art courses are generally divided into theory and practice. Students' learning performance may differ in different types of learning content.

First of all, this study conducted a survey on the course attendance rate of students in the past three years: the average attendance rate for theoretical courses was 92.47%, and the average attendance rate for practical courses was 98.78% (data from the background data of the educational administration system of the school). Subsequently, this study also invited ten professional teachers to score students' classroom performance, including students' "concentration," "engagement," and "activity" in class, using a 5-point Likert scale.

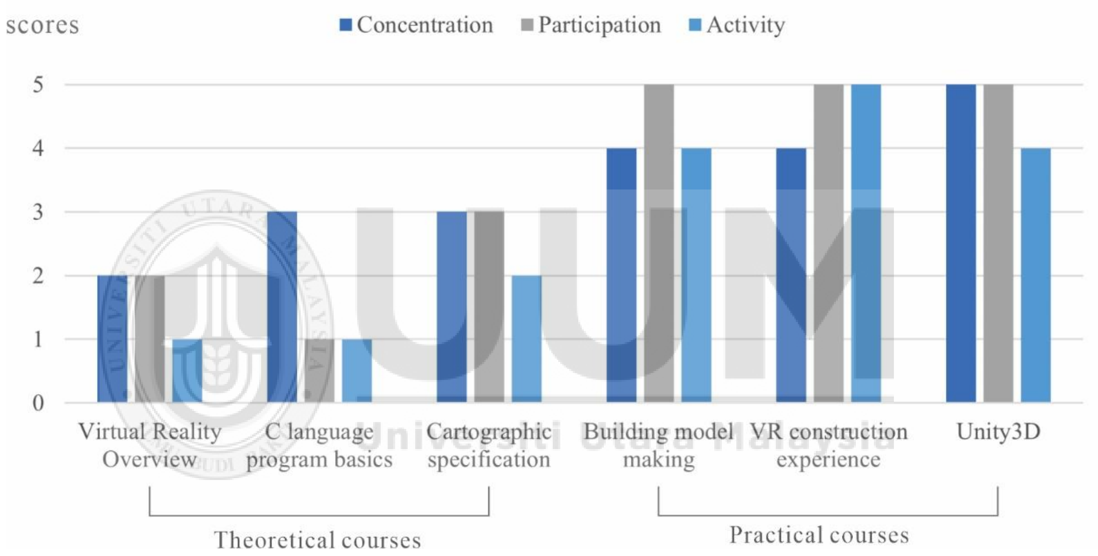

Figure 4.4. Student learning performance in class

Figure 4.4 shows students' classroom performance in both theoretical and practical courses. The average score of "concentration" is 2.67, "participation" is 2, and “activity” is 1.33 in theoretical courses. However, the average score for practical courses was 4.33 for "concentration", 5 for "participation", and 4.33 for "activity". It can be seen that students' performance in "concentration", "engagement", and "activity" in theoretical courses is lower than that in practical courses.

To sum up, students show higher enthusiasm for practical learning content, which may be because practical art courses include learning activities such as operation, interaction, and discussion, which enrich the learning content. Theoretical courses are relatively dull, and students struggle to become interested. However, no matter the course, it should be taken seriously. Therefore, improving students' enthusiasm for all types of learning content is also the focus of the conceptual model in this study.

4.4 The First Version of the Conceptual Model

Conceptual models consist of assumptions, principles, and deterministic assumptions (Sekaran, 2003). It helps researchers identify relationships between components to improve understanding of research problems and solutions (Zulkifli et al., 2013). Hypothetical modelling is an important asset in research because the model can help researchers, designers, and developers visualize the project from the researcher's perspective (Zulkifli et al., 2013).

This study builds a conceptual model of spatial ability in an immersive learning environment based on VR technology. By simulating a real learning environment, students can interact directly with design objects, rotate, identify, compose, and decompose materials, and thus better grasp the connotation of spatial concepts. Therefore, based on the output of the literature review, the first version of the conceptual model is generated. Figure 4.5 shows the conceptual model presented in this study before the expert survey.

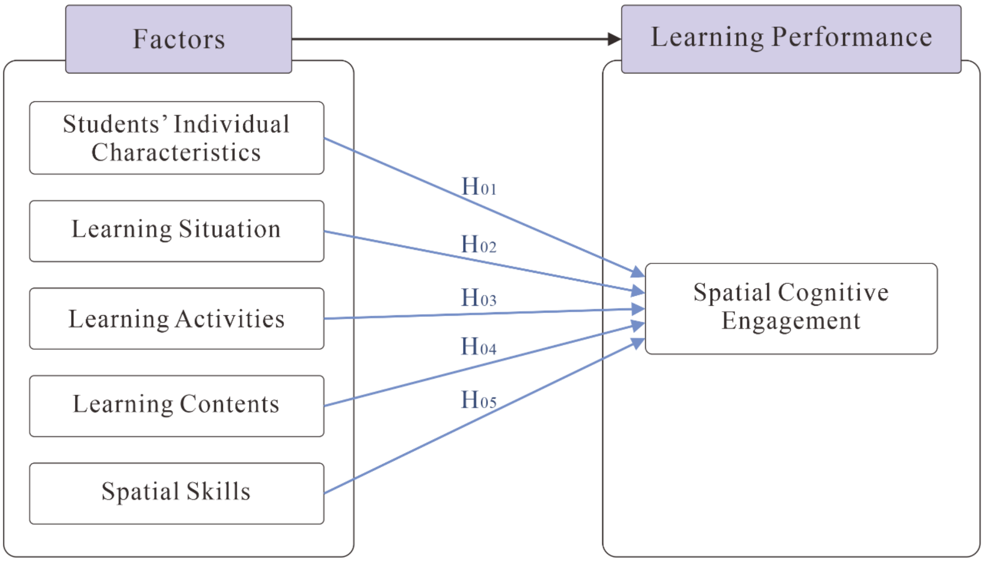

Figure 4.5. The first version of an initial conceptual model of ILE

In cultivating spatial ability, students' individual characteristics, skills, teaching environment, and materials impact students' learning performance. The specific factors include students' individual characteristics, learning situation, learning activities, learning contents, and spatial skills. The conceptual model needs to demonstrate the relationship between spatial ability, immersive learning environment, and learning performance. By observing the performance of students' spatial ability for learning and development in ILE, students' learning performance can be evaluated to verify the validity of this conceptual model.

4.5 Expert Review

After the conceptual model is developed, the proposed ILE conceptual model is validated by industry experts. The instrument for expert review is shown in Appendix I. This validation is important not only for checking the accuracy of the conceptual model but also for effective and executable checks. Section 3.4 describes the expert review methodology.

4.5.1 Results

The first phase of the expert review was a Content validity ratio (CVR) analysis of 52 items on the scale. The results show that 32 items are directly retained with a score of 1. Sixteen questions need to be revised because the score is above 0. Four items below 0 should be removed from these subscales. To sum up, from 52 items, it was found that 48 items had CVR > 0, which was recognised as valid by the experts. Detailed results are shown in Appendix J.

In the second phase, the five subscales were verified. According to the results measured by S-CVI, all the subscales achieved a high level of validity in terms of clarity and comprehensibility, which indicated that the overall validity of the Scales was good. The results of S-CVI are shown in Table 4.3.

Table 4.3

S-CVI for actors affecting spatial ability development

Scales	Number of items with I-CVI values meeting the criterion	Total number of items	S-CVI/Sum
Student learning style scale	17	17	1
Learning Situation scale	3	4	0.75
Learning Activities scale	11	13	0.85
Learning Contents scale	6	7	0.86
Spatial Skill Scale	12	12	1

4.5.2 Discussion

In this study, according to the Learning Style subscale scores, students can be divided into divergent, assimilator, aggregator, and adaptor, which is consistent with the research results of Wilkinson et al. (2014). The study by Wilkinson et al. (2014) shows that the types of students can be distinguished through the learning style subscale so that targeted teaching can be carried out. The findings of Ariastuti and Wahyudin (2022) further prove that different learning styles impact students' learning performance.

The Learning Situation subscale measures a student's experience of flow in the context or context in which learning takes place, making students aware that learning is not isolated but takes place in a specific context and can have a significant impact on how individuals acquire knowledge, skills, and understanding (Pearce et al. 2005). Questions such as "I have more desire to learn in ILE" in this subscale verify the research content of Pelikan et al. (2021). Pelikan used these items to test the learning situation in the experiment, and the research results showed that completing tasks on the computer can get better grades than completing tasks on paper, which is consistent with the view that ILE mode and traditional mode have an impact on students' learning performance in this study.

The Learning Activity subscale measures students' overall course experience in the learning process from four aspects: participation, challenge, interest, and ability (Abdullah 2014; Huang et al. 2016). The subscale examines students' learning performance in spatial ability from the aspects of students' involvement, learning ability, difficulty perception, and learning attitude, which verifies the research of Molina-Carmona et al. (2018). This subscale can further analyse the influence of students' different experiences in learning activities on learning performance by measuring the effect of students' experiences on course learning.

The Learning Content subscale measures students' mastery of basic knowledge, fundamental skills, basic concepts, and some advanced knowledge and skills. Questions such as "ILE provides more space for the curriculum" and "ILE can provide complete information about the coursework" in this subscale verify the views of Pat-el et al. (2013), and research shows that students can use these questions to identify and review classroom assessment practices to support the acquisition of classroom learning content.

The Spatial Skill subscale measures students' mastery of spatial skills in ILE and verifies students' ability to perform mental rotation, navigation, transformation, combination, and decomposition. The questions in Pazzaglia and Moe's (2013) experiment are similar to those in this subscale. Questions such as "I can mirror and flip objects vertically and horizontally" and "I can view maps and draw routes" can effectively measure students' spatial skills. The experiment of Zhou et al. (2022) measured the change in students' spatial skills with the Spatial Skill subscale, and the experiment proved that students' spatial skills were significantly improved in the spatial ability training system developed by VR technology.

The results of the expert review clearly showed that the effectiveness of the scale reached the standard value, and almost all items in the scale were also very positively evaluated, both in terms of content validity and facet validity, which means that these scales are satisfactory as a tool to measure the impact of students' spatial ability learning.

4.6 The Verified Conceptual Model of ILE

By verifying the validity of the scale, this study successfully identified the factors affecting the development of spatial ability. Experts believe that the five factors proposed in the first version of the conceptual model have a certain impact on the development of spatial ability. However, there are some differences between these factors. Students' individual characteristics and spatial skills are internal factors studied from the perspective of students' differences. Learning situation, learning activity, and learning content are external factors studied from the learning environment perspective and belong to the immersive learning environment research category.

Elements of learning situation, learning activity, and learning content include avatar, interaction, navigation, etc., which are discussed in Section 2.7. Therefore, based on the results of the expert review, a modified version of the conceptual model is output.

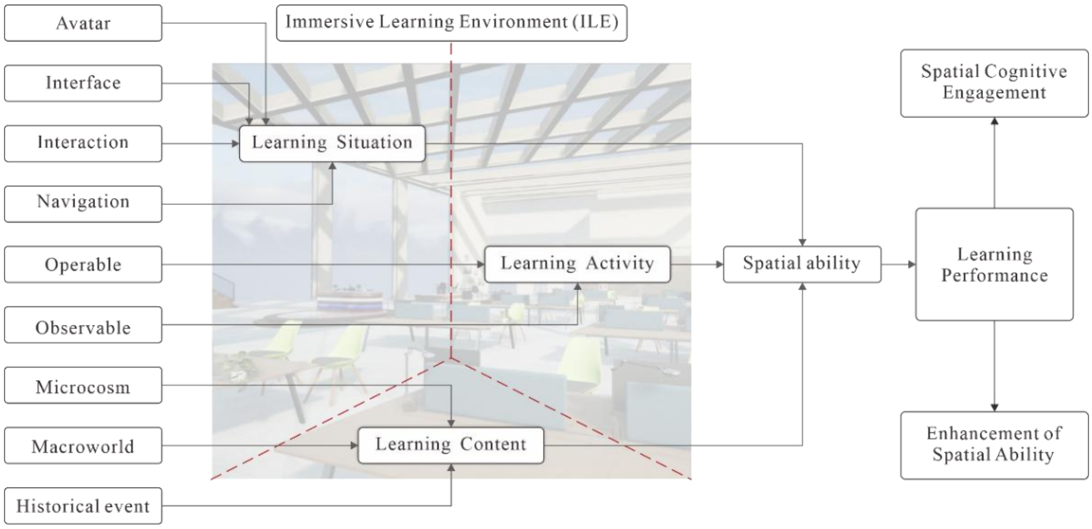

Figure 4.6. The revised version of the conceptual model of ILE

The revised conceptual model retains only three main external factors, namely, learning environment, learning activity, and learning content, to determine the characteristics of ILE. The revised conceptual model illustrates the relationships between several elements: the immersive learning environment provides learning situations, learning activities, and learning content, and students learn and train spatial abilities in the developed VR prototype by wearing HMD helmets and touch gloves. The learning scenario of the VR prototype contains different learning activities and provides learning content related to spatial visual presentation, spatial orientation, and mental rotation. Finally, students' learning performance is reflected through spatial cognitive engagement and enhancement of spatial ability. The measures of spatial cognitive engagement include cognitive load, flow experience, and activity embodiment. The measurement methods for enhancing spatial ability include spatial ability standardized tests and academic ability tests.

4.7 Summary

This chapter first sorted out the relationship between spatial ability, immersive learning environment, and learning performance, identified the ILE factors affecting learning performance in the development of spatial ability, and built the ILE conceptual model of spatial ability. Experts were invited to review the conceptual model, and the verified ILE conceptual model was the output at the end of the evaluation process. In addition, CVR and S-CVI analyses were performed to determine the validity of the instrument contents. The results show that all the proposed ILE factors and characteristics are valid and acceptable. The conclusion of this chapter confirms that the ILE conceptual model is ready for implementation and can be used to teach spatial ability, thus verifying the effect of the conceptual model on learning performance.

CHAPTER FIVE

EVALUATION AND EFFECT ON ENHANCING SPATIAL ABILITY IN IMMERSIVE LEARNING ENVIRONMENT

In this chapter, the experimental results are systematically analyzed, and the impact of an immersive learning environment based on VR is explored, enhancing the spatial ability and learning performance of art students. The results of the Pilot Test confirm that the IVRSA learning system can be used to teach art courses. Therefore, 58 first-year art students were divided into a control group (CG) and an experimental group (EG) to learn spatial ability in traditional learning mode and ILE mode. At the end of the course, students took the spatial ability standardized test (SAST) and academic ability test (AAT), respectively. Then, they completed the spatial ability self-statement report, cognitive load, flow experience, and activity embodiment scales. This study also conducted one-on-one interviews with EG students to analyze their views on ILE mode from a qualitative perspective. The research results show that the learning environment impacts students' spatial ability and learning performance, and learning in ILE can improve students' spatial ability and learning performance more effectively.

5.1 Verification Result of the IVRSA Learning System

The pilot test includes an expert evaluation of the content of the IVRSA learning system and the student’s sense of embodiment after learning spatial ability in traditional learning mode and ILE mode.

5.1.1 Teaching Contents of the IVRSA Learning System

Experts pointed out that the teaching mode of ILE may play a certain role in developing art students' spatial ability. The realistic sense of ILE constructed based on IVRSA reduces students' resistance to the new learning mode and the restriction of the natural environment on spatial ability learning. Students can learn repeatedly in ILE, which is conducive to developing spatial ability. This conclusion also obtained corresponding results from the Wu et al. (2022) experiment. At the same time, the expert test results also reflected whether the questionnaire content reflected the students' spatial ability. Professional teachers pointed out that the original questionnaire did not divide the questions related to spatial visualization, spatial orientation, and psychological rotation, nor did it establish the same number, which may result in students' scores not showing the mastery of each ability.

5.1.2 The Usability of the IVRSA and the Validity Reliability of the Questionnaire

The results showed that students who used the IVRSA learning system were more satisfied with the learning mode than those who used the traditional learning method. Students believe that the ILE learning mode is different from the traditional teaching mode in which teachers show and explain, and students learn passively and can participate in learning more deeply (Guerra-Tamez, 2023; Marougkas et al., 2023). At the same time, students are more willing to use the ILE model to develop spatial ability learning, and they think that they are more willing to accept the ILE model than the unilateral use of slides or video output teaching resources. The IVRSA learning system is easy to operate and lightweight, which not only does not increase the learning process's burden but also helps simplify the learning process (Wu et al., 2021). Using the IVRSA learning system in the curriculum is novel and exciting for students and can stimulate students' learning initiative and motivation, thereby improving their learning attitude (Asad et al., 2021; Wu et al., 2020).

Students said that the knowledge received in traditional classes is completely passive and output by teachers in one direction. A lot of spatial expertise can only be constructed in their minds in 3D space, which consumes many cognitive resources, resulting in low enthusiasm for them in class. They are unwilling to spend much time searching for relevant materials for self-study and completing homework after class. However, by adding scientific and technological elements, learning in ILE mode stimulates students' interest. The IVRSA learning system can display 3D space well and reduce students' cognitive load (Buchner et al., 2021). Therefore, students are active in class learning and take the initiative to collect relevant knowledge and materials for self-study after class. At the same time, the student's test results and process also reflected the difficulty of the questions and the test time. Finally, it was found that the students could complete all the questions. The average time for students to complete the Spatial Ability Standardized Test was 30 minutes, and the average time for the Academic Ability Test was 30 minutes. Spatial ability Self-report, Flow experience, Cognitive Load, and Activity Embodiment Scales are all completed in 1-2 minutes.

The research results show that the IVRSA learning system is more practical, more economical, and more environmentally friendly than other teaching methods because teachers and students do not need to buy a lot of production materials and solve the problem of students' limited funds for the creation of works, as well as the waste of resources caused by the storage or disposal of works (Soliman et al., 2021). The "Composing Foundation" course is developed into the IVRSA learning system, making it a sustainable teaching resource that can be used repeatedly for learning, in line with the concept of green sustainable development.

In addition, with the rapid development of science and technology, traditional online education is faced with a series of problems such as declining students' attention, poor learning effect, low motivation, difficulty in scoring, and lack of situational environment required for courses (Zhao & Wu, 2022). Innovative educational technology is a developing trend. The ILE mode provides a new perspective on spatial ability education for art students and verifies the feasibility and advantages of virtual reality technology in art education.

5.2 Difference Analysis of SAST

5.2.1 The pre-SAST Analysis in CG and EG

This study investigated whether there were differences in students' spatial ability before the experiment, then conducted a one-way ANOVA on students' spatial ability in the control and experimental groups and the changes in the three sub-dimensions before the experiment. Before that, to ensure the rationality of ANOVA, the Shapiro–Wilk test was used to test the normality of data.

The results of the control group show that the value of mental rotation test was 0.937, p=0.085>0.05, the value of spatial orientation test was 0.944, p=0.128>0.05, the value of the spatial visualization test was 0.946, p=0.148>0.05, and the value of overall spatial ability test was 0.932, p=0.060>0.05. In experimental groups, the value of mental rotation test was 0.956, p=0.262>0.05, the value of spatial orientation test was 0.935, p=0.074>0.05, the value of spatial visualization test was 0.956, p=0.257>0.05, and the value of overall spatial ability test was 0.973, p=0.655>0.05. The above data indicate that the samples in this study are in line with normal distribution, and all meet the condition of homogeneity of variance, as shown in Table 5.1.

Table 5.1

Normality Test of pre-SAST in CG and EG

Group	Dimension	Kolmogorov–Smirnov			Shapiro–Wilke		
		Statistics	**Free Degree**	**Significance**	**Statistics**	**Free Degree**	**Significance**
CG	MR	0.153	29	0.080	0.937	29	0.085
	SO	0.168	29	0.037	0.944	29	0.128
	SV	0.167	29	0.038	0.946	29	0.148
	SA	0.182	29	0.015	0.932	29	0.060
EG	MR	0.168	29	0.035	0.956	29	0.262
	SO	0.188	29	0.010	0.935	29	0.074
	SV	0.164	29	0.044	0.956	29	0.257
	SA	0.104	29	0.200	0.973	29	0.655

CG=Contral Group; EG=Experiment Group

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.

The results of one-way ANOVA are shown in Table 5.2. Judging by the results, there was no significant difference in Mental rotation (f=0.033,p=0.856>0.05), spatial orientation (f=0.070, p=0.792>0.05), spatial visualization (f=0.033, p=0.856>0.05), and overall spatial ability (f=0.021, p=0.886>0.05). This showed that the overall level of spatial ability and the basic level of the three sub-dimensions of mental rotation, spatial orientation, and spatial visualization were similar between the control group and the experimental group before the experiment.

Table 5.2

One-way ANOVA Results of pre-SAST in CG and EG

Dimensions	**Group**	**N**	**M**	**SD**	**SE**	***f***	***p***
MR	CG	29	6.759	1.431	0.266	0.033	0.856
	EG	29	6.828	1.441	0.268		
SO	CG	29	6.517	1.639	0.304	0.070	0.792
	EG	29	6.414	1.373	0.246		
SV	CG	29	6.276	1.510	0.280	0.033	0.856
	EG	29	6.207	1.373	0.255		
SA	CG	29	19.552	2.898	0.538	0.021	0.886
	EG	29	19.448	2.544	0.472		

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.

CG=Contral Group; EG=Experiment Group.

N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error.

The distribution of the mean of spatial ability and its three sub-dimensions is shown in Figure 5.1. For the sub-dimension of mental rotation, the level of mental rotation in the control group (M=6.759, SD=1.431) and the experimental group (M=6.828, SD=1.441) was basically the same (mean difference was 0.069). For the sub-dimension of spatial orientation, the level of spatial orientation in the control group (M=6.517, SD=1.639) and the experimental group (M=6.414, SD=1.373) were basically the same (mean difference was 0.103). For the sub-dimension of spatial visualization, the level of spatial visualization in the control group (M=6.276, SD=1.510) and the experimental group (M=6.207, SD=1.373) was the same (mean difference was 0.069). For the overall level of spatial ability, the control group (M=19.552, SD=2.898) and the experimental group (M=19.448, SD=2.544) had the same level of spatial ability (mean difference was 0.104).

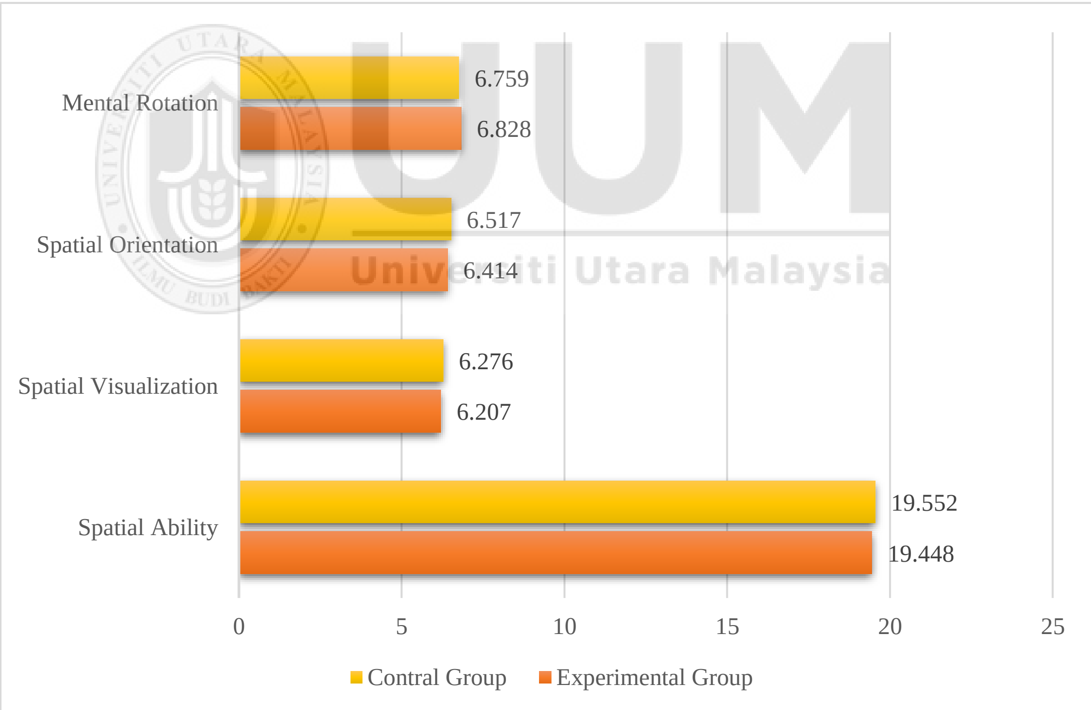

Figure 5.1. Comparison of mean of spatial ability and sub-dimension in CG and EG (pre-test)

The results showed that the students' overall spatial ability (M_{CG}=19.552; M_{EG}=19.448) and mental rotation (M_{CG}=6.759; M_{EG}=6.828), spatial orientation (M_{CG}=6.517;

M_{EG}=6.414), spatial visualization (M_{CG}=6.276; M_{EG}=6.207) the levels of the three dimensions are similar, which indicates that there is no difference in the spatial ability of students before the experiment, which can effectively reduce the impact of differences in initial ability on the final result.

5.2.2 The post-SAST Analysis in CG and EG

After verifying that there is no difference in the student's prior level, this study conducted spatial ability teaching for students in different learning environments to explore whether the learning environment impacts the development of spatial ability.

First, this study carried out a one-way ANOVA analysis of the post-test results of students' SAST. Before that, to ensure the rationality of a one-way ANOVA, the Shapiro–Wilk test was used to test the normality of data. The results show that, in the control group, the value of the mental rotation test was 0.955, p=0.248>0.05, the value of the spatial orientation test was 0.956, p=0.268>0.05, the value of the spatial visualization test was 0.947, p =0.152>0.05. The value of the overall spatial ability was 0.957. p = 0.274 > 0.05; In the experimental group, the value of the mental rotation test was 0.933, p=0.068>0.05, the value of the spatial orientation test was 0.930, p=0.055>0.05, the value of the spatial visualization test was 0.928, p=0.051>0.05, and the value of the overall spatial ability was 0.956. p= 0.254 > 0.05. The above data indicate that the samples in this study are in line with normal distribution, and all meet the condition of homogeneity of variance, as shown in Table 5.3.

Table 5.3

Normality Test of post-SAST in CG and EG

Group	Dimension	Kolmogorov–Smirnov			Shapiro–Wilke		
		Statistics	**Free Degree**	**Significance**	**Statistics**	**Free Degree**	**Significance**
CG	MR	0.164	29	0.044	0.955	29	0.248
	SO	0.148	29	0.103	0.956	29	0.268
	SV	0.141	29	0.147	0.947	29	0.152
	SA	0.120	29	0.200	0.957	29	0.274
EG	MR	0.179	29	0.018	0.933	29	0.068
	SO	0.171	29	0.030	0.930	29	0.055
	SV	0.164	29	0.043	0.928	29	0.051
	SA	0.119	29	0.200	0.956	29	0.254

CG=Contral Group; EG=Experiment Group

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.

The results of one-way ANOVA are shown in Table 5.4. The results showed that there were extremely significant differences in mental rotation (f=8.290, p=0.006<0.01), spatial visualization (f=15.758, p=0.000<0.01), and overall spatial ability (f=30.666, p=0.000<0.01) between the control group and the experimental group. There were significant differences in spatial orientation (f=6.000, p=0.017<0.05), which shows that ILE, based on VR technology, can significantly improve students' overall spatial ability, mental rotation, spatial visualization, and spatial orientation.

Table 5.4

One-way ANOVA Results of post-SAST in CG and EG

Dimensions	Group	N	M	SD	SE	*f*	*p*
MR	CG	29	6.966	1.500	0.278	8.290	0.006
	EG	29	8.035	1.322	0.246		
SO	CG	29	7.035	1.842	0.342	6.000	0.017
	EG	29	8.069	1.334	0.248		
SV	CG	29	6.310	1.692	0.314	15.758	0.000
	EG	29	7.966	1.476	0.274		
SA	CG	29	20.310	2.647	0.492	30.666	0.000
	EG	29	24.069	2.520	0.468		

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.
EG=Experiment Group; CG=Contral Group.
N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error.

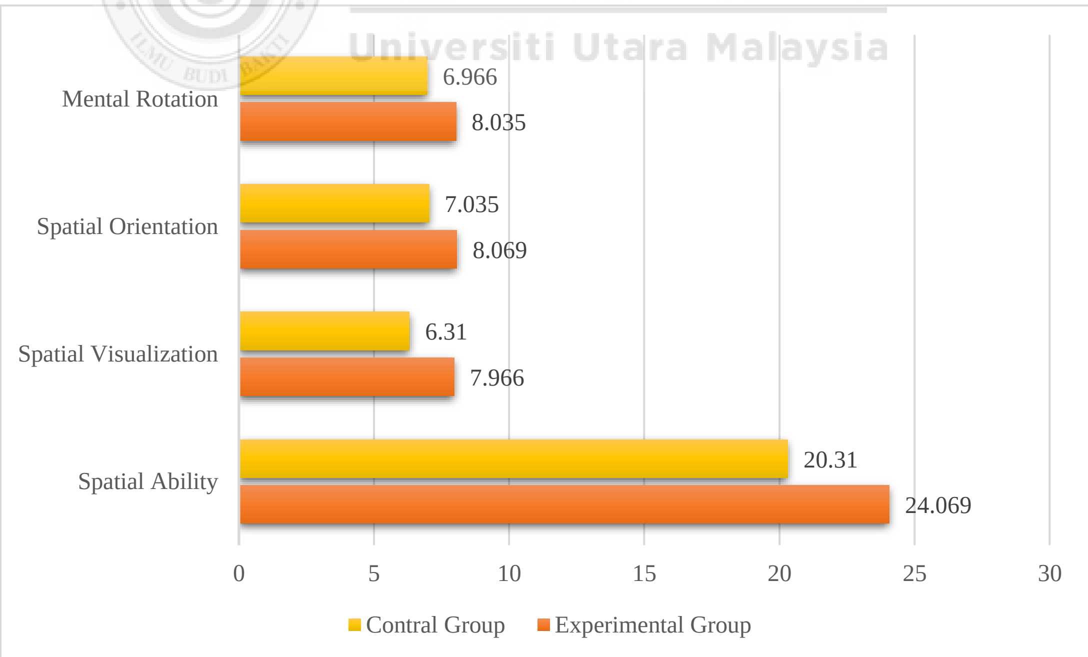

Figure 5.2. Comparison of mean of spatial ability and sub-dimension in CG and EG (post-test)

The distribution of the mean values in spatial ability and its three sub-dimensions are shown in Figure 5.2. Regarding the mental rotation sub-dimension, the experimental group (M=8.035, SD=1.322) had 1.069 mean values higher than the control group (M=6.966, SD=1.500). Regarding spatial orientation sub-dimension, the experimental group (M=8.069, SD=1.334) had 1.034 more mean values than the control group (M=7.035, SD=1.842). Regarding the spatial visualization sub-dimension, the experimental group (M=7.966, SD=1.476) had 1.656 more mean values than the control group (M=6.310, SD=1.692). For overall spatial ability, the experimental group (M=24.069, SD=2.520) had 3.759 mean values higher than the control group (M=20.310, SD=2.647). It can be seen that the mental rotation, spatial orientation, spatial visualization and overall spatial ability of the experimental group were significantly higher than those of the control group.

From the perspective of the overall level of spatial ability, compared with traditional classroom teaching, learning activities carried out in ILE mode can significantly improve the overall level of spatial ability of students (M_{CG}=20.310, M_{EG}=24.069, f=30.666, p=0.000 <0.01), it is consistent with the findings of Supli and Yan (2023), who demonstrated that the experimental group had a statistically significant improvement in the total score of the spatial ability test. The study of Gomez-Tone et al. (2023) also shows that an immersive virtual environment is very effective in spatial skill training.

From the perspective of mental rotation subdimension, compared with traditional classroom teaching, learning activities carried out in ILE mode can significantly improve students' mental rotation ability (M_{CG}=7.035, M_{EG}=8.069, f=6.000, p=0.017<0.05). The results show that the ILE model has certain advantages in cultivating mental rotation ability. In the study of Piri (2023), immersive training environments can improve the ability of mental rotation to convert between two and three dimensions. Piri and Cajy (2023) also proved that three-dimensional space training and training of mental rotation ability is more effective than two-dimensional training.

From the subdimension of spatial orientation, compared with traditional classroom teaching, learning activities carried out in ILE mode can significantly improve students' spatial orientation ability (M_{CG}=7.035, M_{EG}=8.069, f=6.000, p=0.017<0.05), which indicates that ILE model has certain advantages in cultivating spatial orientation ability. The experimental results of Hejtmanek et al. (2020) show that virtual navigation can enhance students' spatial orientation ability and produce significant learning effects. Da Costa et al. (2021) used an immersive virtual environment to test users' spatial orientation ability in a maze, and the results showed that an immersive environment allowed the replication of complex cognitive processes and enabled users to locate and find relevant locations quickly. Experiments conducted by Carrera and Saorin (2017) show that immersive virtual scenes are more effective for students with low spatial navigation ability and can significantly improve their ability to locate spatial positions.

From the perspective of the spatial visualization subdimension, compared with traditional classroom teaching, learning activities carried out in ILE mode can significantly improve students' spatial visualization ability (M_{CG}=6.310, M_{EG}=7.966, f=15.758, p=0.000<0.01), it is consistent with the research results of Conesa et al. (2023). Conesa et al. (2023) experiment proved that the spatial visualization ability of students in the experimental group was significantly improved compared with other groups.

5.2.3 The changes in CG and EG

5.2.3.1 The pre and post-SAST Analysis in CG

The control group's descriptive statistics of the spatial ability and its sub-dimensions before and after the course are shown in Table 5.5. The mean value of the pre-test in mental rotation was 6.759, SD=1.431, and the post-test was 6.966, SD=1.500. The mean value of the pre-test in spatial orientation was 6.517, SD=1.639, and the post-test was 7.035, SD=1.842. The mean value of the pre-test in spatial visualization was 6.276, SD= 1.510, and the post-test was 6.310, SD=1.692. The mean value of the pre-test in overall spatial ability was 19.552, SD= 2.898, and the post-test was 20.310, SD=2.647.

Table 5.5

Descriptive Statistics of pre and post-SAST in CG

Dimension	Test	N	M	SD	SE
MR	Pre-test	29	6.759	1.431	0.266
	Post-test	29	6.966	1.500	0.278
SO	Pre-test	29	6.517	1.639	0.304
	Post-test	29	7.035	1.842	0.342
SV	Pre-test	29	6.276	1.510	0.280
	Post-test	29	6.310	1.692	0.314
SA	Pre-test	29	19.552	2.898	0.538
	Post-test	29	20.310	2.647	0.492

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.
N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error.

In this experiment, a paired sample *t*-test was conducted on the pre-test and post-test results of spatial ability and its sub-dimensions of students in the control group, and the results are shown in Table 5.6. The spatial orientation (t=-2.191, p=0.037<0.05) and overall spatial ability (t=-2.525, p=0.018<0.05) of the control group were significantly different from those of the pre-test. Mental rotation (t=-1.030, p=0.312>0.05) and spatial visualization (t=-0.147, p=0.885>0.05) had no significant differences compared with the pre-test. The experimental results show that the traditional learning model has a positive effect on students' overall spatial ability and spatial orientation ability but has no significant impact on the two sub-dimensions of mental rotation and spatial visualization.

Table 5.6

The Pared-Sample T-Test Result of pre and post-SAST in CG

Dimension	Test	N	M	SD	SE	*t*	*df*	*p*
MR	Pretest-Post test	29	-0.207	1.082	0.201	-1.030	28	0.312
SO	Pretest-Post test	29	-0.517	1.271	0.236	-2.191	28	0.037
SV	Pretest-Post test	29	-0.345	1.267	0.235	-0.147	28	0.885
SA	Pretest-Post test	29	-0.759	1.618	0.300	-2.525	28	0.018

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.
N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error.

5.2.3.2 The pre and post-SAST Analysis in EG

The experimental group's descriptive statistics of the spatial ability and its sub-dimensions before and after the test are shown in Table 5.7. The mental rotation mean value of the pre-test was 6.828, SD=1.441, and the post-test was 8.035, SD=1.322. The spatial orientation mean value of the pre-test was 6.414, SD=1.373, and the post-test was 8.069, SD=1.337; The spatial visualization mean value of the pre-test was 6.207, SD=1.373, and the post-test was 7.966, SD=1.476; the overall spatial ability mean value of the pre-test was 19.448, SD=2.544, and the post-test was 24.069, SD=2.520.

Table 5.7

Descriptive Statistics of pre and post-SAST in EG

Dimension	Test	N	M	SD	SE
MR	Pre-test	29	6.828	1.441	0.268
	Post-test	29	8.035	1.322	0.246
SO	Pre-test	29	6.414	1.373	0.246
	Post-test	29	8.069	1.334	0.248

Table 5.7 continued

SV	Pre-test	29	6.207	1.373	0.255
	Post-test	29	7.966	1.476	0.274
SA	Pre-test	29	19.448	2.544	0.472
	Post-test	29	24.069	2.520	0.468

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.
N=Number; MV=Mean Value; SD=Standard Deviation; SE=Standard Error;

In this experiment, a paired sample *t*-test was conducted for the pre-test and post-test of spatial ability and its sub-dimensions of students in the experimental group, and the results are shown in Table 5.8. Mental rotation (*t*=-7.548, *p*=0.000 <0.01), spatial orientation (*t*=-11.593, *p*=0.000<0.01), spatial visualization (*t*=-12.807, *p*=0.000<0.01), and overall spatial ability (*t*=-16.882, *p*=0.000 < 0.01) compared with the results of the pre-test, the difference was extremely significant. After the experiment, the experimental group's overall spatial ability and the three sub-dimensions of mental rotation, spatial orientation and spatial visualization were higher than before the experiment. The results show that the ILE model significantly affects the overall spatial ability and the three sub-dimensions of mental rotation, spatial orientation and spatial visualization.

Table 5.8

The Pared-Sample T-Test Result of pre and post-SAST in EG

Dimension	Test	N	M	SD	SE	*t*	*df*	*p*
MR	Pretest-Post test	29	-1.207	0.861	0.160	-7.548	28	0.000
SO	Pretest-Post test	29	-1.655	0.769	0.143	-11.593	28	0.000
SV	Pretest-Post test	29	-1.759	0.739	0.137	-12.807	28	0.000
SA	Pretest-Post test	29	-4.621	1.474	0.274	-16.882	28	0.000

MR=Mental Rotation; SO=Spatial Orientation; SV=Spatial Visualization; SA=Spatial Ability.
N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error; *df*= Degree of Freedom.

5.2.3.3 The effect on the different learning environments of SAST

Spatial ability is not innate but a dynamic skill that can be reinforced through interaction with real or virtual objects. Virtual environments and interactive animation are promising tools for training spatial thinking, and dynamic geometric systems can be utilized better to understand spatial relationships (Nagy-Kondor, 2016).

According to the analysis of the two modes, after learning in the traditional teaching mode, the overall level of spatial ability of students has a significant difference of 0.759 mean values (M_{pre}=19.552, M_{post}=20.310) compared with the pre-test score, and the change is significant (t=-2.525, $p=0.018<0.05$). After learning in ILE mode, the overall level of spatial ability of students had a significant difference of 4.621 mean values (M_{pre}=19.448, M_{post}=24.069) compared with the pre-test scores (t=-16.882, $p=0.000<0.01$). The results show that both the traditional learning mode and the ILE mode can improve students' overall level of spatial ability. Still, in ILE mode, students' overall level of spatial ability is improved more significantly, which indicates that ILE has more advantages in cultivating spatial ability.

The virtual environment provides an exciting opportunity for many spatial proficiency training tasks based on reading printed illustrations (two-dimensional planes) to be migrated into an environment with a high degree of three-dimensional interaction and visualization. De Back et al. (2020) study shows that students' learning effect is significantly improved after learning in CAVE (virtual environment) compared with textbook teaching mode. In addition, students benefit from the spatial cues provided by the immersive virtual environment, effectively improving their spatial abilities. Zhou et al. (2022) combined virtual reality technology to develop a system for spatial ability training in an immersive virtual environment. The study found that students' spatial skills were significantly improved through training.

Mental rotation is a spatial skill that requires an individual to mentally rotate objects in space to verify how they look from different angles or perspectives (Reilly. et al., 2016). Mental rotation ability can be better trained using immersive techniques with 3D visualization, authenticity, and interactivity (Piri & Cajltay, 2023).

According to the analysis of the two learning modes, after learning in the traditional teaching mode, students' mental rotation ability has a difference of 0.207 mean values (M_{pre}=6.759, M_{post}=6.966) compared with the pre-test scores, and there is no significant change (t=-1.030, p=0.312>0.05). After learning in ILE mode, students' mental rotation ability had a significant difference of 1.207 mean values (M_{pre}=6.828, M_{post}=8.035) compared with their pre-test scores (t=-7.548, p=0.000<0.01). The results show that the traditional learning mode has no obvious effect on the student's mental rotation ability, while the ILE mode can significantly improve the students' mental rotation ability.

Mental rotation is a challenging task for most people. Essentially, mental rotation is an imagination process that requires visualizing the rotation of a 3D object. Previously, mental rotation ability was trained using two-dimensional representations, but this approach tends to increase students' cognitive load during 3D visualization (Terlecki et al., 2007). One way to improve students' mental rotational reasoning processes is to have them cultivate and practice these imaginative behaviours. Traditional learning models develop mental rotation by analysing and interpreting two-dimensional images, orthogonal views, and graphics on a blackboard or paper. This approach has obvious limitations, as the lack of interaction between students and representations hinders the conceptualization and assimilation of content (Chen et al., 2011). Kadam et al. (2021) enable the mental rotation process to be observed and executed by utilizing virtual reality technology and 3D tools, which allow users to visualize these hard-to-achieve expressions without any media.

VR technology is a useful tool for analyzing spatial orientation (Pastel et al., 2021), and the immersive spatial environment that provides rich multi-sensory cues leads to students' significant acquisition of spatial knowledge. Developing immersive tasks through VR technology can effectively assess spatial orientation (Da Costa et al., 2021).

According to the analysis of the two modes, after learning in the traditional teaching mode, the spatial orientation ability of students has a significant difference of 0.517

mean values (M_{pre}=6.517, M_{post}=7.034) compared with the pre-test score, and the change is significant (t=-2.191, p=0.037<0.05). After learning in ILE mode, the spatial orientation level of students had a significant difference of 1.655 mean values (M_{pre}=6.414, M_{post}=8.069) compared with the pre-test scores (t=-11.593, p=0.000<0.01). The experimental results show that both the traditional mode and ILE mode can improve the spatial orientation level of students. Still, in ILE mode, the spatial orientation level of students is more significantly improved. According to the research of Hejtmanek et al. (2020), immersive learning environments have slight advantages in spatial positioning, navigation, and information transmission compared with traditional learning environments. Pastel et al. (2021) compared the spatial positioning ability of objects in the virtual environment and the real environment through experiments, and the results showed that participants in the virtual environment had higher accuracy in locating objects.

Spatial visualization, which refers to the ability to perceive and mentally reconstruct two-dimensional and three-dimensional objects or models (Linn & Petersen, 1985), plays an important role in spatial ability learning by allowing students to learn to navigate within and between representational patterns (Gilbert, 2005). Spatial visualization represents objects, information as diagrams or other images, or something that forms a mental picture (Tufte, 2001). Zan et al. (2023) proved that an immersive learning environment is conducive to developing spatial ability, which is reflected in improving students' spatial visualization ability and learning enthusiasm.

Rafi et al. (2005) also showed that spatial visualization capabilities can be developed through immersive technologies.

According to the analysis of the two modes, after learning in the traditional teaching mode, the spatial visualization level of students has a difference of 0.034 mean values ($M_{pre}=6.276$, $M_{post}=6.310$) compared with the pre-test scores, and there is no significant change ($t=-0.147$, $p=0.885>0.05$). After learning in ILE mode, students' spatial visualization ability had a significant difference of 1.759 mean values ($M_{pre}=6.207$, $M_{post}=7.966$) compared with their pre-test scores ($t=-12.807$, $p=0.000<0.01$). The results show that the traditional learning mode has no obvious effect on the spatial visualization ability of students. In contrast, the ILE mode can significantly improve students' spatial visualization ability. Yuksel's (2016) study noted that using written materials did not enhance spatial visualization ability. In the traditional teaching of art majors, teachers only explain with simple plans and sections and impart knowledge to students through simple pictures, lacking curriculum interaction, application, and practice. The visualization and interactive manipulation of space provided by an immersive learning environment can promote the development of spatial thinking. Wenk et al. (2021) pointed out that an immersive virtual environment is more stimulating than a 2D effect and can better stimulate individuals' spatial thinking.

5.3 Difference Analysis of AAT

5.3.1 The pre-AAT Analysis in CG and EG

This study conducted an academic ability test of spatial ability for students in the control and experimental groups before the experiment to understand whether students' prior knowledge is similar. A one-way ANOVA was carried out on the test results. Before this, the Shapiro–Wilk test was used to test the normality of data. The results showed that the value of the spatial ability academic ability test in the control group was 0.969, p=0.531>0.05, and that of the experimental group was 0.969, p=0.532>0.05. The research samples were in line with normal distribution, and all met the condition of homogeneity of variance, as shown in Table 5.9.

Table 5.9

Normality Test of pre-AAT in CG and EG

Group	Kolmogorov–Smirnov			Shapiro–Wilke		
	Statistics	**Free Degree**	**Significance**	**Statistics**	**Free Degree**	**Significance**
CG	0.099	29	0.200	0.969	29	0.531
EG	0.094	29	0.200	0.969	29	0.532

EG=Experimental Group; CG=Contral Group.

The results of one-way ANOVA are shown in Table 5.10. There is no significant difference between the control group (M=47.759, SD=22.262) and the experimental group (M=48.621, SD=20.233) in the academic ability test (f=0.024, p=0.878>0.05). It can be seen that the prior knowledge level between the two groups of students was similar before the experiment.

Table 5.10

One-way ANOVA Results of pre-AAT in CG and EG

Dimensions	Group	N	M	SD	SE	*f*	*p*
AAT (pre-test)	CG	29	47.759	22.262	4.134	0.024	0.878
	EG	29	48.621	20.233	3.757		

AAT= Academic Ability Test;

EG=Experimental Group; CG=Contral Group.

N=Number; M=Mean; SD=Standard Deviation.

5.3.2 The post-AAT Analysis in CG and EG

At the end of the experiment, a one-way ANOVA analysis was performed on the academic ability test of the control and experimental groups. Before this, the Shapiro–Wilk test was used to test the normality of data. The results showed that the test value of spatial ability academic ability test in the control group was 0.931, $p=0.060>0.05$ and that in the experimental group was 0.935, $p=0.073>0.05$. The research samples were in line with normal distribution, and all met the condition of homogeneity of variance, as shown in Table 5.11.

Table 5.11

Normality Test of post-AAT in CG and EG

Group	Kolmogorov–Smirnov			Shapiro–Wilke		
	Statistics	Free Degree	Significance	Statistics	Free Degree	Significance
CG	0.139	29	0.162	0.931	29	0.060
EG	0.150	29	0.094	0.935	29	0.073

EG=Experimental Group; CG=Contral Group.

The results of one-way ANOVA are shown in Table 5.12. There were significant differences between the control group (M=53.483, SD=17.681) and the experimental group (M=67.379, SD=19.927) in the academic ability test (f=7.891, p=0.007<0.01).

Table 5.12

One-way ANOVA Results of post-AAT in CG and EG

Dimensions	**Group**	**N**	**M**	**SD**	**SE**	***f***	***p***
AAT (post-test)	CG	29	53.483	17.681	3.283	7.891	0.007
	EG	29	67.379	19.927	3.700		

AAT= Academic Ability Test;

CG=Contral Group; EG=Experimental Group;

N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error;

Then, students carry out spatial ability learning in traditional learning mode and the ILE model. The experimental results show that the major test scores of students in ILE mode (M=67.379) are significantly higher than those in traditional teaching mode (M=52.483), which indicates that ILE mode has a positive effect on improving the professional ability of art students, which has been verified by Chang et al. (2022). In the study of Chang et al. (2022), students carried out learning in virtual reality application and multimedia lecture modes, respectively, and the experimental results showed that the virtual scene learning mode had a positive impact on students' creative design process, aesthetic effect, and originality and novelty of creative design results.

Art majors include interior design, landscape design, packaging design, display design, advertising art design, animation design, and other directions. They have in common that students need subjective creativity, such as artistic thinking and aesthetics, and spatial ability, which is an essential skill for their design and creation. For example, when students carry out interior design, students who do not have a clear grasp of spatial relations easily cause problems such as environmental imbalance and orientation confusion, resulting in unnecessary losses. In the packaging design, the low spatial ability of the packaging plane to three-dimensional conversion process makes it easy to produce deviation, resulting in the final product not being closed or pattern dislocation and other problems. However, an immersive learning environment has potential benefits in art teaching, which makes teaching and learning barrier-free and enables students to use spatial thinking and skills better to create and produce excellent design works (J. Lee et al., 2023).

In the design process, students should not only have a certain ability to solve problems but also have a certain ability to accumulate design knowledge (Demirkan & Hasyrk, 2009). However, many students have difficulty expressing their ideas externally with 2D drawings or 3D models, even with sufficient design knowledge (Kaur et al., 2019). J. Lee et al. (2023) found that immersive virtual reality can help strengthen students' interaction with design space, develop better spatial understanding, and improve students' ability to interact with space, understand spatial information, and solve problems.

5.3.3 The changes in CG and EG

5.3.3.1 The pre and post-AAT Analysis in CG

To further verify the difference in the impact of different learning environments (traditional teaching mode and ILE mode) on students' academic ability, this experiment conducted a paired sample *t*-test on the pre-test and post-test results of the spatial ability academic ability test of students in the control group (traditional teaching mode), and the results were shown in Table 5.13. The post-test results of the control group were significantly different from the pre-test results (t=-2.267, p=0.031<0.05).

Table 5.13

The Pared-Sample T-Test Result of pre and post-AAT in CG

Dimension	Test	N	M	SD	SE	*t*	*p*
AAT	Pretest-Post test	29	-5.724	13.599	2.525	-2.267	0.031

AAT=Academic Ability Test

N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error;

Spatial ability plays a unique role in developing creativity and is a key content in teaching art and design (Tang et al., 2022). Suppose the standard test of spatial ability measures students' spatial thinking and spatial reasoning ability theoretically. In that case, the professional ability test further measures the application of art students' spatial ability in art design and creation in practice.

Before the experiment, this study conducted a pre-test on students to investigate whether there was any difference in their professional ability before the experiment.

The results show no difference in the students' professional ability (M_{CG}=47.759; M_{EG}=48.621). It can be seen that prior knowledge levels among students were similar before the beginning of the teaching experiment, which can effectively reduce the impact of differences in initial ability on the final result.

5.3.3.2 Pre and Post-test Analysis of AAT in EG

To further verify the difference in the impact of different learning environments (traditional teaching mode and ILE mode) on students' academic ability, the paired sample *t*-test was conducted on the pre-test and post-test results of spatial ability academic ability test of students in the experimental group (ILE mode). The results are shown in Table 5.14. The experimental group's post-test results were extremely significantly different from the pre-test results (t=-6.079, p=0.000<0.01).

Table 5.14

The Pared Sample T-test Result of Pre and Post-AAT in EG

Dimension	**Test**	**N**	**M**	**SD**	**SE**	***t***	***p***
AAT	Pretest-Post test	29	-18.759	16.617	3.086	-6.079	0.000

AAT=Academic Ability Test

N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error;

5.3.3.3 The effect on the different learning environments of AAT

To further verify the differences in spatial ability cultivation between the two learning environments, this study analyzed and compared the changes in students' professional ability test results before and after the traditional learning mode and the ILE mode.

In the traditional learning mode, the difference between the students' professional ability test results and the pre-test results was 4.724 mean values (M_{pre}=47.759, M_{post}=52.483), with significant changes (t=-2.267, p=0.031<0.05). In the ILE model, students' professional ability test results showed a significant difference of 18.758 mean values (M_{pre}=48.621, M_{post}=67.379) compared with the pre-test scores (t=-6.079, p=0.000<0.01). The experimental results show that both the traditional learning mode and the ILE mode can guide art students to use spatial ability in artistic design and creation. Still, in ILE mode, students' professional ability is more significant, which is the same as the conclusion of Yang et al. (2018). In a study by Yang et al. (2018), students were assigned to create art in a virtual reality environment and a pen and paper environment, and the results showed that participants in an immersive virtual reality environment had higher quality creative products than those in a pen and paper environment. Analysis of the participants' brain wave sequences also showed that participants in the immersive virtual reality environment maintained more stable attention.

In contrast, those in the pen-and-paper environment were more relaxed. Obeid and Demirkan's (2020) research also shows that immersive virtual design environments can promote participants' creativity in the design process more than non-immersive virtual design environments due to the difficulty in understanding design problems using traditional instructional materials or traditional tools for external representations of design ideas (Kaur et al., 2019).

5.4 Difference Analysis of Spatial Ability Self-perception

At the end of the experiment, the data after the teaching intervention was used to understand whether the spatial ability self-perception of the control and experimental groups differed after the course learning. In this study, one-way ANOVA was used to analyze the changes in students' spatial ability self-perception (SAS), object manipulation ability (OMA), and spatial navigation ability (SNA) in the control and experimental groups.

To ensure the rationality of ANOVA, the Shapiro–Wilk test was used to test the normality of data. The results showed that, in the control group, the test value of OMA was 0.952, $p=0.203>0.05$, the test value of SNA was 0.951, $p=0.198>0.05$, and the test value of SAS was 0.960, $p=0.327>0.05$. In the experimental group, the test value of OMA was 0.972, $p=0.576>0.05$; the test value of SNA was 0.941, $p=0.107>0.05$; the test value of SAS was 0.972, $p=0.620>0.05$. The research samples were in line with normal distribution, and all met the condition of homogeneity of variance, as shown in Table 5.15.

Table 5.15

Normality Test of SAS and sub-Dimensions

Group	Dimension	Kolmogorov–Smirnov			Shapiro–Wilke		
		Statistics	Free Degree	Significance	Statistics	Free Degree	Significance
CG	OMA	0.113	29	0.200	0.952	29	0.203
	SNA	0.176	29	0.022	0.951	29	0.198
	SAS	0.106	29	0.200	0.960	29	0.327

Table 5.15 continued

EG	OMA	0.087	29	0.200	0.972	29	0.576
	SNA	0.186	29	0.011	0.941	29	0.107
	SAS	0.117	29	0.200	0.972	29	0.620

CG=Contral Group; EG=Experimental Group;

OMA=Object manipulation ability; SNA= Space navigation ability; SAS= Spatial ability self-perception

The results of the one-way ANOVA are shown in Table 5.16. The results showed that there were significant differences between the control group (M=48.207, SD=8.347) and the experimental group (M=57.931, SD=8.552) in the SAS (f =19.202, p =0.000<0.01). Further analysis of the sub-dimensions of SAS showed that the control group (M=34.966, SD=6.657) and the experimental group (M=41.483, SD=7.366) had significant differences in OMA (f=12.495, p=0.000<0.01). And there were significant differences in SNA between the control group (M=13.241, SD=2.460) and the experimental group (M=16.448, SD=2.707) (f=22.299, p=0.000<0.01).

Table 5.16

One-way ANOVA results of SAS in CG and EG

Dimensions	Group	N	M	SD	SE	*f*	*p*
OMA	CG	29	34.966	6.657	1.235	12.495	0.000
	EG	29	41.483	7.366	1.368		
SNA	CG	29	13.241	2.460	0.457	22.299	0.000
	EG	29	16.448	2.707	0.503		
SAS	CG	29	48.207	8.347	1.550	19.202	0.000
	EG	29	57.931	8.552	1.588		

OMA=Object manipulation ability; SNA= Space navigation ability; SAS= Spatial ability self-perception

CG=Contral Group; EG=Experimental Group;

N=Number; M=Mean; SD=Standard Deviation; SE=Standard Error;

A key aspect of self-perception in virtual worlds is the sense of embodiment, which is the individual's subjective feeling (Mejia-Puig & Chandrasekera, 2022). In the previous research, this study carried out the SAST and AAT to help students understand the spatial ability level of students from an objective perspective. However, it is impossible to know whether students have experienced spatial reasoning and calculation from a subjective point of view. The spatial ability self-perception is based on students' subjective point of view to understand their self-perception of personal spatial ability. Akcay, M. and Akcay, G. (2017) point out that virtual technology promotes students' positive self-perception and self-efficacy by fostering active participation in learning and improving visualization of complex topics. Students with higher self-perception can improve their self-efficacy, self-confidence, and learning performance (Radianti et al., 2020). Therefore, the spatial ability self-report was adopted in this study to further understand students' subjective consciousness in learning spatial ability and explore the relationship between ILE and learning performance.

In this study, the learning environment influences students' spatial ability self-perception when learning spatial ability. It was found that the spatial ability self-perception in the traditional teaching mode (MCG=48.207) was lower than that in the ILE mode (M_{EG}=57.931). This conclusion has been confirmed by Mysore Harish (2023) and Makransky et al. (2017). They suggest that using immersive technologies to teach spatial abilities may significantly affect students' self-perception of their talent and potential for success. With the development of virtual reality technology, students are more sensitive to the perception of space (Amon, 2023). The virtual learning environment provides students with more comprehensive imagination space and interactive, contextual, and immersive learning opportunities to better feel the abstract process of spatial reasoning (Cheng & Tsai, 2014; Dunleavy & Dede, 2013).

Further analysis of the sub-dimensions of spatial ability self-perception showed that the "Object manipulation ability" (M_{CG}=34.966) of students in traditional learning mode was significantly lower than that in ILE mode (M_{EG}=41.483). Experiments have proved a significant positive correlation between perceptual style and spatial perception ability (Globerson et al., 1985). ILE patterns can give students more spatial concepts and improve their spatial thinking. "Spatial ability of objects" refers to the ability to manipulate two-dimensional or three-dimensional objects in space, which corresponds to the mental rotation and spatial visualization dimensions of spatial ability. Previous studies have confirmed that the ILE model can objectively improve students' mental rotation and spatial visualization abilities. The study of Mysore Harish (2023) further proves that the virtual environment also impacts students' subjective cognitive abilities of mental rotation and spatial visualization.

"Spatial navigation ability" can be defined as routes, directions, cognitive maps, map reading, environmental geometry, spatial information about the surrounding environment, and the location of objects. These spatial skills constitute spatial navigation ability. In this experiment, the "spatial navigation ability" of the traditional learning mode (M_{CG}=13.241) is lower than that of the ILE mode (M_{EG}=16.448), which is the same as the research result of Parong et al. (2020). The experimental results of Parong et al. (2020) show that an immersive environment can better present landmarks, routes, measurements, and other data, enabling students to acquire more spatial knowledge and form spatial navigation thinking. The influence of the learning environment on students' spatial ability is significant (Sun et al., 2018). The research of Zhang et al. (2021) shows that an immersive learning environment can help students develop spatial thinking more effectively, form mental maps, and further expand their navigation knowledge.

To sum up, this experiment proves that, compared with traditional classroom teaching, carrying out "Composing Foundation" learning activities in ILE based on VR technology can significantly improve art students' spatial ability and self-perception of spatial ability.

5.5 Difference Analysis of Cognitive Load

At the end of the experiment, the data after their post-intervention tests were used to understand whether the cognitive load of the control and experimental groups differed. In this study, one-way ANOVA was used to analyze the changes in cognitive load, mental workload, and mental effort of students in the control and experimental groups. To ensure the rationality of one-way ANOVA, the Shapiro–Wilk test was used to test the normality of data. The results showed that in the control group, the test value of mental workload was 0.936, *p*=0.081>0.05; the test value of mental effort was 0.957, *p*=0.284>0.05; the test value of cognitive load was 0.930, *p*=0.056>0.05; In the experimental group, the test value of mental workload was 0.942, *p*=0.115>0.05; the test value of mental effort was 0.956, *p*=0.263>0.05; the test value of cognitive load was 0.941, *p*=0.107>0.05. The research samples were in line with normal distribution, and all met the condition of homogeneity of variance, as shown in Table 5.17.

Table 5.17

Normality test of cognitive load

Group	**Dimension**	**Kolmogorov–Smirnov**			**Shapiro–Wilke**		
		Statistics	**Free Degree**	**Significance**	**Statistics**	**Free Degree**	**Significance**
CG	MW	0.164	29	0.044	0.936	29	0.081
	ME	0.130	29	0.200	0.957	29	0.284
	CL	0.158	29	0.064	0.930	29	0.056
EG	MW	0.159	29	0.058	0.942	29	0.115
	ME	0.150	29	0.095	0.956	29	0.263
	CL	0.149	29	0.098	0.941	29	0.107

CG=Contral Group; EG=Experiment Group

MW= Mental Workload; ME=Mental Effort; CL= Cognitive Load.

The results of the one-way ANOVA are shown in Table 5.18. The results showed that there were significant differences in cognitive load between the control group (M=30.138, SD=3.114) and the experimental group (M=22.379, SD=4.395) (*f*=60.176, *p*=0.000<0.01). Further analysis of the sub-dimensions of cognitive load showed that the control group (M=20.241, SD=2.198) and the experimental group (M=15.035, SD=3.354) had significant differences in "mental workload" (*f*=48.892, *p*=0.000<0.01). And there was a significant difference in mental effort between the control group (M=9.900, SD=1.633) and the experimental group (M=7.345, SD=1.518) (*f*=37.971, *p*=0.000<0.01).

Table 5.18

One-way ANOVA results of cognitive load in CG and EG

Dimensions	Group	N	M	SD	SE	*f*	*p*
MW	CG	29	20.241	2.198	0.408	48.892	0.000
	EG	29	15.035	3.354	0.623		
ME	CG	29	9.900	1.633	0.303	37.971	0.000
	EG	29	7.345	1.518	0.282		
CL	CG	29	30.138	3.114	0.578	60.176	0.000
	EG	29	22.379	4.395	0.816		

MW= Mental Workload; ME=Mental Effort; CL= Cognitive Load.

CG=Contral Group; EG=Experiment Group

N=Number; M=Mean Value; SD=Standard Deviation; SE=Standard Error

The human cognitive structure includes working memory, which has limited duration and capacity (Leppink & Hanham., 2019). Long-term memory has an unlimited capacity for storing automated schemas that can be brought into working memory for processing when needed. A schema is a cognitive structure that enables an individual to organize information according to the user of the information, automating cognitive activities with sufficient practice (Kim & Kishore., 2019). Cognitive load theory is the theory that has to do with the consequences of limited working memory. The theory is an instructional theory based on knowledge of human cognitive structures, with a core focus on the finiteness of working memory (Sweller, 2011). The mental activity that is realized at the same time as working memory is called cognitive load.

Students may experience a certain degree of cognitive load in an immersive learning environment because modern information means, such as virtual reality technology, require students to process a large amount of information they encounter in the learning environment. Cognitive load is generated when data is represented, resulting in cognitive overload (Ginns, 2006). Spatial ability involves transforming 2D and 3D relationships and consumes more cognitive resources. Dan and Reiner (2017) showed that the cognitive load index of watching a 2D teaching video on a computer was much higher than that of watching a 3D teaching movie. According to this theory, when dealing with highly interactive teaching materials, instructional designers should first consider the limitation of working memory (Sweller, 2011). Therefore, in the instructional design process, any unnecessary burden on working memory should be minimized, and the opportunity to acquire and develop automated schemata should be maximized. The theory also suggests that good instructional design should allow working memory resources to focus on learning rather than extraneous activities unrelated to the learning process. In this study, some teaching design principles proposed by cognitive load theory are referred to, and a learning environment design and presentation strategy based on virtual reality technology is constructed.

There is evidence that displaying data in virtual reality can reduce unnecessary load. Several studies have demonstrated that using AR in education can bring specific learning benefits, such as reducing cognitive load (Papakostas et al., 2021). Building on this, Darwish proposes that spatial learning can be enhanced by creating an environment that may reduce cognitive load (Darwish et al., 2023), especially for complex learning materials. Increasing relevant information elements' spatial or temporal continuity can lead to substantial learning gains (Papakostas et al., 2021). Sound instructional design should allow working memory resources to be focused on learning rather than external activities unrelated to the learning process.

In this study, the learning environment influenced students' cognitive load when learning spatial ability. It is found that the cognitive load of students' learning spatial ability in traditional teaching mode (M=30.138) is higher than that in ILE mode (M=22.379), which is consistent with the research results of Khalil et al. (2010) and Elford et al.,(2022). The research results of Khalil et al. (2010) are consistent with the cognitive load theory. Compared with traditional paper-based teaching strategies, innovative computer teaching strategies reduce external cognitive load. Elford et al. (2022) found that the performance of spatial ability between the observation groups based on slide teaching and VR teaching was significantly improved.

Mental workload and mental effort are important components of cognitive load (Paas & Van Merrienboer, 1994). Further analysis of the subdimensions of cognitive load showed that the mental workload (M_{MW}=20.241) and mental effort (M_{ME}=9.900) of students' learning spatial ability in traditional teaching mode were higher than those in ILE mode (M_{MW}=15.035; M_{ME}=7.345). It showed that immersive learning environments based on VR technology can significantly reduce students' mental workload and mental effort compared with traditional classroom teaching. Cai et al. (2023) pointed out that students must make certain mental efforts to learn spatial skills such as mental rotation, spatial orientation, and spatial visualization. The presentation of a virtual learning environment simplifies the learning process and gives students more cognitive resources to learn spatial knowledge. Yan et al. (2010) also proved that compared with traditional teaching (static picture + text explanation + video), the learning environment of immersive teaching (virtual scene + dynamic picture + voice explanation) can effectively reduce students' mental workload and mental effort, and improve learning efficiency and effect.

Cognitive resources theory holds that human cognitive resources are limited. When the cognitive load is high, the higher-order cognitive resources used for attention allocation are occupied, so students cannot effectively inhibit their responses to task-independent stimuli and thus are susceptible to interference from task-independent stimuli. Conversely, when cognitive load is low, students have sufficient cognitive resources to suppress their responses to task-independent stimuli to focus on learning tasks (Lavie and Tsal 1994; Lavie et al. 2004).

Traditional teaching modes (such as video or animation) consume a lot of students' cognitive resources, increase cognitive load, and lead to the limited spatial ability of students to learn (Liu et al., 2022). According to cognitive load theory, this can decrease learning performance (Mayer, 2001). Cultivating spatial ability requires students to spend a lot of cognitive resources. Students need to use mental rotation, spatial orientation, navigation, and other spatial skills to build 3D models in their minds. Sweller (2011) believes that working memory is limited, which may affect students' recognition, composition, and decomposition of 3D models. ILE can provide a wider range and a higher degree of synthetic sensory stimulation to enhance art students' perception of space (Serrano-Ausejo and Marell-Olsson, 2023). By visualizing the steps of building 3D models, students can better construct mental models and reduce the cognitive memory they consume in recognizing 3D models, leaving enough working memory time for understanding, composing, and decomposing 3D models. Finally, students' cognitive load is reduced, and their learning performance is improved (Liu et al., 2022).

Therefore, this experiment proves that the learning environment impacts students' cognitive load, and the cultivation of spatial ability in ILE can effectively improve students' spatial ability. Learning spatial skills in ILE brings about a positive experience for students. For students, assembling in a virtual space may seem like an interesting novelty, more exciting than learning in a real physical space. Student acceptance of the ILE model is essential, as student interest in VR is one of the main drivers of its adoption in education (Rojas-Sanchez et al., 2022).

With the rapid development of computer technology, VR technology has unique advantages in simulating reality, interactivity, visibility, and expansion of design ideas of the objective world. The results of this study may be favourable because ILE based on VR technology may be a more accurate medium for assessing spatial skills than traditional teaching (Bartlett & Camba, 2022). Therefore, innovative educational technology is a development trend, and ILE provides a new perspective for spatial ability learning, verifying the feasibility and advantages of virtual reality technology in education (Wu et al., 2022).

5.6 Difference Analysis of Flow Experience

At the end of the experiment, the data after their post-intervention tests were used to understand whether the flow experience of the control and experimental groups was different after the course. This study used one-way ANOVA to analyze the flow experience changes between the control and experimental groups.

To ensure the rationality of ANOVA, the Shapiro–Wilk test was used to test the normality of data. The results showed that the test value of the flow experience in the control group was 0.941, $p=0.108>0.05$ and that in the experimental group was 0.972, $p=0.627>0.05$. The research samples were in line with normal distribution, and all met the condition of homogeneity of variance, as shown in Table 5.19.

Table 5.19

Normality Test of Flow Experience in CG and EG

Group	Kolmogorov–Smirnov			Shapiro–Wilke		
	Statistics	Free Degree	Significance	Statistics	Free Degree	Significance
CG	0.146	29	0.114	0.941	29	0.108
EG	0.114	29	0.200	0.972	29	0.627

CG=Contral Group; EG=Experiment Group

The results of the one-way ANOVA are shown in Table 5.20. The results showed that there were significant differences in flow experience between the control group (M=38.586, SD=4.917) and the experimental group (M=45.690, SD=5.022) (*f*=29.621, p =0.000<0.01).

Table 5.20

One-way ANOVA Results of Flow Experience in CG and EG

Dimension	Group	N	M	SD	SE	*f*	*p*
Flow Experience	EG	29	38.586	4.917	0.913	29.621	0.000
	CG	29	45.690	5.022	0.933		

CG=Contral Group; EG=Experiment Group

N=Number; M=Mean Value; SD=Standard Deviation; SE=Standard Error

Flow Experience was first proposed by Csikszentmihalyi (2001), who believes that individuals fully invest their energy in a certain activity while generating a high degree of excitement and a sense of fulfilment, which is called flow. The user is not limited by time and space in the virtual scene, is very motivated to invest in the whole body, and is guided to a delightful mental state- a flow experience. Studies have shown that flow experience runs through the whole process of learning activities and affects students' willingness to continue learning (Wang et al., 2017), and is more likely to stimulate personal motivation and achieve positive results (Chen & Hsu, 2020; Finneran & Zhang, 2005).

In this study, the learning environment influences students' flow experience when learning spatial ability. It is found that the flow experience of students' learning spatial ability in the traditional teaching mode (M_{CG}=38.586) is lower than that in the ILE mode (M_{EG}=45.690), which is consistent with the research results of Wang and Zhang (2018). They believe that a virtual learning environment enables students to pay more attention. Create more flow. Cheng et al. (2024) also pointed out that flow experience plays a significant role in virtual space learning. The experiments of Martin and Wiemeyer (2012) also show that stereoscopic 3D presentation and first-person perspective shooting can enable users to experience more profound spatial existence and produce strong changes in flow.

Flow theory holds that when individuals feel a stronger sense of presence, they are more inclined to enter the flow state, which plays a direct role and positively impacts engaging in virtual environment learning (Ozhan & Kocadere, 2019). At the same time, this kind of experience can reduce students' feelings of isolation in the virtual learning environment to a certain extent, thus stimulating students' participation in learning activities (Dai & Liu, 2015). Students gain a sense of presence and experience in the virtual space, which can enhance their confidence and motivation for learning, help students concentrate, and significantly improve the effect and quality of learning. Especially in virtual learning scenarios, once students feel the support and recognition of the environment, they are more likely to reach a state of flow, thus improving their learning effectiveness and motivation to continue learning (Cesari et al., 2021). According to the research of Mesurado et al. (2015), when students think they are capable of learning, they are more likely to have a flow experience and participate in learning activities more. Hong et al. (2018) also pointed out that students with a high-flow experience were more interested in learning content in a virtual space, and their learning performance greatly improved.

Therefore, in the learning process of an immersive learning environment, when students have a higher flow precursor of presence and experience, it is easier to form a pleasant flow experience, which has a positive and positive impact on learning (Mesurado et al., 2015), which makes students more willing to continue learning and ensuring better learning performance.

Therefore, this experiment proves that the learning environment impacts students' flow experience, and learning in ILE can effectively improve students' flow experience and thus effectively improve their spatial ability.

5.7 Difference Analysis of Activity Embodiment

At the end of the experiment, the data from their post-intervention tests were used to explore whether there were differences in the activity embodiment between the control and experimental groups. In this study, one-way ANOVA was performed on the activity embodiment and changes in four sub-dimensions of students' “Involvement,” “Ability,” “Challenge,” and “Interest” in the control and experimental groups.

To ensure the rationality of ANOVA, the Shapiro–Wilk test was used to test the normality of data. The results of the control group showed that the value of “Involvement” was 0.967, p=0.471>0.05, the value of “Ability” was 0.961, p=0.338>0.05, the value of “Challenge” was 0.952, p=0.207>0.05, the value of “Interest” was 0.958, p =0.289>0.05, and the value of “Activity Embodiment” was 0.933, p=0.068>0.05.

In the experimental group, the value of “Involvement” was 0.934, p=0.072>0.05, the value of “Ability” was 0.949, p=0.177>0.05, the value of “Challenge” was 0.942, p=0.115>0.05, the value of “Interest” was 0.931, p=0.058>0.05, and the value of “Activity Embodiment” was 0.956, p=0.263>0.05. The research samples were in line with normal distribution, and all met the condition of homogeneity of variance, as shown in Table 5.21.

Table 5.21

Normality Test of Activity Embodiment in CG and EG

Group	Dimension	Kolmogorov–Smirnov			Shapiro–Wilke		
		Statistics	Free Degree	Significance	Statistics	Free Degree	Significance
	Involvement	0.125	29	0.200	0.967	29	0.471
	Ability	0.097	29	0.200	0.961	29	0.338
CG	Challenge	0.182	29	0.015	0.952	29	0.207
	Interest	0.150	29	0.093	0.958	29	0.289
	Activity Embodiment	0.130	29	0.200	0.933	29	0.068
	Involvement	0.168	29	0.037	0.934	29	0.072
	Ability	0.173	29	0.027	0.949	29	0.177
EG	Challenge	0.164	29	0.045	0.942	29	0.115
	Interest	0.190	29	0.009	0.931	29	0.058
	Activity Embodiment	0.115	29	0.200	0.956	29	0.263

CG=Contral Group; EG=Experiment Group

The results of the one-way ANOVA are shown in Table 5.22. According to the results, the students in the control group (M=46.310, SD=6.274) and the experimental group (M=49.586, SD=3.670) had significant differences in Activity Embodiment (f=5.891, p=0.018<0.05). Further analysis of the sub-dimension of Activity Embodiment showed that there was an extremely significant difference between the control group (M=10.345, SD=1.798) and the experimental group (M=12.172, SD=1.466) in " Involvement" (f=17.998, p=0.000<0.01). There were significant differences between the control group (M=22.551, SD=3.951) and the experimental group (M=24.276, SD=2.359) in "Ability" (f=4.071, p=0.048<0.05). There was an extremely significant difference between the control group (M=6.207, SD=1.520) and the experimental group (M=5.138, SD=1.274) in "Challenge" (*f*=8.419, *p*=0.005<0.01). There were significant differences between the control group (M=7.207, SD=1.497) and the experimental group (M=8.000, SD=1.282) in "Interest" (*f*=4.696, *p*=0.034<0.05).

Table 5.22

One-way ANOVA Results of Activity Embodiment in CG and EG

Dimensions	**Group**	**N**	**M**	**SD**	**SE**	***f***	***p***
Involvement	CG	29	10.345	1.798	0.334	17.998	0.000
	EG	29	12.172	1.466	0.272		
Ability	CG	29	22.551	3.951	0.734	4.071	0.048
	EG	29	24.276	2.359	0.438		
Challenge	CG	29	6.207	1.520	0.282	8.419	0.005
	EG	29	5.138	1.274	0.236		
Interest	CG	29	7.207	1.497	0.278	4.696	0.034
	EG	29	8.000	1.282	0.238		
Activity Embodiment	CG	29	46.310	6.274	1.165	5.891	0.018
	EG	29	49.586	3.670	0.681		

CG=Contral Group; EG=Experiment Group

N=Number; M=Mean Value; SD=Standard Deviation; SE=Standard Error

"Activity Embodiment" refers to the overall experience effect of students on the course in the learning process (Kolb,2014). By engaging in learning activities, students understand the core elements of the learning task and explore the relationship between the concept and meaning of the activity. However, the amount of knowledge and insights students gain during participation is affected by the experience effect (Clark et al., 2010). Laricheva and Ilikchyan (2023) believe that ILE, based on VR technology, can use the proximity effect to create an immersive learning experience for students struggling with spatial images to obtain a better course experience effect.

In this study, the learning environment influences students' experiential activities when learning spatial ability. It is found that the experiential activities of students' learning spatial ability in the traditional teaching mode (M=46.310) are lower than those in the ILE mode (M=49.586), which indicates that using the immersive learning environment based on VR technology to learn the basic curriculum can improve the effect of students' experiential activities. Cai et al. (2023) believe that the way information presentation has a significant impact on the learning effect, and a lifelike virtual environment has a strong positive impact on the experience effect of students in the learning process (Maulana et al., 2016; Lester et al., 1997).

Further analysis of the subdimensions of experiential activities shows that when students learn spatial ability in the traditional teaching mode, the "engagement" (M_{CG}=10.345) is lower than that in the ILE mode (M_{EG}=12.172). "Engagement" refers to the student's learning engagement when participating in curriculum activities. Park, Flowerday, et al. (2015) believe that in the one-to-many environment, that is, the traditional teaching mode, due to the lack of diversity of forms of expression, cannot meet the needs of individual students for the diversity of things, and it isn't easy to make students actively invest in and participate in learning. Therefore, an immersive learning environment based on VR technology can give students more freshness and make students more involved in education (Zou et al., 2023). Immersive learning environments reduce the influence of other surrounding factors on students (Serkwem et al., 2024), which can effectively improve students' concentration and prevent distraction.

"Ability" refers to the student's learning ability when participating in course activities. In this experiment, when students learn spatial ability in traditional mode, "ability" (M_{CG}=22.551) is lower than that in ILE mode (M_{EG}=24.276). It indicates that ILE can better demonstrate students' ability, which is consistent with the research conclusion of Agbo et al. (2023). They believe that immersive and interactive experiences can improve students' understanding. In the experiment of Ma and Ouyang (2020), the virtual environment makes students feel real and friendly, reduces the anxiety caused by language communication, and enables students to devote themselves to learning and show their abilities. Bagher et al. (2022) also proved that students in ILE mode have significantly higher reflective thinking than students in traditional learning mode.

"Challenge" refers to students' perception of the difficulty of the course activity process. In this experiment, when students learn spatial ability in the traditional mode, the "challenge" (M_{CG}=6.207) is higher than the ILE mode (M_{EG}=5.138). When students face challenges in the course, the technical services provided by the immersive learning environment based on VR technology can reduce the difficulties encountered by students, which is consistent with the experimental results of Valenti et al. (2020). Valenti et al. (2020) found that students learning in virtual environments better understand how to evaluate their learning content than those in traditional teaching mode. Moreover, students' anxiety about learning is slightly reduced, and they are satisfied with virtual reality technology. Aguayo and Eames (2023) also proved that a virtual immersive learning environment can encourage students to carry out independent learning and make it easier to understand complex knowledge.

"Interest" refers to the student's learning attitude towards participating in course activities. In this experiment, when students learn spatial ability in the traditional mode, "interest" (M_{CG}=7.207) is lower than that in the ILE mode (M_{EG}=8.000). Engaging technology increases students' knowledge of the environment and fosters a more positive emotional attachment to the environment, thereby developing an interest in the teaching environment. Compared with the traditional model in which teachers explain, and students learn according to instructions, the ILE model successfully stimulates students' positive emotions and improves learning. In the study by Del Cerro Velazquez and Mendez (2021), students had a positive view of the virtual environment, which captured their attention from the beginning and increased their interest and motivation for learning.

In the interview after the learning activity, the students said the immersive "Composing Foundation" course was exciting. The self-exploration mode provided by the IVRSA learning system could stimulate their learning interest and enthusiasm, which was more helpful for their spatial ability learning, which was also verified in the experiment conducted by Huang et al. (2016). The experiment of Huang et al. (2016) shows that virtual learning spaces stimulate students' interest, and students get more fun from learning, become more focused on learning, and obtain higher learning performance.

This study proves that the learning environment impacts students' experiential activities. Compared with traditional classroom teaching, the use of an immersive learning environment based on VR technology for spatial ability learning can not only significantly improve students' "input," "ability," and "interest" but also reduce the "challenge" of students from teaching difficulties in the course. Learning in ILE can stimulate students' experience, thus effectively improving students' spatial ability and learning performance.

5.8 Qualitative Research and Analysis of Spatial Ability

To support the quantitative research results, this study conducted one-to-one semi-structured interviews with 29 students in the experimental group. In response to the interview question: "What are your thoughts on learning the relevant knowledge of the course of" Composing Foundations "in ILE?". According to the interview results, most students believe that the course "Composing Foundation" in ILE has a positive effect on their learning. Table 5.23 presents the results of students' qualitative analysis of the use of immersive technologies that constitute the foundation course.

Table 5.23

Students' Thoughts and Feelings about Learning in ILE

Fields	Theme	Percentage
knowledge	I can learn more knowledge in ILE.	64.29%
Spatial thinking	Learning in ILE has stimulated my spatial thinking.	46.43%
Immersion	Studying in ILE makes me feel like reality.	42.86%
Hands-on practice	Learning in ILE allows me to practice manually.	39.29%
Interest	It is very interesting to study in ILE.	35.71%
Pleasure	Studying at ILE makes me very happy.	28.57%
Stereoscopic presentation	ILE can render three-dimensional objects.	32.14%
Interactivity	I can have all kinds of interactions in ILE.	21.43%
Usability	Compared with traditional courses, ILE is more convenient to study.	17.86%

As can be seen from Table 5.23 above, 64.29% of the students believe that ILE has a positive effect on their learning performance, and they think that the course can help them understand basic knowledge; 46.43% of students believe that learning in ILE can stimulate their spatial thinking, and they feel that rotating, dragging and splitting objects can make they're thinking active; 42.86% of the students believe that ILE has a strong sense of immersion and reality, which makes people immersive; In addition, 39.29% of students think that they can exercise their practical ability in ILE, and practice in ILE is accessible from the practical problems of location factors, and they can practice anytime and anywhere. In addition, 35.71% of students think that learning in ILE is very interesting and that the course and learning content are exciting. 28.71% of the students think that learning in ILE is full of pleasure, and the course makes them happy. Here are some examples from student interviews:

"The environment is novel, and the curriculum is rich and interesting, allowing us to learn about space composition."

"There is a lot of fun so that our minds can be active."

"The virtual classroom atmosphere makes me feel relaxed and fun."

"It requires a lot of hands-on, and the mind needs to be more active."

In addition, some students also described the advantages of immersive technology from the perspective of its characteristics. Students pointed out that ILE can present three-dimensional objects (32.14%) and has strong interactivity (21.43%). Besides, ILE is more convenient than traditional courses, which can save a lot of material costs and time and carry out learning anytime and anywhere (17.86%). Here are some examples from their interviews:

"The object shape presented in the virtual classroom is three-dimensional and beautiful."

"The virtual classroom adds interactive links to make the course lively and interesting."

"A virtual classroom is more convenient than a traditional classroom, and it can save a lot of materials and time."

5.9 Summary

The purpose of measuring spatial ability change is to determine the validity of the ILE conceptual model based on the IVRSA learning system. This study used comparative tests and statistical analysis techniques, such as one-way ANOVA, normality test, and corresponding paired sample t-test, to analyze students' spatial ability and learning performance changes. The results show that compared with traditional classroom teaching, using ILE based on VR technology can significantly improve students' spatial ability and professional skills. In terms of learning performance, using ILE based on VR technology to conduct learning activities that constitute basic courses can significantly improve students' flow experience and enhance their learning experience. At the same time, the learning environment can also reduce students' cognitive load and reduce the interference of external factors in learning. In addition, interviews with students show that there are many advantages to an immersive "Composing Foundation" course. For example, most students believe that the immersive "Composing Fundation" course positively affects their knowledge learning and that the course can teach more Composing Fundation. At the same time, students think the immersive "Composing Foundation" course is very interesting and can stimulate their interest in and enthusiasm for learning. This course can exercise students' practical ability, have an immersive experience, and have strong interaction, which can save a lot of materials and time.

CHAPTER SIX

CONCLUSION

This chapter describes the conclusion and prospect of this research and discusses the influence of an immersive learning environment oriented to spatial ability development on students' spatial ability. This chapter also discusses the contribution of conceptual models to the spatial ability development of art students, as well as the limitations of this study and suggestions for future research.

6.1 Research Objective Achievement

This study aims to provide the ILE conceptual model for art students' spatial ability development, which is achieved by dividing the research goal into three research objectives, as stated below.

RO1: To determine the factors that enhance spatial ability through the immersive learning environment in art education.

Through systematic analysis and literature review, this study achieved its research objective (RO1), as described in Section 2.7. Understanding these developmental elements can help guide the development of spatial capacity in schools' educational environments.

This research finds that the immersive learning environment oriented to spatial ability development is a learning environment with the development of spatial ability as the goal, virtual reality technology as the medium, and the integration of students' characteristics, learning context, learning content, and learning activities. This learning environment is a new kind of immersive learning environment, which has great application potential in the field of education. However, the design of the learning environment should follow certain design principles, meet the required design elements, and design learning activities according to the specific development elements of spatial ability to play students' main role in the environment. The factors affecting the development of spatial capabilities are defined as follows:

i: Learning situation

Learning context refers to the environment or context in which learning occurs and is influenced by external factors that affect the sustainability of internal activities (Asvio, 2017). Its core is to set the learning content in a real or simulated specific environment so that students can learn and apply knowledge and skills in this environment.

ii: Learning activity

Learning activity is a kind of active participation of students in the teaching process, which is a process in which they acquire knowledge needs and change the external environment (Pranoto & Suprayogi, 2021).

iii: Learning content

Learning content refers to information, materials, resources, and pedagogical elements provided to students to facilitate the acquisition of knowledge, skills, or understanding in an educational setting (Al-Samarraie et al., 2013; Chen & Chen, 2022). The learning content should also have a certain epochal and forward-looking. The design and selection of learning content should consider students' age, gender, interests, learning ability and other factors. To meet the needs of social and individual development.

RO2: To construct a conceptual model of enhancing spatial ability through the immersive learning environment in art education based on the identified factors.

RO2 is realized by analyzing the relationship between spatial ability, immersive learning environment and academic performance and combining the factors affecting spatial ability development identified by RO1. The results of RO1 support the design of the ILE conceptual model to cultivate art students' spatial ability in teaching and improve their learning performance.

This study developed the IVRSA learning system to verify the validity of the ILE conceptual model, composed of the course "Composing Foundation" and suitable for art students. An iterative cycle is then used in expert review to determine the validity of the conceptual model. The results show that experts believe the proposed ILE conceptual model is practical and can be effectively implemented to improve students' learning performance.

RO3: To evaluate a conceptual model of enhancing spatial ability through the immersive learning environment in art education by the changes in students' learning performance.

RO3 is evaluating the validity of the ILE conceptual model. This study carried out an experiment on the " Composing Foundation " course based on an immersive learning environment and determined students' learning performance by setting up a control group and an experimental group and carrying out pre and post-tests. The results show that ILE can significantly improve students' spatial ability and academic ability, and affect students' spatial ability self-perception, cognitive load, flow experience and activity experience.

At the same time, the one-on-one semi-interview after class also confirms this view from the side. The students believe that the immersive "Composing Foundation" course can present three-dimensional "three-dimensional objects", which can stimulate their spatial imagination and spatial thinking ability.

6.2 Research Contribution

The main contribution of this study is to establish a conceptual model of a self-learning immersive learning environment to improve the learning performance of art students' spatial ability. In addition, this study also designed and developed an IVRSA learning system to cultivate students' spatial ability.

6.2.1 Theoretical Innovation

Firstly, it promotes research on the characteristics and rules of spatial ability development. From the school education situation perspective, this study expounds on the development stage of spatial ability. It extracts the key elements of spatial ability development, which can encourage educational researchers and teachers to explore how to cultivate middle school students' spatial ability.

Secondly, it promotes an understanding of the relationship between immersive technology and spatial ability. This study systematically combs and thinks about the development factors of spatial ability, the potential advantages of immersive technology in promoting spatial ability development, and the design model of immersive learning environment oriented to spatial ability development, which lays a certain theoretical foundation for further research on the connotation and essential characteristics of learning environment design oriented to spatial ability development supported by immersive technology.

The learning environment design model conforms to the design direction of spatial ability development in the learning environment enabled by VR and realizes the unity of VR, learning situation, learning activity and learning content, which is conducive to promoting operable learning environment design model in the education stage.

Thirdly, the comprehensive theoretical framework of immersion techniques in education should be expanded. Most studies at home and abroad focus on exploring an immersive virtual environment for learning performance. However, spatial ability is paid less attention and is closely related to learning performance, especially in school education. This study has made a meaningful attempt to introduce cutting-edge technology into the school classroom. At the same time, it combines immersive technology with the research of spatial ability, which expands the research field of spatial ability and immersive education.

6.2.2 Practice Innovation

Firstly, this study constructs a conceptual model of an immersive learning environment for spatial competence development. One of the topics of recent research in the 21st century is the impact of digital technology on the creativity of middle school students in art and design education (Yalcinalp & Avci, 2019). Therefore, based on the dilemma that the traditional learning mode is insufficient in cultivating art students' spatial ability in current school education, this study constructs a conceptual model of an immersive learning environment oriented to spatial ability development. It follows the corresponding design principles, the elements that meet the development of spatial ability, and the necessary elements to design the learning environment. It verifies the good practical application effect of the learning environment through case application.

This learning environment can support students in carrying out different types of spatial reasoning learning activities.

Secondly, this study provides empirical evidence of the use of immersive technologies in school contexts to develop the spatial abilities of learners. Spatial ability is an essential cognitive skill, and how to improve students' spatial ability in school education has always been a topic of concern for scholars at home and abroad. Based on the experience in domestic and foreign-related research, this study selected suitable content and designed the related learning activities. At the same time, the curriculum teaching knowledge, the cultivation of spatial ability, and hands-on practice of organic union are in the school classroom, with the tools of the information teaching how to enhance the capacity of a valuable exploration space. This study also provides a reference for applying immersive technology support in the learning environment and classroom teaching. It provides a reference case for integrating education and emerging technology in an innovative classroom teaching model.

6.2.3 Method Innovation

This study examines the impact of an immersive virtual environment on spatial ability from the perspectives and methods of learning science, psychology, cognitive psychology, educational technology, and other fields, breaking through the previous studies on spatial ability from a single psychological perspective or pedagogical perspective, and the lack of a single research method to fully reveal spatial ability. This study proposes a more comprehensive research perspective, adopts the research paradigm of quantification as the main and qualitative as the auxiliary, and, based on the measurement method of data triangulation, conducts a group comparison experiment on first-year college students.

6.3 Limitations and Future Work

Although this study reveals that virtual reality technology has significant advantages in promoting students' spatial ability, this study has some shortcomings.

i. The IVRSA learning system developed in this research focuses on art majors and is in line with the training programs of various schools. The target users are Chinese students majoring in art. Therefore, the IVRSA learning system uses Chinese as the primary language. However, this also means it has limitations, and only local students can use it. For future research, this study suggests collecting more teaching materials and syllabuses, developing multiple languages, enriching the learning content, and meeting the learning needs of international students in the university. This is a timely and rational suggestion in the rapidly developing trend of multicultural exchanges.

ii. The IVRSA learning system only focuses on an immersive virtual reality course for teaching experiments, which has certain limitations. Therefore, in the future, the content of the IVRSA learning system may need to be targeted to expand to experimental activities in different art majors (such as environmental art design or advertising art design), which have been transformed into 3D animation experiments and students can have unlimited access to learn. It is important to explore the effects of IVRSA learning systems on spatial ability by testing diverse subject areas.

iii. The conceptual model is designed for HMD equipment. Therefore, students who do not have access to immersive devices (such as 3D dizziness) will not be able to use and learn. In the future, a PC-based learning system can be developed to meet the needs of more students in a semi-immersive mode.

iv. For the course of "Composing Foundation," the intervention time is relatively short, and the novelty of the technology may cause this positive effect. Therefore, future research can develop a series of diversified supporting school-based art courses courses and carry out long-term follow-up research.

v. The conceptual model presented in this study is a generic model that can be used in other disciplines to stimulate and enhance student learning performance.

Future research directions can be explored: (i) the differences between students with different levels of spatial ability in different learning environments; (ii) the difference in spatial ability of students with different immersion tendencies; (iii) The impact of immersive learning environments on different subject areas.

6.4 Summary

This study identified three elements that constitute spatial ability. In an immersive learning environment, spatial ability can be cultivated through some specific elements, so this study established a conceptual model of ILE. Then, combining these elements, this study developed the IVRSA learning system and verified the validity of the conceptual model by using the IVRSA learning system to collect students' learning performance in ILE. This study verifies the performance of middle school students' spatial ability in different learning environments by carrying out traditional teaching and ILE teaching for students. The results show that the IVRSA learning system can help students learn spatial ability and improve their learning performance in spatial ability, thus proving the effectiveness of the ILE conceptual model in cultivating spatial ability.

Finally, the factors and features used in the conceptual model can be used as a guide for developing IVRSA learning systems for other subjects to enhance learning performance in art teaching experiments.

Overall, this study successfully develops a conceptual model of immersive learning environments and assesses their impact on the learning performance of spatial ability in art students.

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Appendix A:

Personal Questionnaire

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

Q1: Do you have any experience with computers?	
□ Yes	□ No

Q2 How much experience do you have with computers?	
□ Within half a year	□ Within a year
□ Within two years	□ Two years or above two years

Q3 Your level of computer use?	
□ Skilled	□ So-so
□ Can use/unskilled	□ not completely

Q4 What do you mainly use your computer for? (multiple choice)		
□ Learn/get information	□ Work	□ Socialize/chat
□ Watch movies/TV	□ Listen to music	□ Play games
□ Other (please fill in the sheet)		

Q5 Have you ever had a 3D experience? Such as VR environments, 3D games, etc.?	
□ Yes	□ No

Q6 How do you feel about using 3D or immersive environments?		
□ Very like	□ Average/optional	□ Dislike

Q7 Do you accept using electronic devices such as computers, VR goggles, controllers, etc.?		
□ Acceptable	□ Average/ Not mind	□ Reject

Appendix B

Spatial Ability Standardized Test

NAME:	Gender:	Age:

Part I: Mental Rotation Test (Test time: 10 minutes)

1. Mental Rotation in 2D

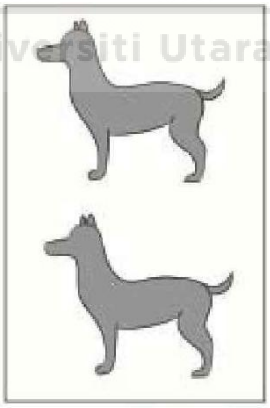
Test instructions:

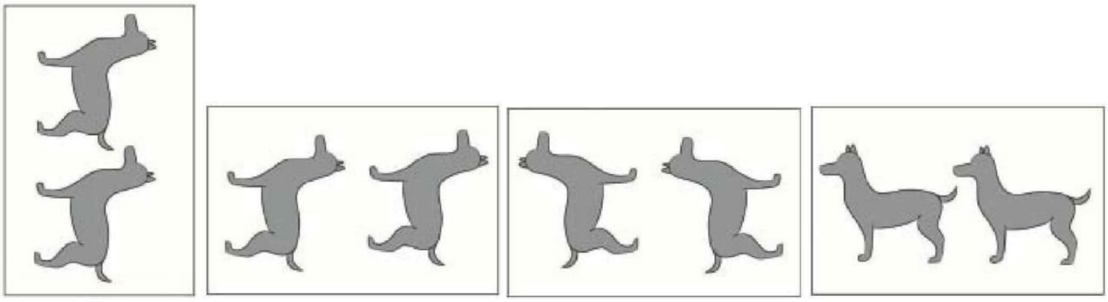
(1) Observe the picture shown on the first row.

(2) Imagine what state the object will be in after rotated according to the requirement, and choose the correct answer from the four answers given

Test question:

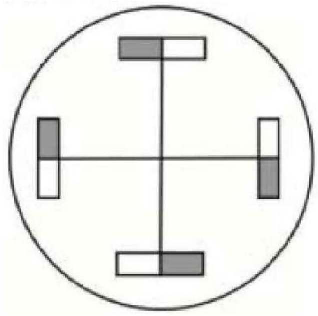
1. Which of the following is the correct state after clockwise rotation at 90° ( )

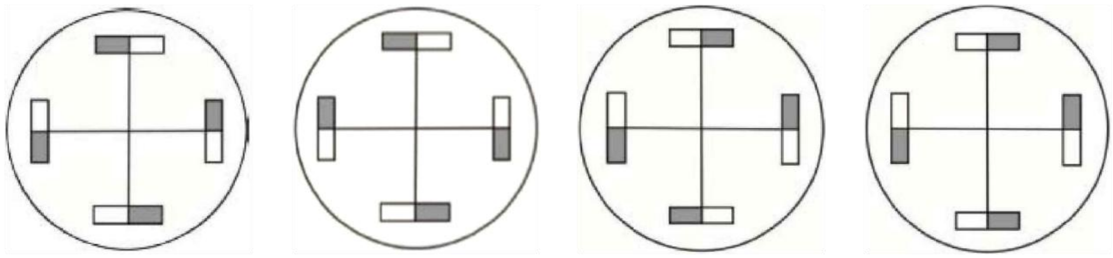




A B C D

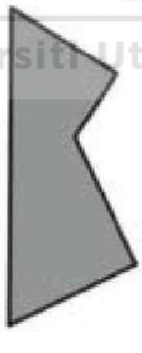
2. Which of the following is the correct state after clockwise rotation in a quarter ( )

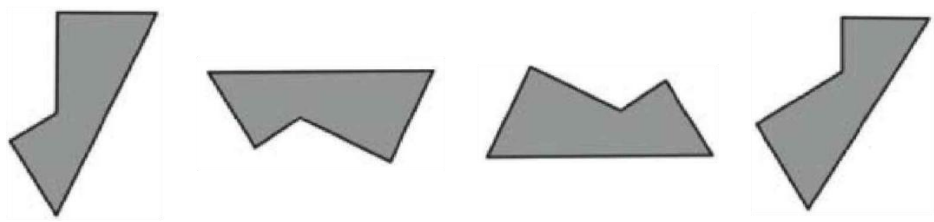




A B C D

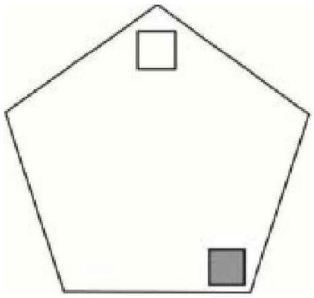
3. Which of the following is the probable correct state after clockwise rotation ( )

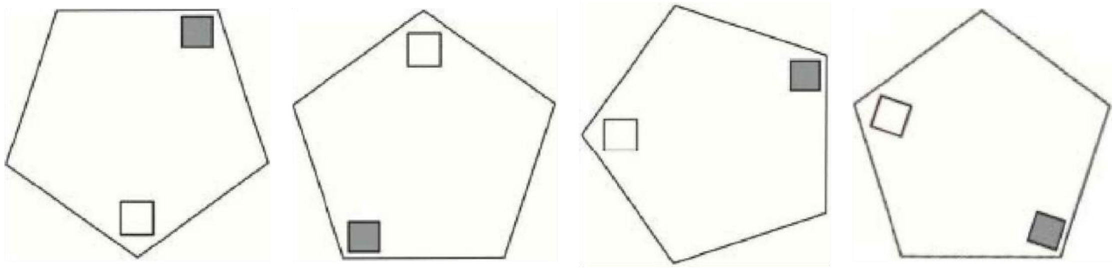




A B C D

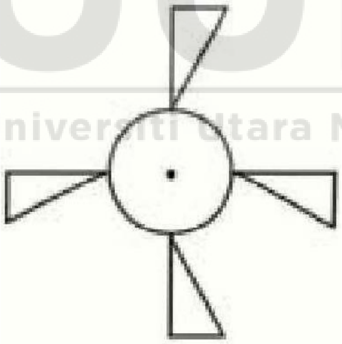
4. Which of the following is the correct state after rotation ( )

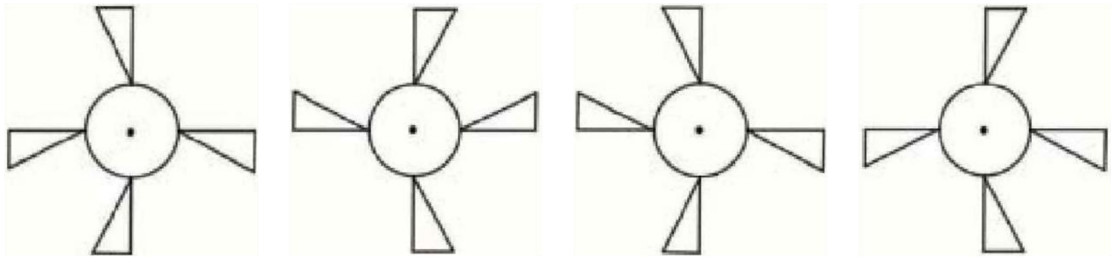




A B C D

5. Which of the following is the correct state after clockwise rotation in a quarter ( )





A B C D

2. Mental Rotation in 3D

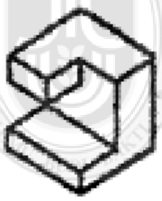
Test instructions:

(1) Think about what kind of rotational motion the object on the left of the first row in the figure becomes the state shown on the right.

(2) If the same rotational motion is applied to the object shown in the second row of the diagram, imagine what state the object will be in and choose the correct answer from the five answers given in the third row of the graph. (Note: In the following test, the object may be rotated one or more times.)

Test question:

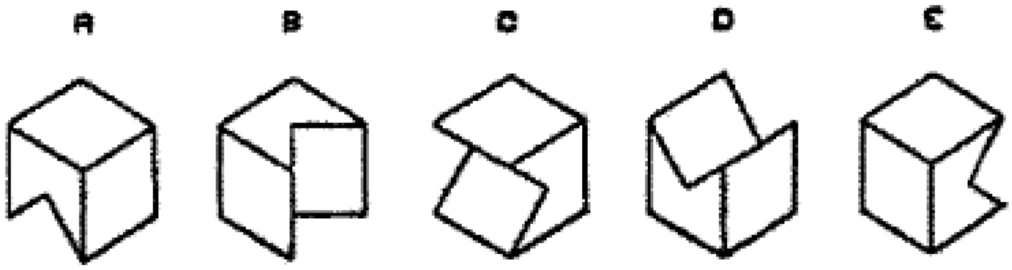
6. Which of the following is the correct state after rotation ( )



Convert

as

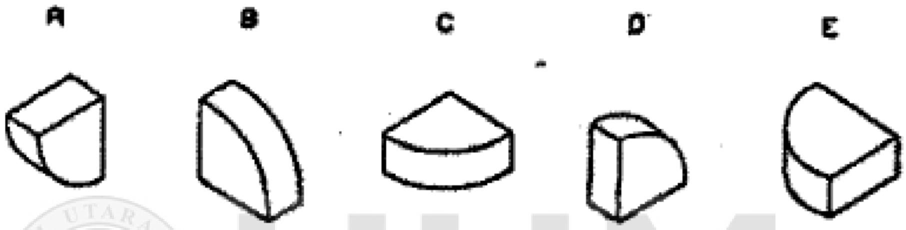
Convert into



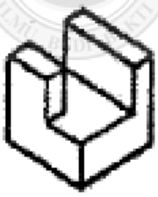
7. Which of the following is the correct state after rotation ( )

Convert into

as  **Convert into**

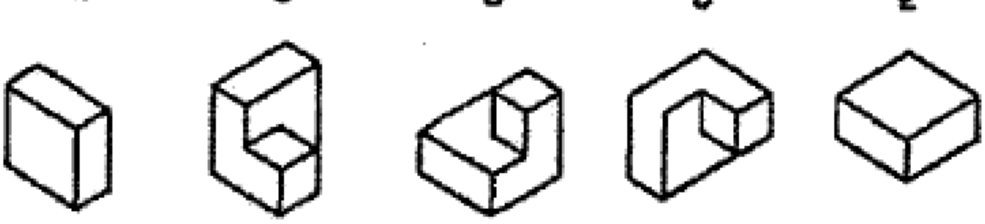


8. Which of the following is the correct state after rotation ( )



Convert into

as  **Convert into**



9. Which of the following is the correct state after rotation ( )

Convert into

as

Convert into

A B C D E

10. Which of the following is the correct state after rotation ( )

Convert into

as

Convert into

A B C D E

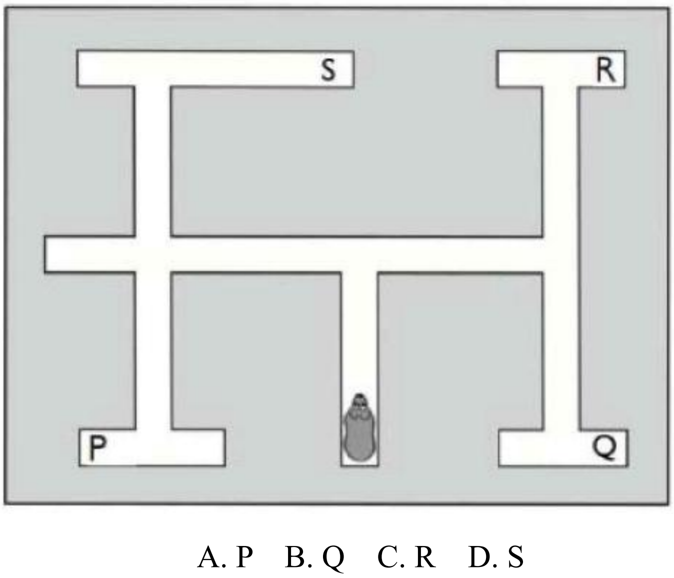
Part II: Spatial Orientation Test (Test time: 10 minutes)

Test question:

11. Which arm is the ballerina holding out to the audience in the picture? ( )

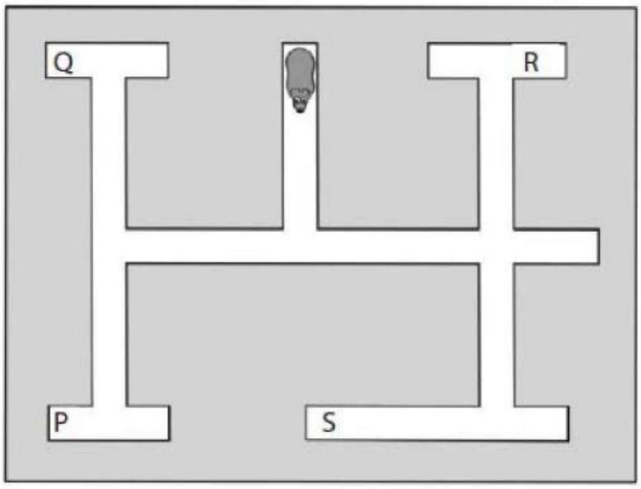
A. Left arm   B. Right arm

12. The hamster is running in the maze. It turns right, then left, then right. Where is the hamster? ( )



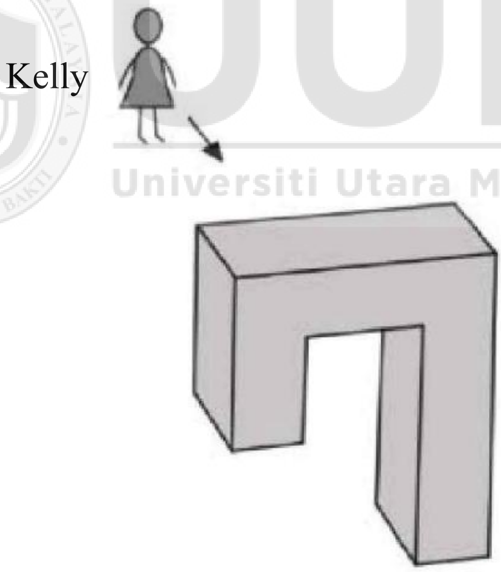
A. P   B. Q   C. R   D. S

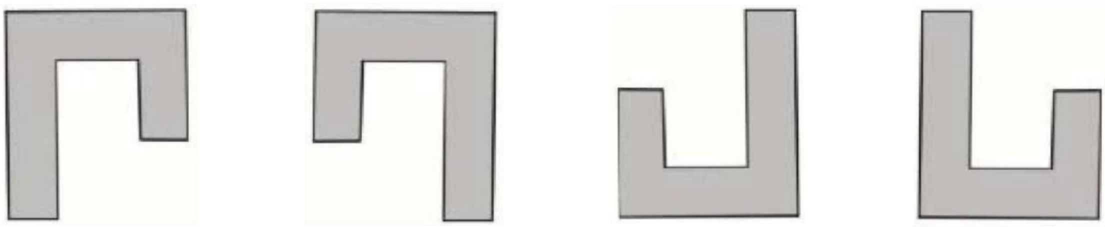
13. The hamster is running in the maze. It turns right, then left, then right. Where is the hamster? ( )



A. S   B. P   C. R   D. Q

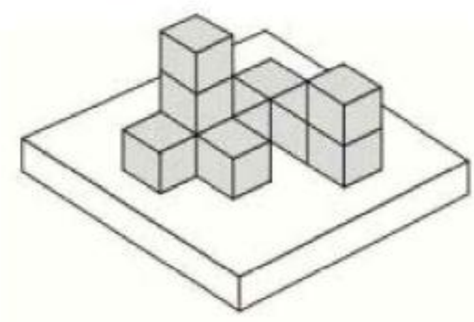
14. What does the front of the model look like from Kelly's point of view ( )

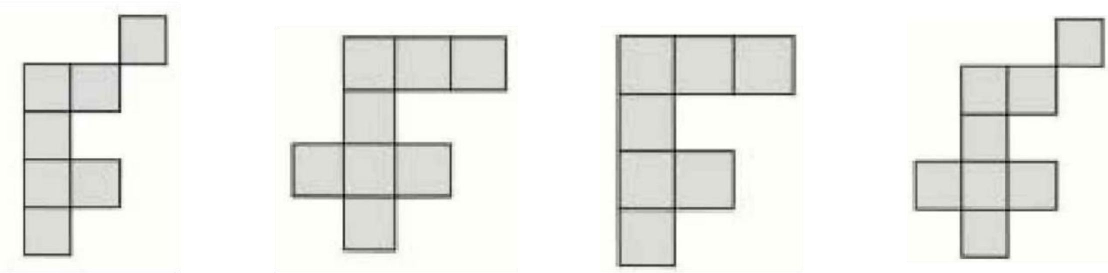




A   B   C   D

15. Which of the following is the correct image when we look down from the top of the model ( )



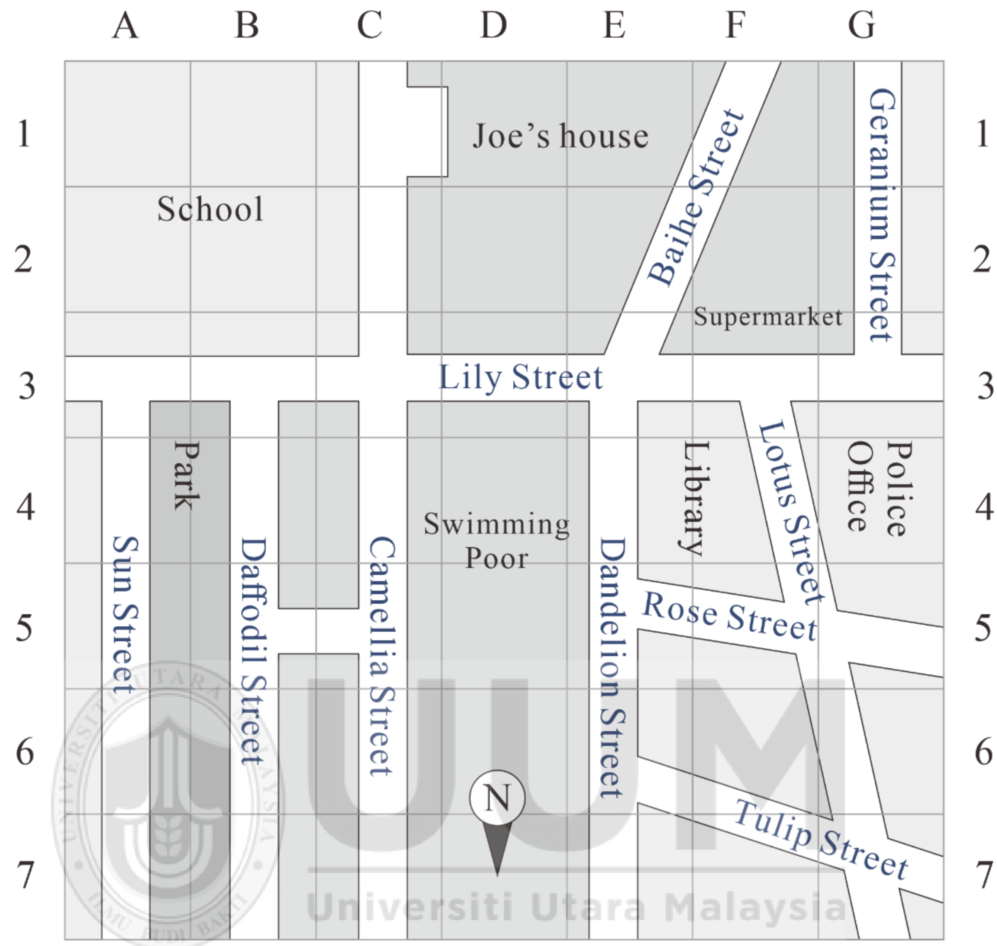


A B C D

16. Kate and William's seating position is shown in the picture. Where is the vase from Kate's point of view? ( )

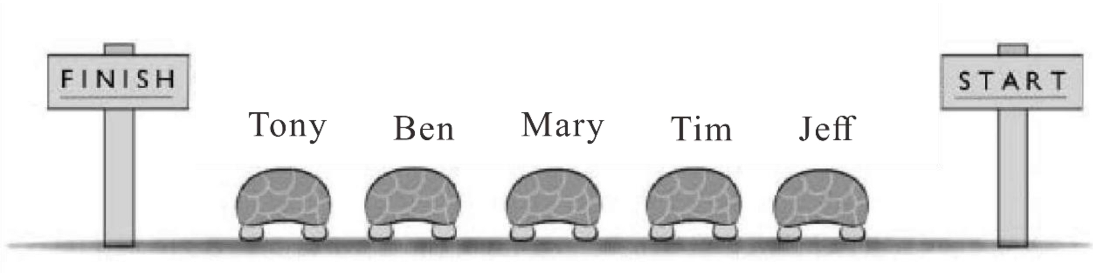
A. On her left B. On her right

17. Joe starts from his home (D1) and drives north. He is going left at the first crossing and right at the second crossing. Which road is he on now? ( )



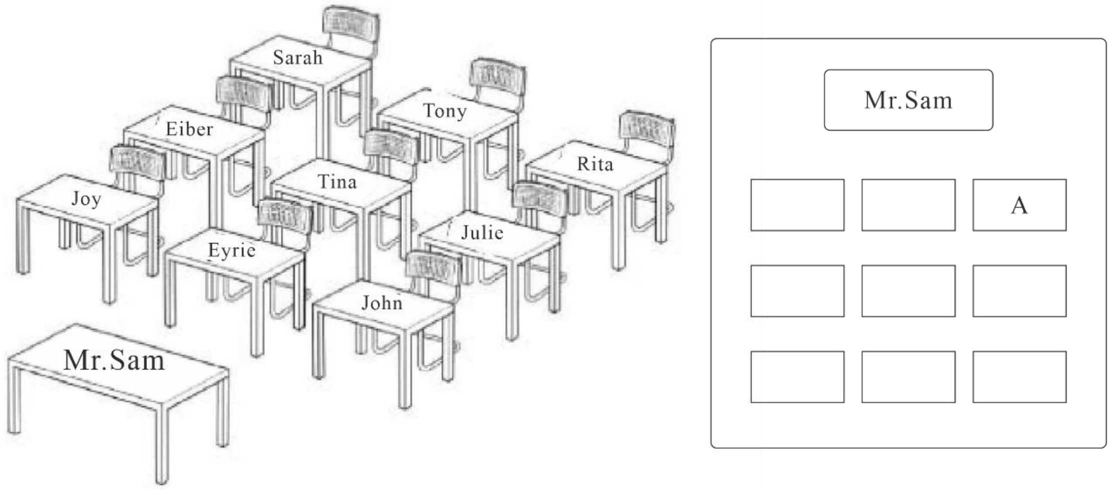
A. Lotus Street B. Geranium Street C. Sun Street D. Daffodil Street

18. The picture below shows five turtles in a race. Which turtle is running after Mary in the race ( )



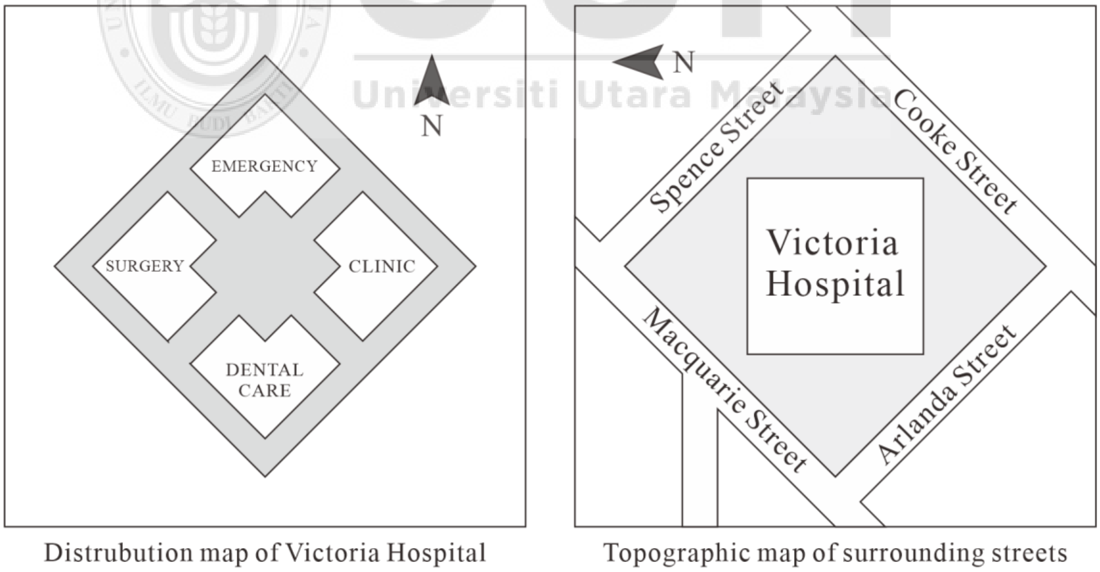
A. Tony B. Ben C. Tim D. Jeff

19. The picture below is the seating arrangement for Mr. Sam's class. On the class plan, who sits in position A? ( )



A. Sarah B. Rita C. Joy D. John

20. Below are two topographic maps of Victoria Hospital. Which department is on the corner of Arlanda Street and Macquarie Street? ( )



A. Emergence B. Dental Care C. Clinic D. Surgery

Part III: Spatial Visualization Test (Test time: 10 minutes)

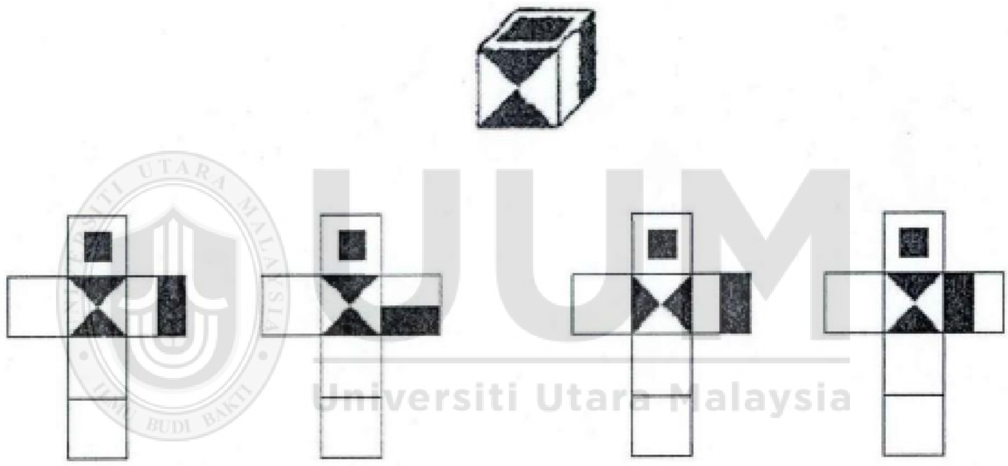
1. Surface development test

Test instructions:

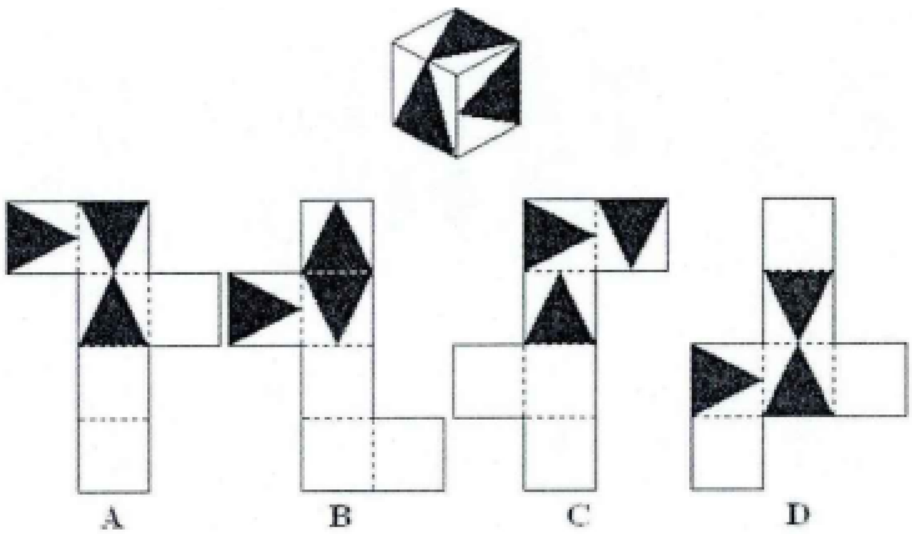
Four options are a cube expansion image for A, B, C, and D. Some faces of the cube have some photos, and please determine which of the expanded images can be restored to the cube in the title.

Test question:

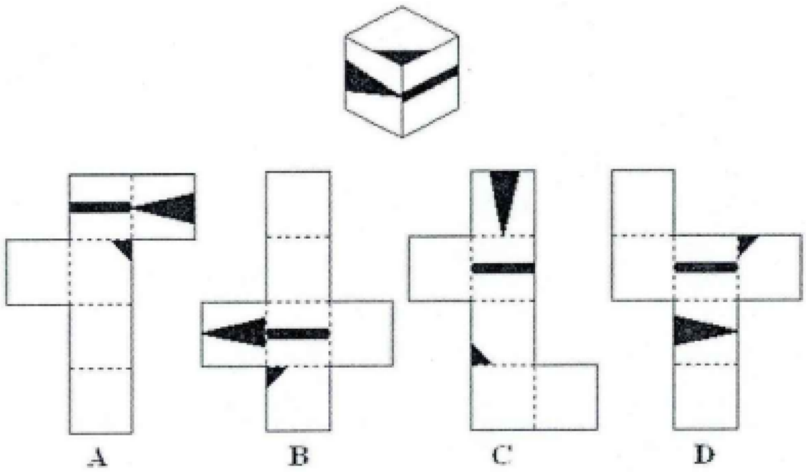
21. Which of the following is the expansion of the above cube ( )



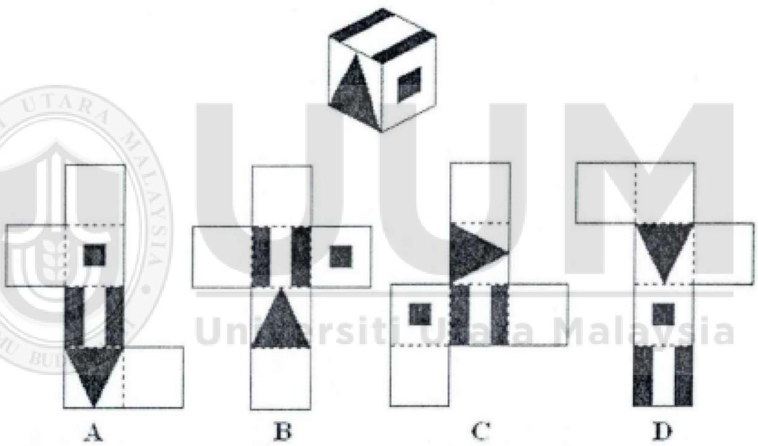
22. Which of the following is the expansion of the above cube ( )



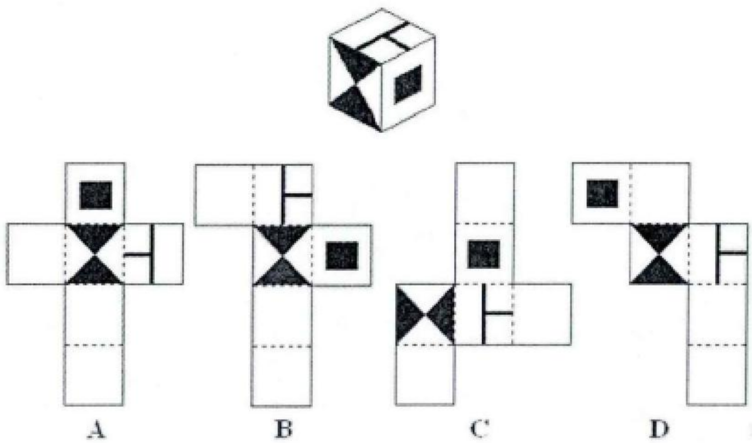
23. Which of the following is the expansion of the above cube ( )



24. Which of the following is the expansion of the above cube ( )



25. Which of the following is the expansion of the above cube ( )



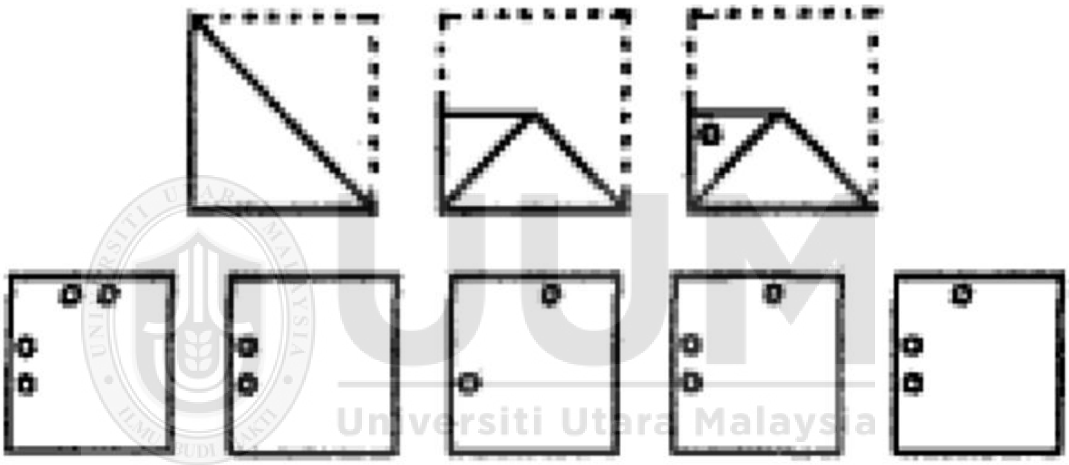
2. Paper folding test

Test instructions:

The picture in the first row shows a piece of paper folded and punched. The diagram in the second row shows the possible positions of the holes if the paper is fully unfolded. Please determine which pictures A, B, C, D, and E have the correct hole position.

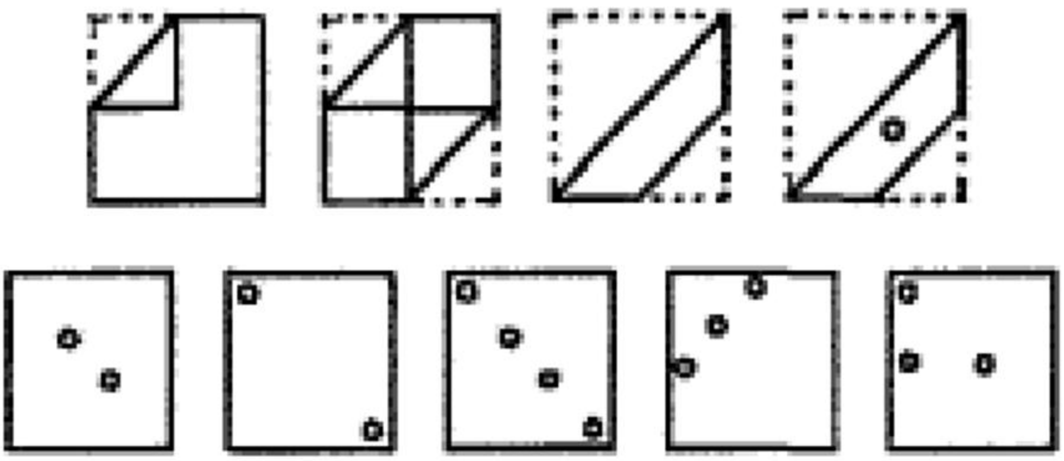
Test question:

26. Which item is the expansion of the first row of paper (   )



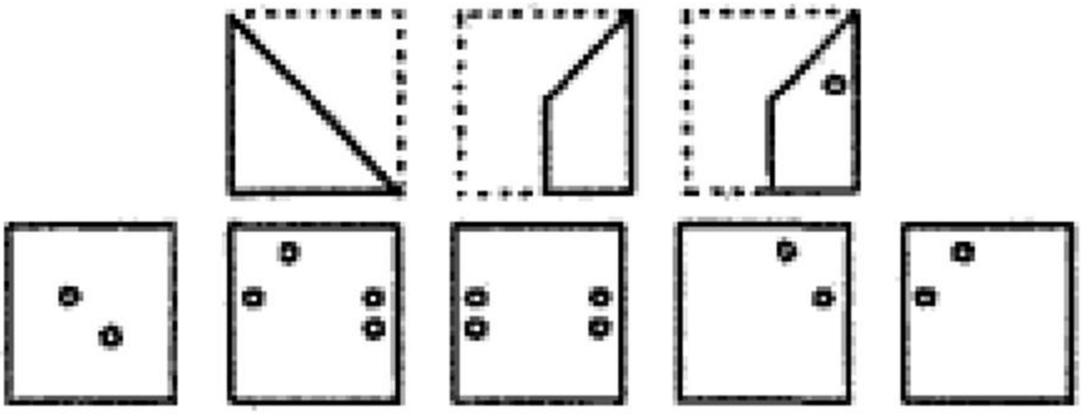
A B C D E

27. Which item is the expansion of the first row of paper ( )



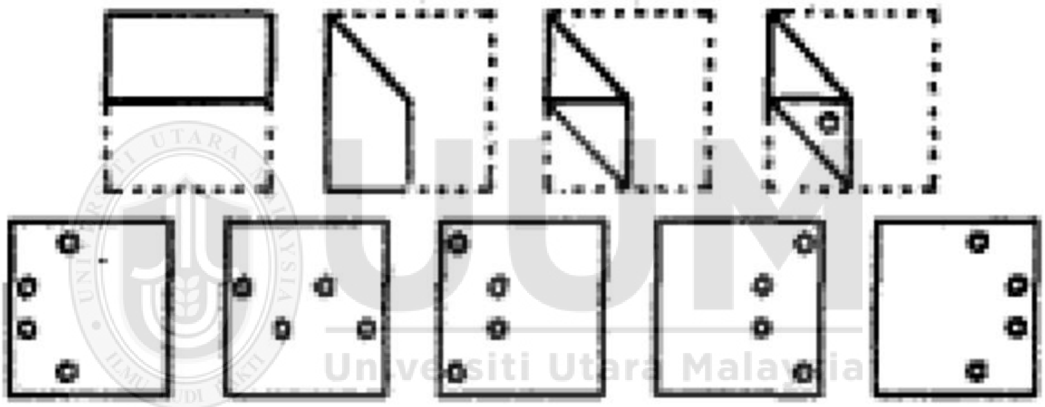
A B C D E

28. Which item is the expansion of the first row of paper (   )



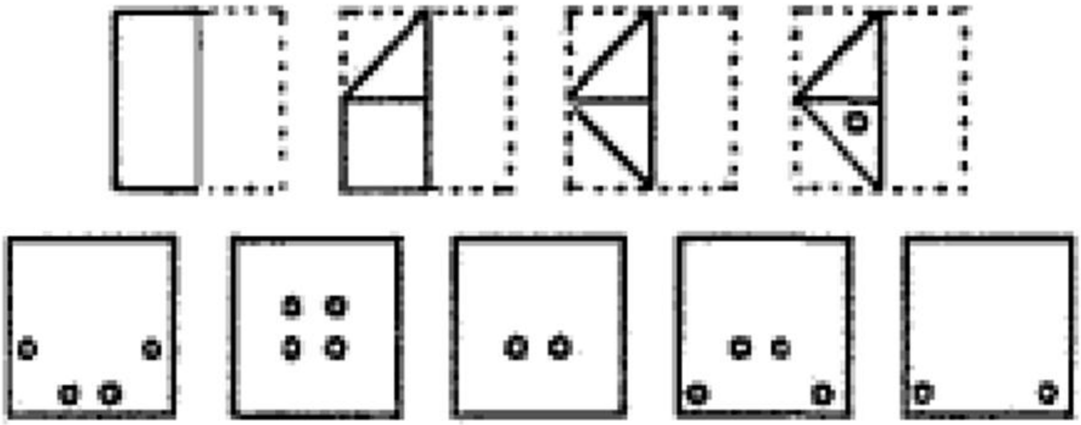
A B C D E

29. Which item is the expansion of the first row of paper ( )



A B C D E

30. Which item is the expansion of the first row of paper ( )



A B C D E

Appendix C

Academic Achievement Test

Name：	Gender：	Age：
Time：		

1. The transformation of three views and three-dimensional modeling

1) Please draw the top view, front view, and side view of the 3D model in Figure 1 and Figure 2

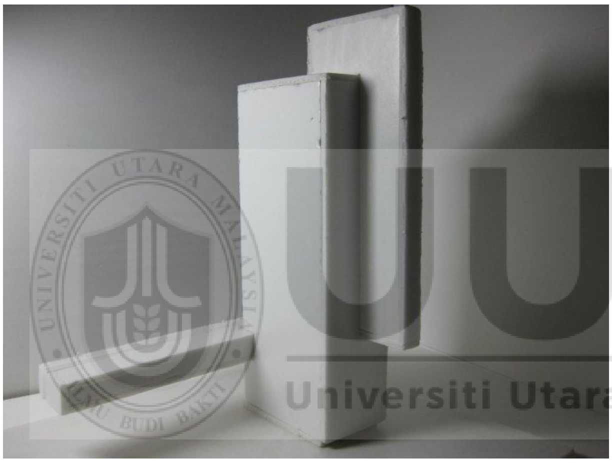
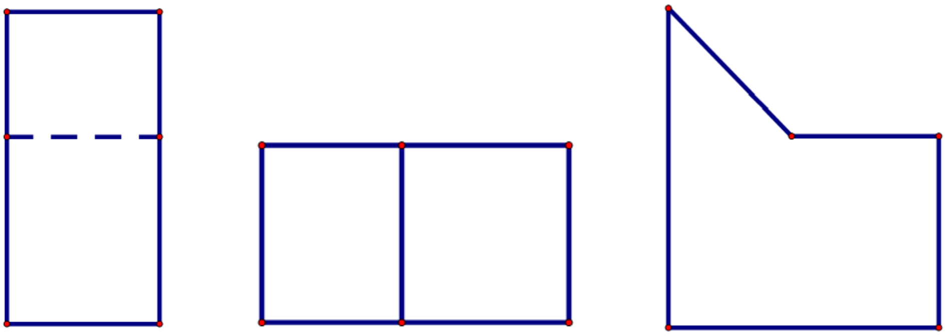


Figure 1 **Figure 2**

	Front View	Top View	Side View
Fig.1			
Fig.2			

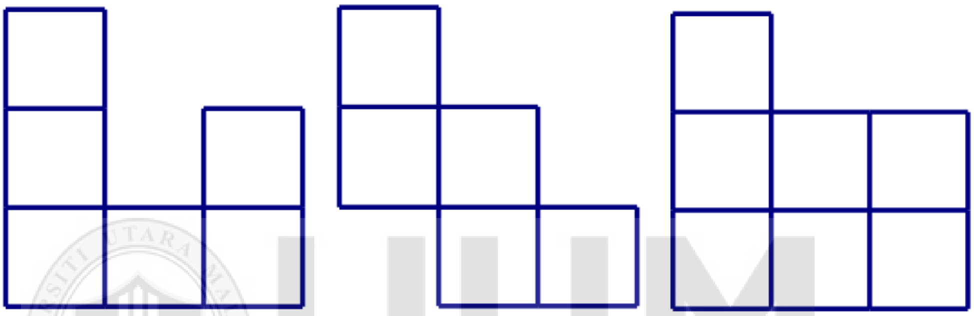
2) Please draw a 3D graph of the object according to the top view, front view, and side view provided below

(1)



Front View Top View Side View

(2)



Front View Top View Side View

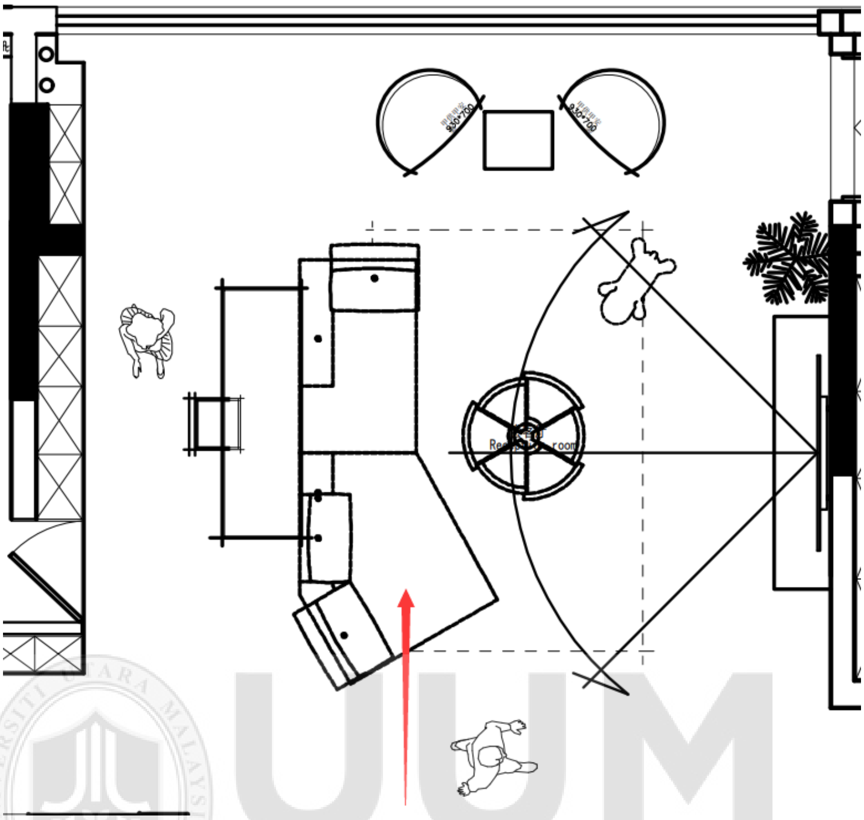
Item	3D Model
（1）	
（2）	

2. Professional development

(1) Please draw an expanded view of the following package box.

Expanded View

(2) Please draw the 3D interior rendering according to the interior plane graph (arrow view)



Appendix D

Spatial Ability Self-statement Report

Hello everyone!

The purpose of this questionnaire is to find out your self-perception of spatial ability during the course of learning. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	I can imagine in my mind what a three-dimensional (3D) object looks like after rotation	5	4	3	2	1
2	I can fold a square of paper in my mind and create a new shape from it	5	4	3	2	1
3	I can easily recognize three-dimensional (3D) shapes drawn on paper	5	4	3	2	1

4	When I see the photos of the buildings taken from different angles, and can imagine the three-dimensional (3D) structure of the buildings in mind	5	4	3	2	1
5	I can draw other figures while solving geometric problems	5	4	3	2	1
6	I can decompose three-dimensional (3D) objects composed of cubes in my mind	5	4	3	2	1
7	I can imagine a figure drawn on a piece of paper rotating around a point in my mind	5	4	3	2	1
8	I can solve geometric problems without drawing pictures	5	4	3	2	1
9	I can cut and fold paper models of 3D objects by visualizing them in my mind	5	4	3	2	1
10	When I want to design the shape of fruits, vegetables, or cakes, I can easily imagine how to cut them	5	4	3	2	1
11	I can visualize in my mind the solid shape of a three-dimensional (3D) object when presented in flat form	5	4	3	2	1
12	I have never lost my way on the road that I have traveled before	5	4	3	2	1
13	I can imagine the shortest way out on the road	5	4	3	2	1
14	If I have been somewhere before, I can find a shorter route to get there	5	4	3	2	1
15	I can find the place that I want to go when I look at the map of a specific area	5	4	3	2	1

Appendix E

Cognitive Load

Hello, everyone!

The purpose of this questionnaire is to find out how much cognitive load you are under during the course of your course. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	The learning content in this learning activity is difficult for me	5	4	3	2	1
2	It took me a lot of effort to answer the question in this learning activity	5	4	3	2	1
3	It bothers me to answer the question in this learning activity	5	4	3	2	1

4	I feel frustrated to answer the question in this learning activity	5	4	3	2	1
5	I don't have enough time to answer the questions in this learning activity	5	4	3	2	1
6	In this learning activity, it is difficult for me to present the teaching method or textbook content	5	4	3	2	1
7	I have to put a lot of effort into accomplishing the learning activity or achieving the goal of the learning activity	5	4	3	2	1
8	The teaching method of this learning activity is difficult to understand or keep up with	5	4	3	2	1

Appendix F

Flow experience

Hello, everyone!

The purpose of this questionnaire is to find out your experience during the course. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	In the learning process, I feel I can control what I do	5	4	3	2	1
2	The learning activities deeply attract me	5	4	3	2	1
3	Learning activities make me happy	5	4	3	2	1
4	I think of other things	5	4	3	2	1
5	I find learning activities attractive	5	4	3	2	1

6	I was frustrated with what I had done	5	4	3	2	1
7	Study activities make me feel bored	5	4	3	2	1
8	I get distracted easily	5	4	3	2	1
9	Learning activities arouse my curiosity	5	4	3	2	1
10	I know what to do	5	4	3	2	1
11	I need a lot of energy to concentrate on academic activities	5	4	3	2	1

Appendix G

Activity Embodiment

Hello, everyone!

The purpose of this questionnaire is to understand your experience of the course. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	Taking a VR composition class makes me feel happy	5	4	3	2	1
2	The learning activities of a VR composition class are an enjoyable thing	5	4	3	2	1
3	I enjoy participating in the learning activities of the VR composition course	5	4	3	2	1

4	In class, I remembered to recognize the appearance and structure of objects	5	4	3	2	1
5	I felt a sense of accomplishment after completing the course's learning activities	5	4	3	2	1
6	Participating in the course learning activities improved my learning ability in the practical extension course	5	4	3	2	1
7	Participating in the course learning activities improved my understanding of the spatial structure of objects (such as appearance, structure, characteristics, etc.)	5	4	3	2	1
8	Participating in the course learning activities improved my knowledge of the position of objects in space (such as direction and orientation)	5	4	3	2	1
9	Participating in course learning activities improved my ability to observe things (such as appearance, structure, characteristics, etc.) from different angles	5	4	3	2	1
10	Curriculum learning is challenging	5	4	3	2	1
11	I think the functions of the course learning activities are complicated	5	4	3	2	1
12	Participation in course learning activities enhanced my curiosity and interest in practical extension courses	5	4	3	2	1
13	Participating in the course deepened my understanding of 3D modeling knowledge	5	4	3	2	1

Appendix H

Question of Interview

Question: What do you think about learning the relevant "Composing Foundation" knowledge in ILE? (A one-on-one interview in 15 minutes)

Appendix I

Instrument for Expert Review

Prof./Prof. Madya/Dr./Tuan/Puan,

I am Jian Yi, a Ph.D. candidate from the School of Creative Industry Management & Performing Arts, Universiti Utara Malaysia (UUM). My research title is Conceptual Model of Spatial Ability in Immersive Learning Environment Towards Art Students' Learning Motivation and Performance. The first objective of this research is to determine the factors for an immersive learning environment in the cultivation of spatial ability. The second objective is to develop the conceptual model for cultivating spatial ability in an immersive learning environment. Finally, it evaluates the effectiveness of an immersive learning environment in cultivating spatial ability in terms of learning performance.

Any comments, suggestions, and criticisms given to improve the items for these factors are greatly appreciated. All feedback will be kept confidential.

Based on previous studies, the main factors influencing students' learning performance in ILE included students, learning situations, learning activities, learning contents, and spatial skills. Specific indicators in these dimensions illustrate their impact on spatial ability development.

In connection with that, I would like to invite Prof./Prof. Associate Professor/Dr./Mr./Madam answered the questions to verify the factors influencing art students' learning performance in developing spatial ability.

Factor validation is based on the Content Validity Ratio (CVR) with three scales: (1) Essential, (2) Useful but not essential, and (3) Not necessary (Lawshe, 1975). The questionnaire is divided into expert details, operational definition, factors influencing learning performance in spatial ability development, learning performance judgement, and conceptual model validation.

For further inquiries, please contact:

Jian Yi

School of Creative Industry Management & Performing Arts, Universiti Utara Malaysia (UUM),

E-mail: sabrinajian999@gmail.com

Section 1: Expert Details

Please fill in your personal information:

Name:
Position:
Department:
Affiliation:
E-mail:

Please indicate the experience for each of the following statements based on the rating scale by marking (✔) on the box.

	Spatial Ability	**Virtual Reality**	Others: ____________
1-No experience			
2-Experience less than five years			
3-Experience for 5-10 years			
4-Experience more than ten years			
5-Experience more than 15 years			

Section 2: Operational Definition

1. Spatial Ability

Spatial ability refers to the ability of an individual to recognize, manipulate and transform the spatial characteristics of objects (Bruce, C.D. et al., 2017). In particular, spatial ability involves three main aspects (1) the knowledge and understanding of space itself, (2) spatial visualization, the presentation of spatial reasoning and spatial information, is an ability, through mental manipulation of the whole space shape, imaging the rotation of objects, the folding, and unfolding of plane patterns, and measure the change in a relative position of an object in space (McGee M G. et al.,1979), (3) the encoding and decoding of diagrams(e.g., maps, flow charts), and the reasoning which needs solving the problem and making decisions by interpreting and processing spatial information. In this study, spatial ability mainly refers to the ability of art students to design and create.

2. Immersive Learning Environment (ILE)

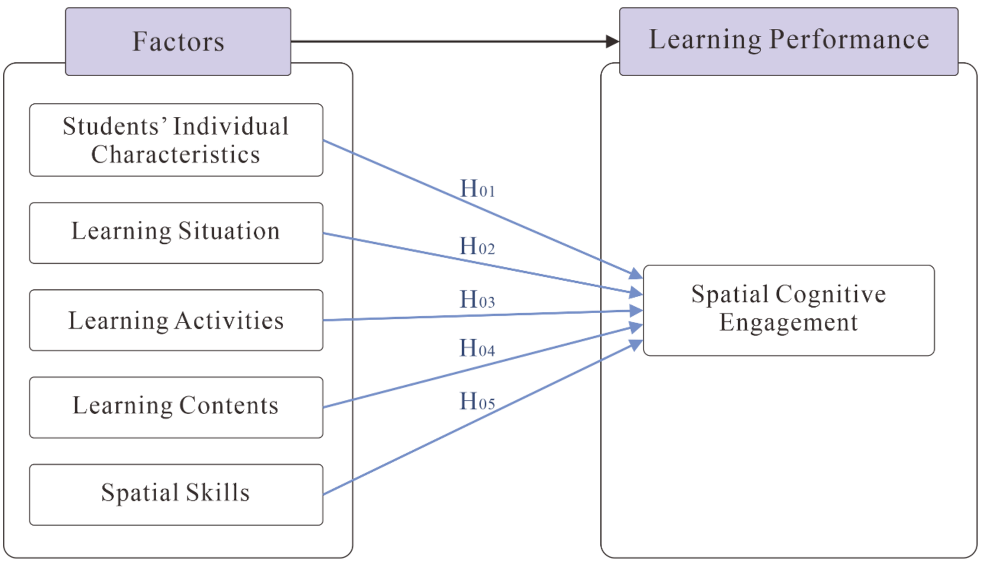
ILE refers to creating a virtual environment close to the real world through virtual reality technology combined with various equipment and providing learners with an "immersive" multi-sensory experience. The immersive learning environment allows learners to immerse themselves in virtual scenes and interact with virtual learning content, virtual scenes, and virtual characters in real-time to feel what they have learned in the experience intuitively. In addition, the immersive learning environment can break through the limitations of time and space, not be restricted by objective conditions such as venues and equipment and support infinite repetitive operations until the ideal learning effect is achieved. It can effectively solve the difficulties faced in the current teaching links, such as experiments, practices, and internships (Wu. J et al., 2014). The immersive learning environment mentioned in this study mainly refers to the learning environment constructed through virtual reality technology.

3. Learning Performance

Learning performance generally refers to students' comprehensive assessment of their performance in knowledge, skills, and other aspects, which specific indicators can measure. For example, David E. Lavin (1965) defined learning performance as students' learning level, which course grades, quantitative or graded forms of possible degrees, could represent. Pascarella et al. (2005) used learning performance to describe test and course scores. Li (2020) analyzed the factors that affect the learning performance of college students and believed that learning performance is a measure of a student's performance in school, including exam results, homework, participation in activities, and so on. Liu et al. (2016) divide academic achievement into curriculum and developmental achievement related to student learning. In addition, Goodman et al. (2000) argued that in addition to tests and other standardized tests, learning performance should also be measured by various indicators such as consciousness, personality, and skills. In other words, besides the essential measurement of knowledge and skills, the learning performance also needs to cover interest, attitude, and other indicators related to students' learning effect (Li, 1987). In general, learning performance can somewhat reflect students' learning ability.

Based on the analysis of the "learning performance" concept in the above literature, it is not difficult to find that learning performance is a measurable variable. Therefore, in this study, we defined it as "measurable behavioral results displayed in the course work of learning." The learning performance in this study mainly refers to art students' learning participation and performance feedback in learning professional courses.

Conceptual Model of Spatial Ability in immersive learning environments towards learning performance



Section 3: Factors influencing learning performance in spatial ability development

Here is a statement that you may or may not agree with. Please select an item by marking (✔) on the box either "*Essentials*," "*Useful but not Essentials,*" or "*Not Necessary*."

A. Students		Improvement in the definition (State if there are any)			
Definition Students are a very important factor (Kim and Irizarry, 2021). Everything is designed to develop students' spatial ability. Their individual characteristics play an important role (Dowker, 2019).					
Item		Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I like to learn by watching and listening.				
2	In the learning process, I like to think about ideas.				
3	I learn best when I trust my instincts and feelings.				
4	I learn best when I listen and observe.				
5	I learn best when I think logically.				
6	I have strong feelings and reactions when studying.				
7	I try to figure things out when studying.				
8	I learn by feeling				
9	I learn by observation.				
10	I learn through a practical operation.				
11	I am an observant person when learning.				
12	I am a logical person when learning.				
13	I learn best when relying on my powers of observation.				
14	I learn best when trying to do something by myself.				
15	I learn best when working hard to get things done.				
16	I like to observe when studying.				
17	I like to take an active part when studying				
If there are any missing terms in describing the **student,** please give a suggestion.					

<table>
<tr><th colspan="2">B. Learning Situation</th><th colspan="4">Improvement in the definition
(State if there are any)</th></tr>
<tr><td colspan="2">Definition
Learning situation is one of the important factors that affect the development of spatial ability (Hamilton, et al.,2021). Whether students can get good learning performance is directly related to the situation. The natural and perceptible situation can improve students' motivation and learning experience and provide a solid material guarantee for the development of contextualized learning (Zhang, et al, 2020).</td><td colspan="4"></td></tr>
<tr><th colspan="2">Item</th><th>Essential</th><th>Less essential</th><th>Not essential</th><th>Any comments on the items?
(State if there are any)</th></tr>
<tr><td>1</td><td>The environment in ILE is visually no different from reality, which makes me feel immersive.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>I have a good sense of experience in ILE.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>In ILE, I have more desire to learn.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>I feel the scenes is very real by using VR devices.</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">If there are any missing terms in describing the Learning situation, please give a suggestion.</td></tr>
<tr><td colspan="6"></td></tr>
</table>

C. **Learning Activities**	Improvement in the definition (State if there are any)			
Definition Learning activities enable students to use teaching content resources to practice and practice repeatedly to achieve the purpose of mastering skills and movements (Zakirman, et al., 2019).				

	Item	Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	Taking a VR class makes me feel happy				
2	The learning activities of a VR class are an enjoyable thing				
3	I enjoy participating in the learning activities of the VR course				
4	In class, I remembered to recognize the appearance and structure of objects				
5	I felt a sense of accomplishment after completing the course learning activities				
6	Participating in the course learning activities improved my learning ability in the practical extension course				
7	Participating in the course learning activities improved my understanding of the spatial structure of objects (such as appearance, structure, characteristics, etc.)				
8	Participating in the course learning activities improved my knowledge of the position of objects in space (such as direction and orientation)				
9	Participating in course learning activities improved my ability to observe things (such as appearance, structure, characteristics, etc.) from different angles				
10	Curriculum learning is challenging				
11	I think the functions in the course learning activities are complicated				
12	Participation in course learning activities enhanced my curiosity and interest in practical extension courses				
13	Participating in the course deepened my understanding of 3D modeling knowledge				

If there are any missing terms in describing the **Learning activities**, please give a suggestion.

D. Learning Contents		Improvement in the definition (State if there are any)			
Definition Selecting appropriate learning content is critical for developing students' spatial ability, and the development of spatial ability can be achieved through learning content in learning activities (Wang, et al., 2020; Connolly, 2009).					
Item		Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I can do three-dimensional modeling design in ILE.				
2	Learning in ILE, I can intuitively observe the three-dimensional features of objects.				
3	I can interact with three-dimensional shapes in ILE.				
4	ILE can provide complete information about the course assignments				
5	ILE can provide instructional videos that I can access and learn from at any time				
6	ILE provides a larger space for art courses.				
If there are any missing terms in describing the **Learning contents, please mak**e a suggestion.					

E. Spatial Skills					
1. Visual presentation		Improvement in the definition (State if there are any)			
Definition Visual presentation (e.g., maps, models) means that students can "see" relationships between objects in the real world or at rest in a picture presentation (Davis, 2015; Lees, et al., 2018).					
Item		Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I can see various scenes in ILE.				
2	I can view a map of their area in ILE and draw a route map.				
3	In ILE, I can identify their location and identify the location of other objects.				
If there are any missing terms in describing the **Visual presentation**, please give a suggestion.					
2. Navigation		Improvement in the definition (State if there are any)			
Definition Navigation refers to the student's ability to "see" the changing relationship between a moving target object from his perspective (first-person perspective) and the target object's perspective (third-person perspective) (Davis, 2015, Yu, et al., 2021).					
Item		Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I can quickly locate myself in ILE.				
2	I can easily reach the designated position in ILE.				
3	I can use reasonable words in ILE, e.g., "near," "next to, " in... Between, "left," "right," and so on				
If there are any missing terms in describing the **Navigation**, please give a suggestion.					

3. Mental Rotation and Transformation	Improvement in the definition (State if there are any)
Definition Mental rotation and transformation (static or dynamic objects) mean that students can mentally rotate and transform static or dynamic objects to recognize the differences that these objects appear to present from different angles (Davis, 2015; Searle and Hamm, 2017).	

	Item	Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I can rotate the object to various angles in ILE and view it from different angles				
2	I can mirror, vertically and horizontally flip objects				
3	I can imagine what the target object looks like after different angles, such as 60 degrees or 90 degrees of clockwise rotation				
If there are any missing terms in describing **Mental Rotation and Transformation**, please give a suggestion.					

4. Identification, Composition, and Decomposition	Improvement in the definition (State if there are any)
Definition Identification, composition, and decomposition (static or dynamic objects) mean that students can identify, compose, and decompose static or dynamic object objects, including students can identify, combine, and decompose a series of shapes (Davis, 2015).	

	Item	Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I can quickly identify regular polygons, cubic blocks, etc.				
2	I can combine objects freely in ILE				
3	I can break down the combination into multiple single individuals				
If there are any missing terms in describing the **Identification, Composition, and Decomposition,** please give a suggestion.					

Section 4: Learning performance

Spatial ability is a necessary professional skill for art students (Tomc and Kočevar, 2020). The factors that affect its development include students, learning situations, learning activities, learning content, spatial skills, etc., and the results are reflected in students' learning performance. Learning performance is measured by spatial cognitive engagement, which consists of students' internal subjective performance and external objective results.

Subjective performance is to judge students' learning performance by observing and recording their enthusiasm and participation in class. The objective results mainly use the “spatial ability standard test” and other relevant tools, which contain multiple options and corresponding scores, to obtain students' test scores to judge students' learning performance.

The "spatial ability standard test" used in this study is a measurement tool that conforms to this study by combining the spatial ability test tools developed by Ramful, et al (2015), Kozhevnikov and Hegarty (2001), Bodner, et al (1999), Ekstrom (1976). The standardized spatial ability test included three dimensions: mental rotation, spatial orientation, and spatial visualization, each dimension contains 10 items, with the correct score for each item being 1 point and the total score for each dimension being 10 points. The sum of all project scores is the total score of spatial ability (30 points in total). The higher the total score is, the stronger the spatial ability is. The specific topic is in the **appendix**.

Spatial Cognitive Engagement		Improvement in the definition (State if there are any)			
Definition Spatial cognitive engagement refers to students' active involvement and participation in spatial mental activities in ILE (Kruka & Dalton, 2020).					
Item		Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
1	I am very informative about completing spatial learning tasks.				
2	I am interested in the learning process.				
3	In the learning process, I can maintain a positive enthusiasm for learning.				
4	I am satisfied with the result of my study.				
5	I was able to focus my attention on spatial learning.				
If there are any missing terms in describing **Spatial Cognitive Engagement**, please give a suggestion.					

Section 5: Conceptual model validation

This section evaluates the relationship of each dimension in the conceptual model and gives feedback on the conceptual model. Please select an item by marking (✔) on the box either "*Essentials*," "*Useful but not Essentials,*" or "*Not Necessary*."

No.	Hypothesis	Essential	Less essential	Not essential	Any comments on the items? (State if there are any)
H_{01}	Male students have greater advantage in spatial cognition than female students (Newhouse, P., et al., 2007; Driscoll, I., et al.,2005).				
H_{02}	Using VR-related equipment (HMD, VR Glasses, etc.) for learning, spatial ability has been effectively improved (Carbonell, et al., 2017).				
H_{03}	Experiential learning activities are more effective in improving spatial ability (Carmona, R., et al., 2018).				
H_{04}	Art courses, especially in terms of spatial ability cultivating, are very suitable for utilizing VR technique to develop skills, which provides more visible details of learning content (Drigas, et al., 2022).				
H_{05}	Spatial visualization, Navigation, mental rotation, decomposition, and combination are necessary skills for art students' spatial ability (Davis, 2015).				
Any comments on missing dimensions or relationships? (State if there are any)					

Checked by,

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Appendix J

The CVR Results of Expert Review

Item	Expert 1	Expert 2	Expert3	CVR
Students Learning Style				
I like to learn by watching and listening	1	1	1	1
In the learning process, I like to think about ideas.	1	1	1	1
I learn best when I trust my instincts and feelings.	1	1	1	1
I learn best when I listen and observe.	1	1	1	1
I learn best when I think logically	1	1	1	1
I have strong feelings and reactions when studying.	1	1	1	1
I try to figure things out when studying.	1	1	1	1
I learn by feeling	1	1	1	1
I learn by observation	1	1	1	1
I learn through practical operation	1	1	1	1
I am an observant person when learning	1	1	1	1
I am a logical person when learning	1	1	1	1
I learn best when relying on my powers of observation	1	1	1	1
I learn best when trying to do something by themselves	1	1	1	1
I learn best when working hard to get things done	1	1	1	1
I like to observe when studying	1	1	1	1
I like to take an active part when studying	1	1	1	1
Learning Situation				
The environment in ILE is visually no different from reality, which makes me feel immersive.	1	1	0	0.33
I have a good sense of experience in ILE.	1	1	0	0.33
In ILE, I have more desire to learn.	1	1	1	1.00
I feel the scenes is very real by using VR devices.	0	1	0	-0.33
Learning Activity				
Taking a VR class makes me feel happy	1	1	0	0.33
The learning activities of a VR class are an enjoyable thing	1	1	0	0.33
I enjoy participating in the learning activities of the VR course	1	1	0	0.33
In class, I remembered to recognize the appearance and structure of objects	1	1	1	1.00
I felt a sense of accomplishment after completing the course learning activities	1	0	1	0.33
Participating in the course learning activities improved my learning ability in the practical extension course	1	1	1	1.00
Participating in the course learning activities improved my understanding of the spatial structure of objects (such as appearance, structure, characteristics, etc.)	1	1	1	1.00
Participating in the course learning activities improved my knowledge of the position of objects in space (such as direction and orientation)	1	1	1	1.00
Participating in course learning activities improved my ability to observe things (such as appearance, structure, characteristics, etc.) from different angles	1	1	1	1.00
Curriculum learning is challenging	0	1	0	-0.33

I think the functions in the course learning activities are complicated		0	1	0	-0.33
Participation in course learning activities enhanced my curiosity and interest in practical extension courses		1	0	1	0.33
Participating in the course deepened my understanding of 3D modeling knowledge		1	1	1	1
Learning Content					
I can do three-dimensional modeling design in ILE.		1	1	1	1.00
Learning in ILE, I can intuitively observe the three-dimensional features of objects.		1	1	1	1.00
I can interact with three-dimensional shapes in ILE.		1	1	1	1.00
ILE can provide complete information about the course assignments		1	0	0	-0.33
ILE can provide instructional videos that I can access and learn from at any time		1	1	0	0.33
ILE provide a larger space for art courses.		1	1	0	0.33
I can do three-dimensional modeling design in ILE.		1	1	1	1.00
Spatial Skill					
Visual presentation	I can see various scenes in ILE	1	1	0	0.33
	I can view a map of their area in ILE and draw a route map	1	0	1	0.33
	In ILE, I can identify their location and identify the location of other objects	1	1	0	0.33
Navigation	I can quickly locate myself in ILE	1	0	1	0.33
	I can easily reach the designated position in ILE	1	1	0	0.33
	I can use reasonable words in ILE, e.g., "near," "next to, " in... Between, "left," "right," and so on	0	1	1	0.33
Mental Rotation and Transformation	I can rotate the object to various angles in ILE and view it from different angles	1	1	1	1.00
	I can mirror, vertically and horizontally flip objects	1	1	1	1.00
	I can imagine what the target object looks like after different angles, such as 60 degrees or 90 degrees of clockwise rotation	1	1	1	1.00
Identification, Composition, and Decomposition	I can quickly identify regular polygons, cubic blocks, etc.	1	1	1	1.00
	I can combine objects freely in ILE	1	1	1	1.00
	I can break down the combination into multiple single individuals	1	1	1	1.00

Appendix K

Learning Mode Satisfaction

Hello, everyone!

The purpose of this questionnaire is to find out your experience during the course. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	The mission of this learning activity makes me better understand how to identify and classify the features of the target learning objects.	5	4	3	2	1
2	I have endeavoured to observe the differences between the target learning objects in this learning activity.	5	4	3	2	1
3	The mission of this learning activity was not easy to complete, but it was easy to understand the way of learning.	5	4	3	2	1

4	I think this learning mode is challenging and interesting	5	4	3	2	1
5	I have a new discovery or understanding of the target learning object through learning.	5	4	3	2	1
6	I have tried new ways or thinking styles to learn owing to the use of this learning mode	5	4	3	2	1
7	This learning mode is very helpful for me to learn how to recognize the characteristics of the target learning object right	5	4	3	2	1
8	This learning mode helps me to observe the differences within the target learning object	5	4	3	2	1
9	Learning in this learning mode, I learned how to view the target learning object from a new perspective	5	4	3	2	1

Appendix L

Technology Acceptance

Hello, everyone!

The purpose of this questionnaire is to find out your experience during the course. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

2. Answer according to the actual situation

No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	The learning approach enriched the learning activity.	5	4	3	2	1
2	This learning mode is very helpful for me to acquire new knowledge.	5	4	3	2	1
3	The learning mechanism provided by this learning mode makes the learning process smoother.	5	4	3	2	1
4	This learning mode helped me obtain useful information when needed.	5	4	3	2	1

5	The learning approach helped me learn better.	5	4	3	2	1
6	The learning activity conducted in this learning mode is easy to understand and follow.	5	4	3	2	1
7	The learning activity in this learning mode is easy to understand and follow.	5	4	3	2	1
8	It is not difficult for me to use this medium for learning.	5	4	3	2	1
9	It only took me a short time to learn how to use this medium.	5	4	3	2	1

Appendix M

Learning Attitudes

Hello, everyone!

The purpose of this questionnaire is to find out your experience during the course. Please consider your actual situation and choose the most suitable option. We ensure that your data will not be disclosed. All the data you provide will be used for research purposes only. Please feel free to answer.

1. Basic information

Name：	Gender：
Age：	Class：

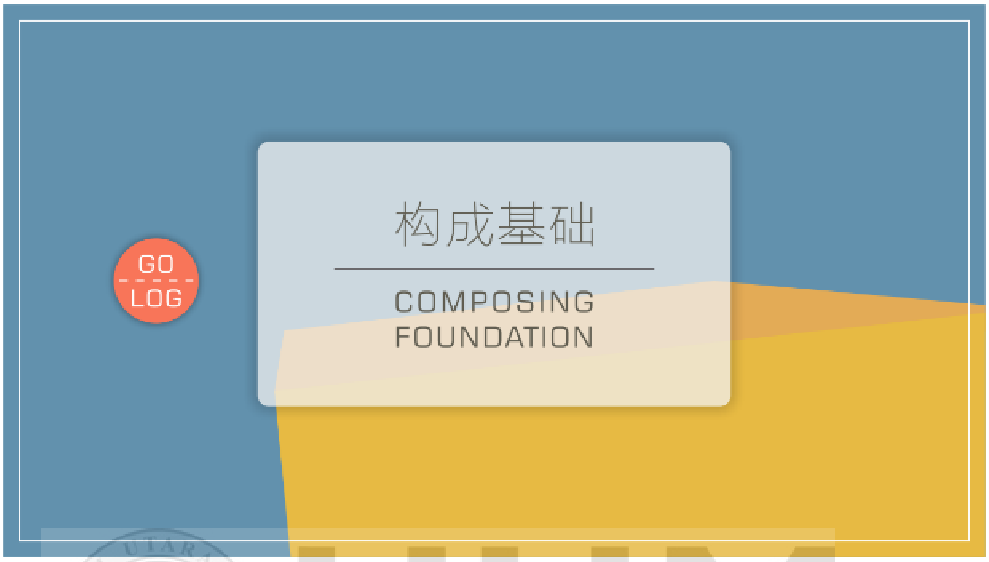
2. Answer according to the actual situation

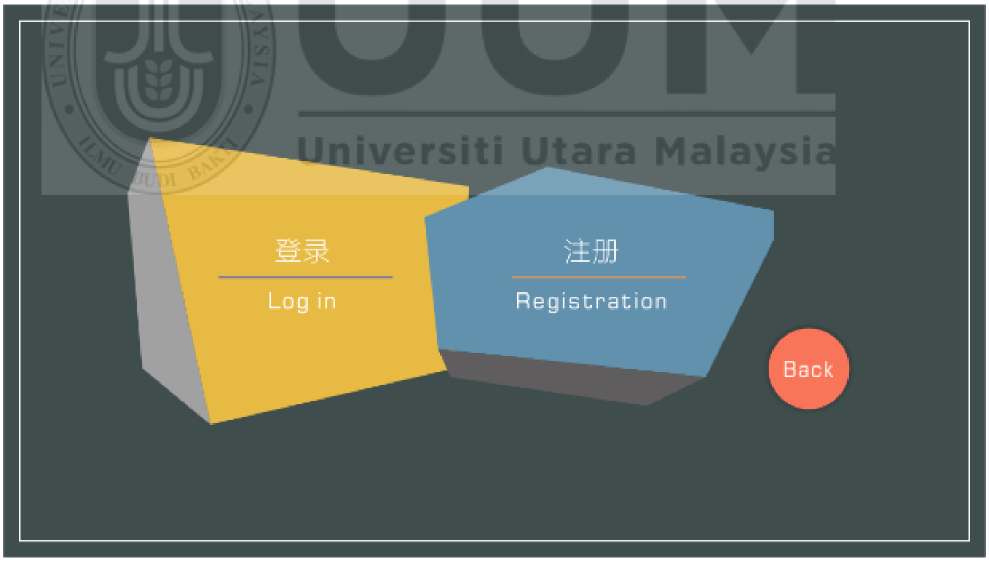
No.	Topics	Very agree	Agree	In general	Disagree	Very disagree
1	After participating in learning activities, I became more interested in observing and exploring spatial relationships.	5	4	3	2	1
2	After participating in the learning activity, I am more confident in recognizing the features between the target learning objects.	5	4	3	2	1
3	After participating in this learning activity, I am more interested in taking the "Composing Foundation" course.	5	4	3	2	1

4	I find it interesting and valuable to study this course.	5	4	3	2	1
5	I like to use this method to carry out the learning of the "Composing Foundation" course.	5	4	3	2	1
6	I will actively try to observe the 3D characteristics of various objects.	5	4	3	2	1
7	I want to learn more and practice more about this course.	5	4	3	2	1

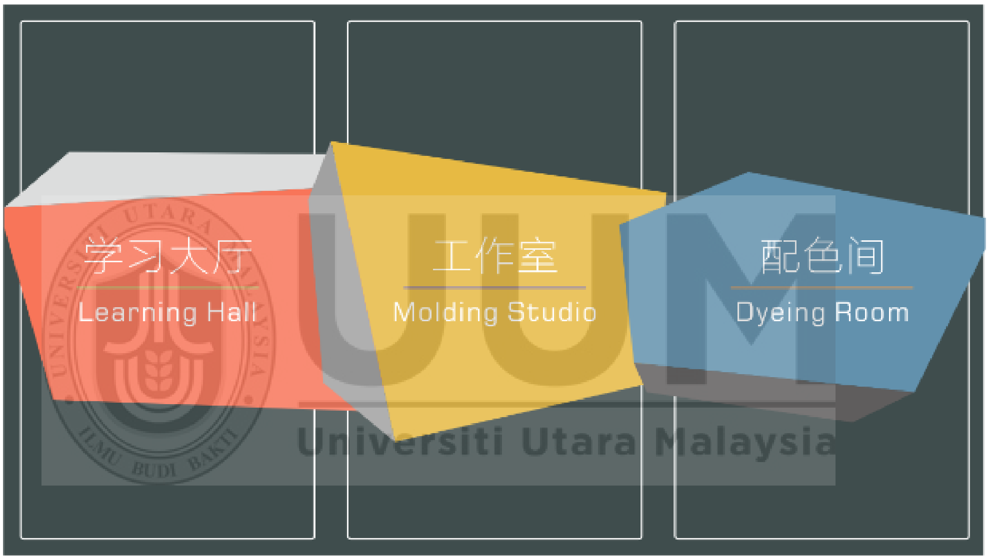
Appendix N

Interface design of the IVRSA learning system






姓名/Name
学号/Matric No.
密码/Password
昵称/Nickname
性别/Gender
男/Male
女/Female
创建/Create a role
返回/Back


学习大厅
Learning Hall
工作室
Molding Studio
配色间
Dyeing Room


Name: Sabrina
Gender: Female
创建/Create
取消/Cancel
服装
Costoms
发型
Hair