THE AUGMENTED REALITY (AR) ENHANCEMENT FOR CUBE PUZZLE ASSEMBLING COGNITION

2020年　3月

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ACKNOWLEDGEMENTS

First of all, I would like to express my deepest gratitude to my advisor Prof. Takamitsu Tanaka for the support of my Ph.D. study and I have been extremely lucky to have an advisor who cared so much about my work, and who responded to my questions and queries so promptly. There would not have been possible without his continued patience, and endless support.

Besides my advisor, I would like to thank my committee members: Prof. Kouichi Konno and Prof. Tadahiro Fujimoto for their insightful comments and encouragement. Also, I would like to acknowledge the Iwate University for their participation and engagement in the study.

I would like to thank my lab mates for their continued support. Dr. Jiang Peng for all of your support and positive motivation and I would like to thank all of the members at the Industrial Design laboratory at Iwate University for their friendship, support, and help throughout my research.

Finally, I would like to thank my parents for their support and encouragement throughout my study.

ABSTRACT

Augmented Reality (AR) is considered to have a high potential to enhance assembling cognition. The visibility of 3D objects merges with the actual environment in AR facilitates and enhances spatial ability that never seen before such as DIY furniture assembling. A process for instruction or manual that contains text, photos, 2D & 3D illustration or diagram to explain the assembly sequence in a step by step from the beginning to the end. Recently, the most instructions or manuals are made by the paper or digital platform such as toy or furniture's manual is typically used to guide for assembly. Thus, people who do not have spatial skills get trouble while follows the manual. They get confused, misunderstand and mistake or error while following the diagram or 3D image in the manual. Especially, different experiences and knowledge have a different spatial skill thus, AR technology will reduce the distinction of different experiences by allowing those people to see accurately interactive 3D objects and the assembly process in 360 degrees. Therefore, this technology provides people to improve spatial ability and mental ability.

Currently, the interactive application comes to help facilitate many different aspects. Such as Navigator, 3D GPS, and Application in various smartphones. The interactive application has a variety of different formats. Mix media technologies are being used in combination with the application such as VR and AR. As well as in education, mix media

have increasingly used such technology by using AR in combination with teaching so that students can learn to understand more than studying in the book. They used with difficult and complex subjects such as sciences and mathematics that needs to memorize various chemical formulas and volume calculated by using AR to create the 3D image and interactive to explain in the complex section and show as a virtual image for understanding more clearly. In addition, disassembling and maintenance for the complex engine (such as aircraft and car engines) are required the specialist. By using the AR can facilitate assemble the complex mechanism and reduce the error and do not require the specialist who specializes in that work.

This study takes advantage of the AR technology to reduce the confusion and error while assembling the cube puzzle in the both previous work "*Investigating affecting the difficulty in assembling a joint of a cube puzzle*" and "*Joint, Space and Volume study by Interactive Cube Puzzle*", that have similar result was the similar shapes, space, and volume confused people to make a mistake and error assembling. Therefore, this experiment takes advantage of the AR technology to enhance assembly ability skills. We choose the most error assembling the cube puzzle of both previous works for this experiment and comparing it with design and non-design ideas because they are different in their thinking and perspective. In particular, the cube puzzle has similar shapes, space, and volume in each part that makes the participant confused when assembling them. Thus, the AR application with interactive 3D cube puzzle can help the different thinking and perspective in design and non-design ideas assemble the actual cube puzzle have similar or different behavior and result while following step by step in the AR application. This experiment uses the same process as previous work by provide the participant assembly the cube puzzle, measure the time of assembly, and record video to analyze the behavior of assembly. The difference is the participant doesn't know while measuring the time and record video because when they know about that it makes them nervous and can't concentrate on the AR application. Finally, the participant has to fill in the satisfaction questionnaire about the AR application easy to use, 3D cube puzzle easy to understand, graphic help to assembly, and etc., by choosing the score +3 (helpful) to -3 (less helpful) respectively.

In this experiment, both ideas can be assembled without confusion or error and the duration time of assembling is almost similar to the previous work. In particular, the non-design groups' assembling duration time was more than the design groups' assembling duration time but the measurement of time showed that some in the non-design group spent less time than the design group because they could not use their imagination when they assembled. They focused on the graphic image of the 3D cube puzzle by looking at the shape and profile more than space and volume and compared it with the actual cube puzzle. Especially, the graphic with 3D modeling facilitates and enhances the assembly cognition of similar shapes, space, and volume. In addition, this is an initial study of the AR application to help assemble DIY furniture or Flat-Pack Design those have the most problem assembly about the various similar rectangular shape in the next session by assembling the actual size of furniture with different graphics in the AR application.

CONTENTS

LIST OF PAPERS AND CONFERENCES

Publication

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Peng Jiang, Thongthai Wongwichai, Sakeson Yanpanyanon, Takamitsu Tanaka, Identifying the Impact of Shape in Assembly of an "Easy-to-Understand" Interlocking Joint Cube Puzzle, Japanese Society for the Science of Design, Journal of the Science of Design Vol.3 No. 2, 2019.

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CHAPTER 1

INTRODUCTION

1. 1 Research Background and Objectives

Spatial reasoning is widely used for spatial tasks such as creating and reading maps. wayfinding diagrams, and assembling toys or furniture. Therefore, people need to have a good ability for spatial skills that require spatial reasoning [1]. Hence, spatial reasoning has gained importance because most current equipments use this ability, for example. computer interfaces, navigators, icons in smartphones or tablets, and buttons in electronic equipment. In particular, customers lacking the ability for assembling objects such as do-it-yourself (DIY) furniture or pack-flat designs [2] make mistakes in choosing the right direction and components while following the instruction manual for assembling furniture, such as 2D illustrators or text. The major problem lies in the fact that there are several components with similar shapes and sizes. The customers can neither separate these components nor recognize the difference among them. However, furniture companies use numbers and alphabets to represent components in the instruction manual. They provide step-by-step instructions on how to assemble each component. However, assembly with a 2D illustrator manual cannot solve the problems of spatial reasoning cognition.

In general, people tend to show little difficulty recognizing familiar objects when they look at them from different perspectives [3]. So, spatial reasoning refers to the cognitive selection, mental imaging, and visual reasoning. The people who have spatial reasoning ability can mentally recognize the rotation of components, how components appear in different shapes and positions, and how they relate to each other. Furthermore, they can understand the components in a 3D environment and have enhanced assembly skills. The augmented reality (AR) technology assists people who do not have spatial reasoning ability by using interactive 3D graphics.

Mix reality is the most significant immersive technology integrated 3D visualizations and actual environments (as shown in Figure 1.1), which is the augmented reality (AR), that merge reality and virtual for creating a new environment and digital exist and interact in real-time [4].

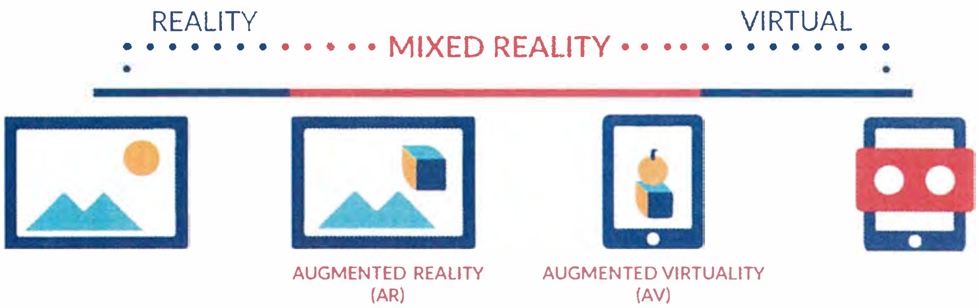

Figure 1.1 Mixed Reality

AR has been investigated in industries since the early 1990s, including robotics, entertainment, medicine, manufacturing, aeronautics, and recently, social networking and education [5], [6]. The recent smartphone has improved function and processing more faster for led to the larger data to work with the AR system and making AR available for general consumers rather than special high-end equipment in industry or laboratory [7] by merging digital into the actual environment for support cognitive assembling difficult or error tasks [8].

Assembly simple or complex components require instructions to be conducted. Normally, the instructions are created in the 2D illustration and text, there are contain a description or diagram to guide assembling step-by-step from the beginning to the end. Thus, AR can change this paradigm, integrated 3D visualizations, and actual environments to guide for assembly tasks (as shown in Figure 1.2). AR software can recognize each component to assemble through the image processing and imitate the component with the 3D object or graphic [9]. Additionally, markers can show identify assembly components and track camera positions. These two features provide image processing implemented object recognition when assembly complex or similar various components [10].

Figure 1.2 Ikea Assemble Application Compare with Original Manual

AR supports people who don't have spatial cognition and mental rotation. Therefore, this technology can facilitate people to recognize and memorize components more effectively when they are assembly with spatial information about physical objects and locations in the real world, AR provides a strong spatial cognition and memory [11], [12]. People were significantly faster and fewer errors when following the 3D Spatial AR application that had to make their mind a slightly lower cognitive [13]. Today, many mobile AR applications are located in to use these AR applications on a mobile device or smartphone, the phone must have many essential tools such as GPS technology, accelerometer, and digital compass. When using the AR application on mobile, users can view the world through a smartphone camera to see digital content integrate with the real environment [14]. The DIY furniture or Flat-Pack design furniture is furniture that can be disassembled. It has many parts/pieces at the time of the installation, and the customers have to assemble it by themselves. However, the assembling is cumbersome because it is designed with these various pieces. After unpacking, some people find assembling difficult and often make mistakes because the shapes are similar rectangles and are many. This makes the customer unable to choose which part or side to assemble to another, even if the instructions are 2D illustrations with text to explain the assembly process. The particular problem is that they do not understand the instructions and the shape of the object for assembling [15]. Considering the cube puzzle in previous work, this is still the same difficulty: not understanding the assembling method. When each part was separate, the participant could not choose the exact parts to assemble because each side had a similar space and volume. Thus, the cube puzzle will be a good study on the advantage of the AR application in reducing the errors and difficulties of assembling, because it does not have many pieces, and is similar to the problem faced in the DIY furniture or Flat-Pack design.

1. 2 Aim

In this particular experiment, we chose to assemble the cube puzzle because there were few pieces in the assembly, and there were similar spaces and volumes that were easily misunderstood. We selected level 3 of the previous work because this level had the most errors in assembling and the longest time duration in both previous experiments. The aim of this experiment is that all the participants should assemble the cube puzzle by following the systematic graphical instruction from this application. Therefore, this experiment aimed to reduce misunderstanding on how to assemble the cube puzzle. This application would have fewer controls on the screen. Therefore, participants could use it easily and with no time limit, which will cause them to focus on correctly assembling the puzzles' parts properly. This experiment focused on observing mistakes while assembling. Thus, there is recorded data on time is taken when the shape of the puzzle was wrongly assembled and when the shape was correctly assembled.

In this study, we will use the results of the experiment to improve and develop solutions for the problems of assembling DIY Furniture or Flat-Pack Design that come with explanations in 2D illustrations on the paper, difficult to understand and causes mistakes in assembling, in the next session.

1.3 Thesis Overview

This study aimed to study the difference in ability, experience, and knowledge in the understanding of similar or different shapes [16]. Therefore, the author divided the participants into two groups: one for design knowledge and another for non-design knowledge [17]. We also brought the problems that had been improved and developed the application to solve them with the AR technology. The procedure complements, makes convenient the creation of the AR application, and reduces mistakes when assembling the actual cube puzzle. The participant had to use a smartphone that had the application, with descriptions on how to assemble the cube puzzle via systematic interactive instructions showing how to use the application. After studying the instructions, the participant was required to assemble the actual cube puzzle following those instructions from the beginning of the first step to the last step, according to the 3D cube puzzle and an interactive display on the smartphone. With the 3D object, the graphic image was to expose the differences of the similar-looking parts, to reduce misunderstanding of these shapes and volumes. Therefore, this experiment was to help people who did not have the ability to assemble to be able to assemble.

Chapter 2 Literature Review

In chapter 2, we define and discuss similar previous experiments that were performed in this field. Configuration of Spatial Ability will be defined as an important ability to assemble. Also, theories of Intelligence show how the behavior, gesture, and mental of a human are different. In this chapter, define the implementation of Augmented Reality, simplified assembly instructions that support and error reduction assembly skill and AR spread in industries work.

Chapter 3 Research Method

In chapter 3, the method used for this experiment is discussed the 2 different experiences and knowledge of participants (design and non-design knowledge) selection. The research implement for the experiment was explained and how the AR assembly process is presented and observation.

Chapter 4 Analysis and Result

In chapter 4, the result of different times of assembly and instruction were shown, including the satisfaction questionnaire. The analyzing of the result from 2 different experiences and knowledge of participants were compared and explained as "*Average Time of Instruction, Average Time of Assembly, App Easy to use, Graphic Helps to Assembly, 3D Obj Show How Assembly is Easy to Understand, 3D object Appears when scan marker points at cube puzzle and App Helps to Assembly*".

Chapter 5 DIY Furniture Assembly using The Augmented Reality

In chapter 5, the second experiment for DIY furniture assembly using the AR application. This chapter was used 3 different graphics for the various similar components of DIY furniture assembly to solved error cognition while assembling by using the AR application. Also, this chapter explained the process of experiment and analyze the result, compare 3 different graphics of thinking time and assembly time, including the questionnaire.

Chapter 6 Conclusion and Future works

In chapter 6, the conclusion was divided into 2 experiments, The first experiment *"The Augmented Reality (AR) Enhancement For Cube Puzzle Assembling Cognition"* discussed how the interactive graphic and 3D objects in AR application enhance assembly ability and error reduction. The second experiment *"DIY Furniture Assembly Using The Augmented Reality"* discussed how 3 different graphics provide facilitate with assembly ability in AR application. In the future discuss consider the User Experience (UX) design that provides the first usage to help and meaningful experiences to users.

Appendix

In the appendix is divided into the section as follow:

Appendix A - In this section, the author provided the implement and process of AR application design and layout for one handholding design.

Appendix B - In this section, the author provided the drawing of Rietveld chair and observation while using the application.

1.4 Definition of Terms

Augmented Reality : augmented reality is a real-time interactive experience of an actual environment integrate with the 3D interactive objects that merge reality and virtual to create a new environment.

Spatial Reasoning : spatial reasoning is reasoning skill refers to cognitive relations among space and objects. This ability can consider, how the objects look when there are rotate in three dimensions.

Mental Rotation : mental rotation is the ability for an imagine rotation of 2D and 3D objects.

DIY Furniture or Pack-Flat Designs : DIY furniture or pack-flat designs are a furniture pack in a box and ready to assemble when unboxing. By following a manual step by step to assembling.

3D Visualizations : 3D visualizations are a technology that creates three dimensions object as know as *"stereoscopic imaging or 3D stereo"* these technologies make a realistic image and use in various industries such as advertising, cinema, game computer, training, and education.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Experiments

In this study, we used the results from 2 experiments. Experiment 1, "*Investigating affecting the difficulty in assembling a joint of a cube puzzle*" (as shown in Figure 2.1), where we gave the tester 3 types of different Cube Puzzles to assemble. The participant assembled Cube Puzzle Level 1 (Easiest), Level 2 (difficult), and Level 3 (hardest). In addition, while the participant assembled each Level, we recorded the time to compare the levels. The result was that Level 1 used the least time, Level 2 used more time than Level 1, and Level 3 used the most time to assemble. Some of the participants could not assemble Level 3 or they took a long time to assemble it. Level 1 had different space and volume in each part that was easy to assemble. Level 2 had different spaces and volumes of shapes that confused a few testers while assembling the puzzle. Level 3 had similar space and volume of shapes problems that confused some participants and caused them to make mistakes while assembling the puzzle (as shown in Figure 2.2). Therefore, space and volume method increased the frequency of errors during the assembling [18].

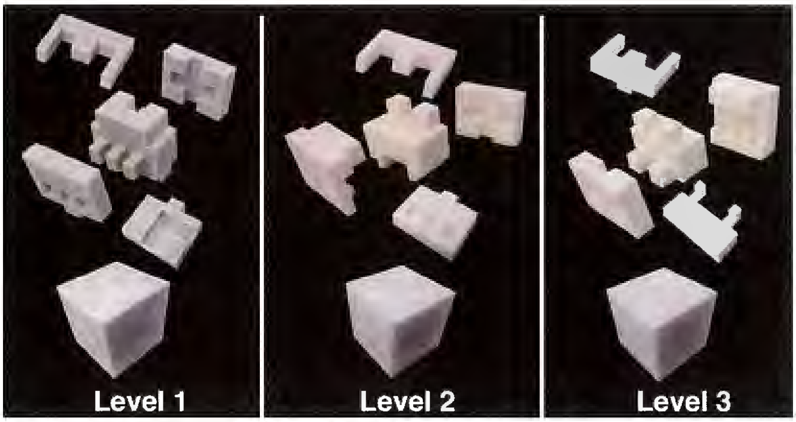

Figure 2.1 Difficulties Valuation of Cube Puzzle

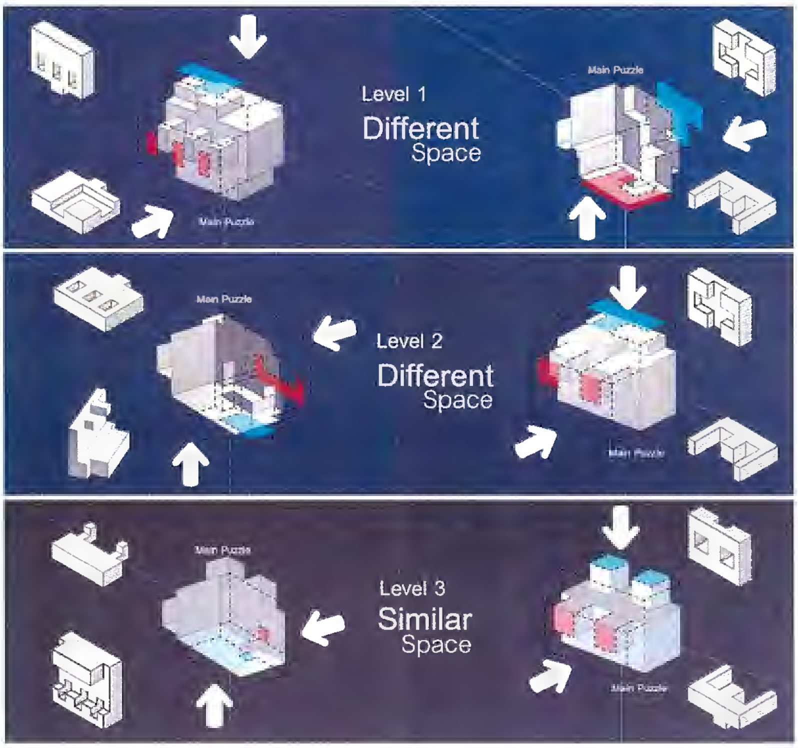

Figure 2.2 Show Different and Similar Space of Each Side Cube Puzzle for Level1, Level2, Level3.

Experiment 2, "*joint space and volume study by Interactive Cube Puzzle*". This experiment created with a 3D interactive application imitated the actual cube puzzle and the process was the same as experiment 1 for comparing the results that similarity or differences. Therefore, experiment 2 had two versions (colored and non-colored), and each version had three levels, the same as experiment 1. The participant was allowed to assemble the cube puzzle by using the application. The result was similar to the previous work but different in Level 1, which used more time than Level 2 [Level 1 > Level 2] because the tester had to learn how to control the application at Level 1 first (as shown in Figure 2.3). Furthermore, Level 3 took the most time to assemble, the same as in experiment 1, and assembling in the application had a longer duration than the actual assembling [19].

In this study, the author chose Level 3 and its problem for both experimentation, because it used the most assembling time and had the most assembly errors owing to the similar shapes. The tester did not know the parts to choose before assembling. This was also the problem when using the controls and interfaces in the application. Another problem was the different experiences and learning styles that design and non-design knowledge groups had about assembling.

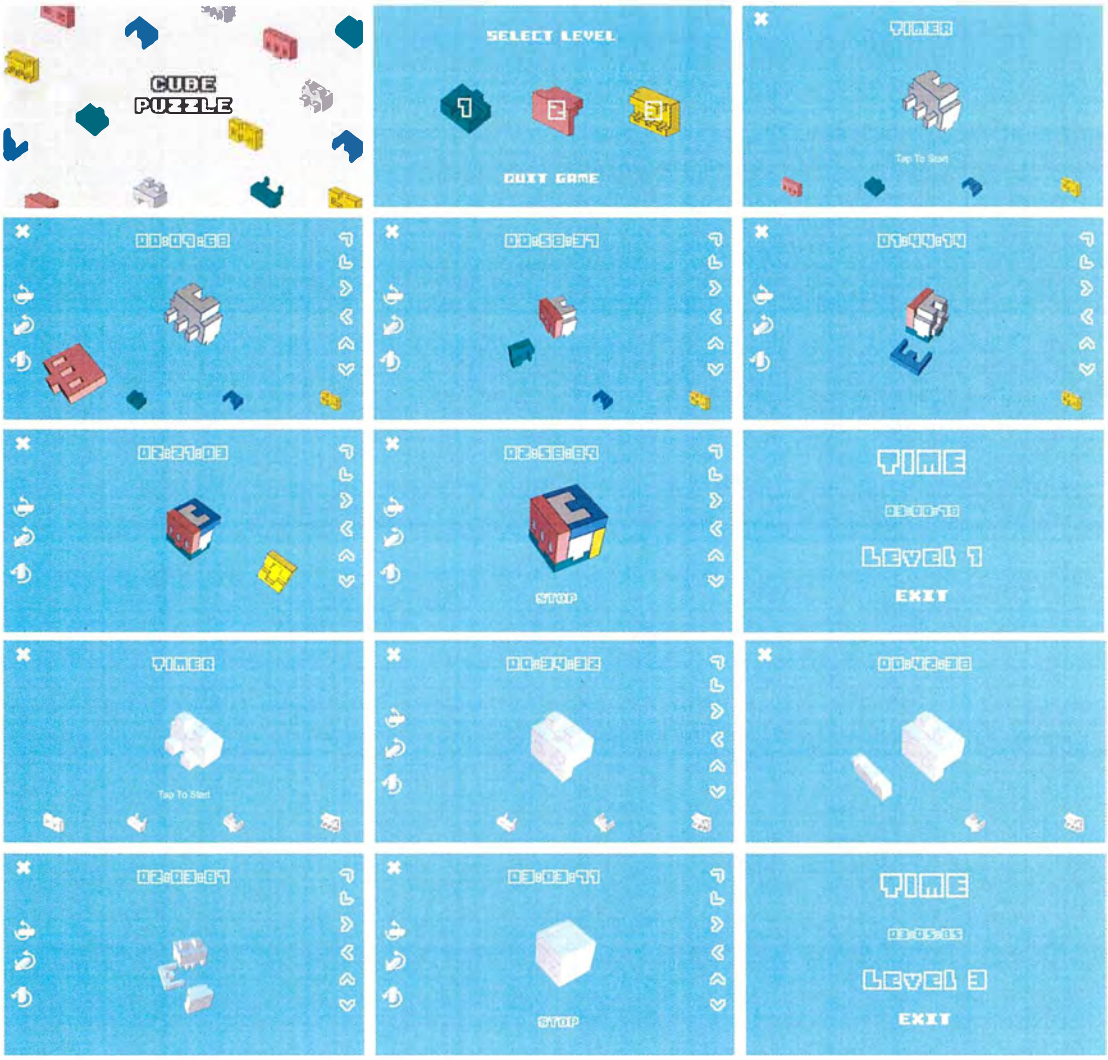

Figure 2.3 Types of Different Cube Puzzle to Assemble in Interactive Application

2.2 Configuration of Spatial Ability

Spatial ability is the ability to recognize as perceive, analyze, synthesize, manipulate and change the structure or shape. According to McGee (1979), spatial ability processes are highly important to enhance assembly skills, consist of visualization and orientation. Visualization is the ability to see the object that is rotated, twisted or changed in direction. This ability can be measured by complex tests. Orientation is the cognitive ability to imagine and understand the objects from different perspectives. In addition, the spatial ability is still different in both sexes men and females [20], [21]. There is a perspective of spatial ability, especially the ability to transform media into symbols, new forms of deformation, and perceptions of the dimensions [22]. Therefore, the spatial ability is the ability of perception to replacement, creation and recognize the symbol. Accordingly, special importance is the finding that a spatial ability positively correlated with mathematics, science, and engineering [23].

Spatial visualization skills, especially the ability to see on the 3D image is cognitive that is involved in Science, Technology, Engineering, Art, Mathematics (STEAM). This skill can learn and practice but the experience and knowledge are an important factor that has a direct influence on spatial skills [24]. Spatial ability has efficiency in thought management that different in each person and essential in recent technology, whether it is educational and occupational. [25] Especially sophisticated the reasoning about shapes, patterns, and figures that have complex tasks that are significant for enhancing the spatial ability.

2.3 Theories of Intelligence

British psychologist Charles Spearman (1863–1945) described a concept that referred to general intelligence or the G factor and Specific intelligence or S factor. G factor is a general cognitive ability that into behavior, gesture, and mental of a human. But it is slightly different for each person. S factor is an important part that makes a different cognitive ability and is a special ability in each person. For example, Engineering, Art, Mathematics, Musical and Logical [26].

The famous American psychologist Louis L.Thurstone (1887–1955) offered a different theory of intelligence. Thurstone 's theory explains *"Factor Analysis"* which means the intelligence can divide into seven different primary mental abilities (*Verbal comprehension, Reasoning, Perceptual speed, Numerical ability, Word fluency, Associative memory, Spatial visualization*) instead of Spearman's theory that intelligence as a single or general ability [27].

Psychologist Robert Sternberg defined the intelligence theory as *"mental activity directed toward purposive adaptation to, selection, and shaping of real-world environments* *relevant to one's life."* Sternberg referred to as *"successful intelligence"* which involves three different factors [28]

- Analytical intelligence: problem-solving abilities.
- Creative intelligence: the aptitude to manage new situations by using experiences and current skills.
- Practical intelligence: ability to solve to changing environments.

2.4 Augmented Reality

AR stands for *"Augmented Reality"* this technology merges virtual 3D images into the real world through a camera and processed by making 3D objects (virtual images) overlapping with real images into one image. Which we can look directly through the computer or smartphone's screen. When we heard that AR is often come up with the VR, which stands for *"Virtual Reality"* this technology is similar with AR, the difference at VR simulate the virtual world by using the accessibility of various accessories such as glasses Oculus Rift, Play Station VR, etc [29]. The main functions of AR (depending on the Engine and Toolkit of each manufacturer), the main parts are similar, such as Tracking: Track inertial measurement, position measurement, give direction in the phone to show the position. Visualization: Visual of 3D model images together with real images to be like the same picture. Interaction: interact 2D or 3D images and sound with the user when control and reacts with the device. Types of AR can divide 2 types.

Location-Based: users do not need to use the smartphone scan from the image, just use the GPS of that device, there can display to 3D images [30]. Thus, this type combines GPS (GPS-based AR) and AR technology systems to work together. For example, the real-time navigator application that provides customers browse or search the place and information by merge 3D objects and graphics in the actual environment to show in a smartphone display. This is an ingenious combination with function and AR technology (as shown in Figure 2.4).

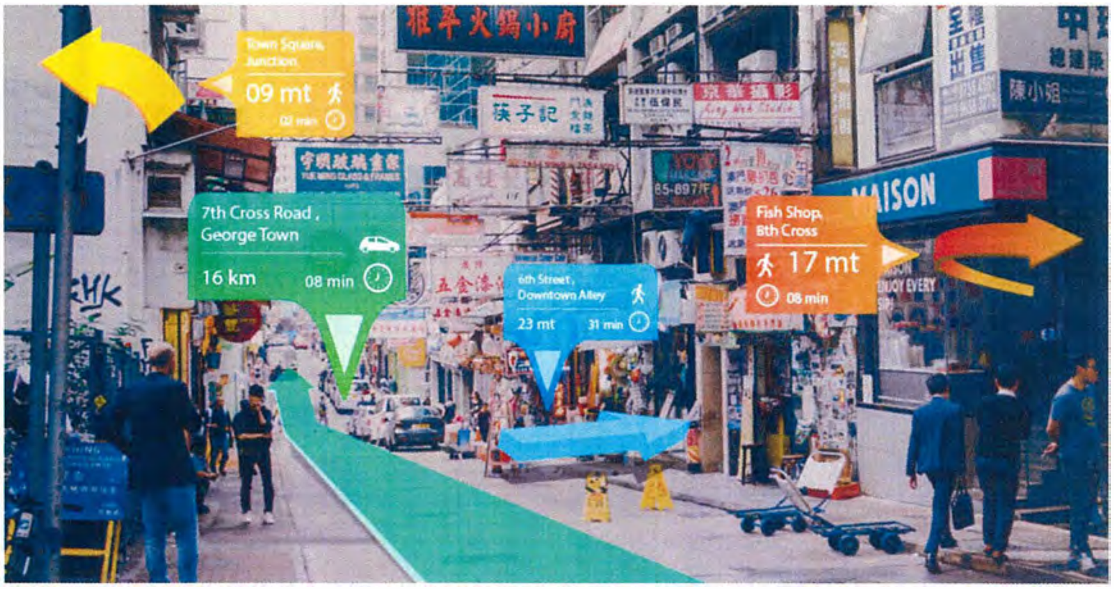

Figure 2.4 GPS-Based AR Realtime Navigator Application.

Marker-Based: is a form of symbols or images. They can be leaflets or brochures. Users scan with a camera from a smartphone to display 3D images [31]. This type facilitates use and not sophisticated for the user. For example, a science book for children that combines 2D illustrator and 3D objects together when using the camera from a smartphone shot to 2D illustrator in a book and then 3D objects show on the screen, there fulfill stories and imagination. Marker-Based Process is adding information to the image by using image analysis calculates the pose estimation from the 3D database which can be calculated until getting the virtual reality (as shown in Figure 2.5).

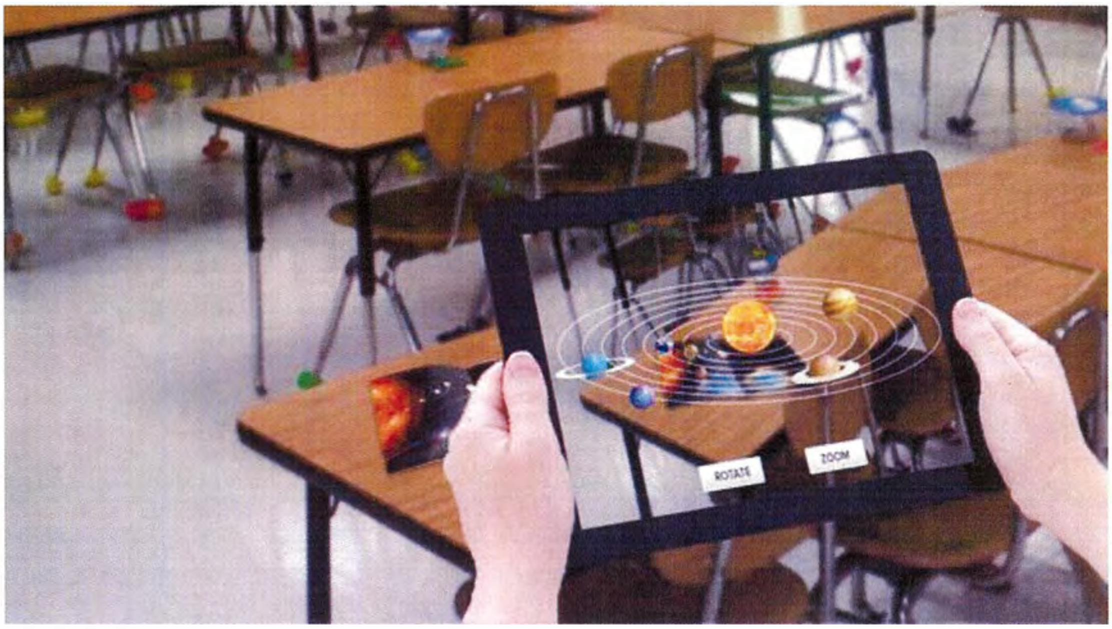

Figure 2.5 AR Science Book

2.5 Simplified Assembly Instructions

The assembling process is a process that has more than one object is put an artifact together. Therefore, the AR system decrease assembly completion times, fewer errors, and lower task load than the typically manual such as the paper-based manual. In particularly, merging the digital and real workspace by using AR technology can improve accuracy and reduce errors [32].

Also, another study H. Rios et al. (2011) compared with 3 different methods for a complex training task in aeronautical processes, which is the first, manuals printed instructions; the second, an audiovisual tool and the third, an AR application using a laptop. They measured the time, errors and questions during the training to the supervisor in the same assembly task. The result was the AR application needed more time to complete the task compared with the audiovisual tool but four times fewer errors using the AR application compared to the other methods and also less help from the supervisor to complete the task [33].

The AR system guides users to assembly tasks. The system recognizes and guides to assembly with virtual graphic signs in each part. Especially, the system accuracy recognizes several different objects that can assist assembly [34].

2.6 AR in Industries Work

AR for the assembly was established already over 20 years ago. AR can provide assembly cognition for difficult tasks. Therefore, this is beneficial technology and can be applied in different kinds of tasks. Examples from industry:

BMW has provided AR to help assembly car components and assembly training in complex and difficult detail. They use smart glasses to display the process sequence of assembling and specify which equipment for assembly [35], [36].

IKEA creates an application called *"IKEA Place AR"* for customers to browse IKEA products to place in their room by using smartphones to show the 3D furniture with the actual environment [37], [38].

Apple company add the AR technology in its products for support ARKit which is apple's augmented reality develop for iOS mobile devices. Thus, Apple allows developers to build high-performance AR application in iPad and iPhone [39].

Recently, immersive technology is the most significant platform in smartphones. This technology benefits and facilities for the assembly processes that means to implement modify assembly procedures with enhance accuracy and reduce errors. Especially complex tasks or similar shapes. These technologies spread in various industries. [40]

CHAPTER 3

RESEARCH METHOD

In this experiment, the instruments of the researcher will be the interactive application and the actual cube puzzle level 3 [18]. The participant has to follow the smartphone application while assembling the actual cube puzzle. When assembling, the smartphone will record a video to note the timing and assembling behavior; these will assist during information analysis (checking the advantage and disadvantages of the AR application). After finishing, the tester will fill a satisfaction survey for using the application.

3.1 Participants

In this study, there were 30 participants, who were divided into 2 groups, all assigned to the different learning and experience methods. The first group was the design knowledge group with 15 participants, while the second group was the non-design knowledge group with 15 participants. There were two groups because of the different modes of thinking and looking, based on the theory of the left hemisphere and the right hemisphere of the brain. The left hemisphere is responsible for the logical, analytical, and objective nature of people, while the right hemisphere is responsible for creativity, recognition, and imagination. [41], [42] (R.W. Sperry won the Nobel Prize for Physiology and Medicine in 1981).

Therefore, the design knowledge group uses more of the right hemisphere than the left hemisphere because they use the mental capacity to create new ideas. In contrast, the non-design knowledge group uses more of the left hemisphere than the right hemisphere because they think logically and reason.

The age range of the participants was 20--45 years, which includes ages where most adults may start purchasing furniture independently, to assemble. Hence, this is a suitable age range for the participants in this experiment.

3.2 Controller

The controller was divided into three types of buttons: gesture, image scanning, and control buttons.

The gesture requires that the finger touches the screen of the smartphone for the application to start and the 3D modeling to show how to assemble the cube puzzle. When the participant's finger touches the screen, the 3D cube puzzle shows how to assemble each part. When the finger stops touching the screen, the 3D cube puzzle is separated from each other.

The image scanning shows the 3D cube puzzle on the real cube puzzle when they use the phone's camera to point at the marker that is stuck on each part of the cube puzzle (as shown in Figure 3.2). The image scanning shows each 3D cube puzzle's part, to reduce the participant's tendency to make mistakes when they choose any part of the cube puzzle.

The control button is used to hide/show the 3D cube puzzle on the graphic screen. It hides/shows the 3D cube puzzle and rotates the 3D cube puzzle at the bottom of the screen because it is easy to use the thumb control for a one-handed holder [43]. In addition, there is a button to switch the language from Japanese to English, reset the button, and preview/ next button at the top of the screen (as shown in Figure 3.3).

3.3 Devices

For smartphones, we limited the participants to use only smartphones and no other devices such as iPad, Google Glass, or VR headset. This is because everyone has a smartphone, and it is easier to use a smartphone than the other devices. The Google Glass and VR headset are special equipment, and most people do not have them, whereas iPads are too big to hold in one hand.

The application display shows in the vertical orientation because this orientation is the basic behavior of people when they hold the smartphone. They can easily control the application with only one hand while they assemble the actual cube puzzle [43], [44].

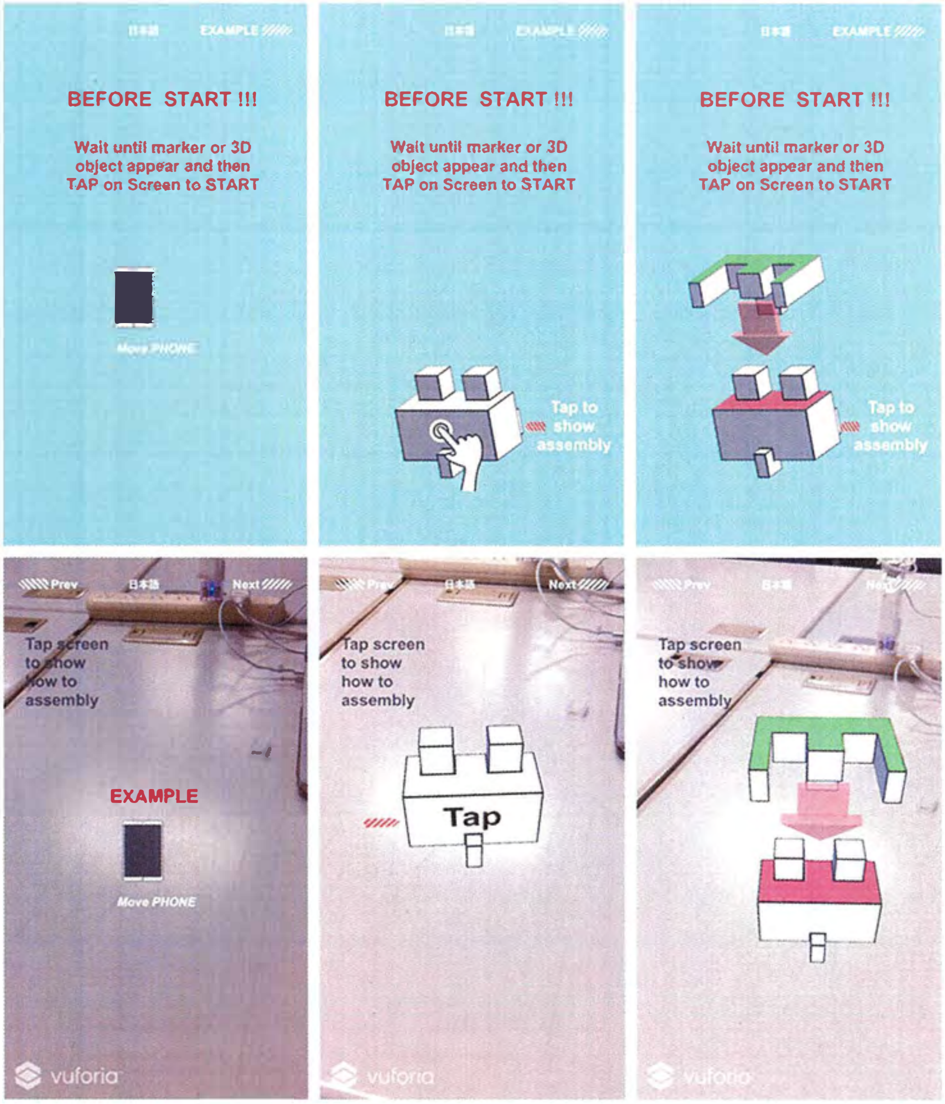

Figure 3.1. Interactive instruction and Example 3D Object Assembly of the Augmented Reality (AR) Application

Figure 3.2 Interactive instruction and Example Image Scan of the Augmented Reality (AR) Application.

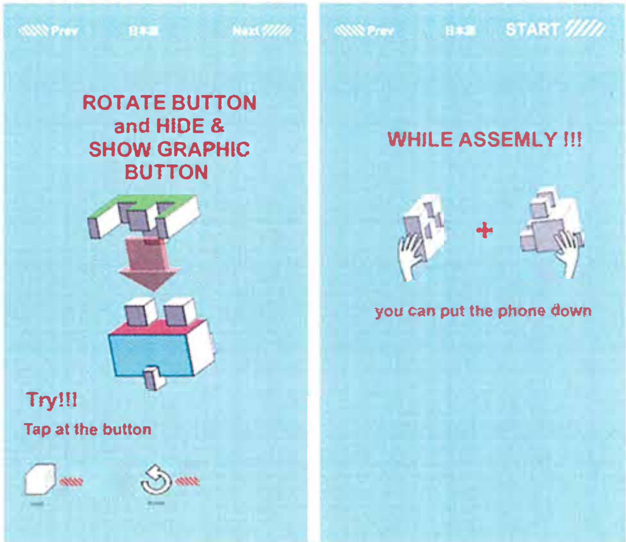

Figure 3.3 Interactive instruction of Button Controller for the Augmented Reality (AR) Application

3.4 Procedures

The application has two parts: the instruction and assembling parts. Therefore, the two groups, design knowledge, and non-design knowledge perform the experiment by testing these two parts.

3.4.1 Instruction

The instruction shows and describes how to use the application. There will also be two language versions, the Japanese and the English versions (as shown in Figure 3.1-3.3). This part also will provide the participant with steps to learn how to use and practice examples with the application before starting to assemble.

Figure 3.1 describes the beginning of the application The participant has to move the smartphone left and right and follow the smartphone icon and waiting for the 3D cube puzzle to appear on-screen. After the 3D cube puzzle appears, they will tap on the screen and the application will show an interactive 3D cube puzzle guide on how to assemble a cube puzzle.

Figure 3.2 describes how to use the 3D cube puzzle image when the scan marker touches the cube puzzle, then the 3D cube puzzle will replace the real cube puzzle. The participant can then choose the right cube puzzle that will reduce the mistake in assembling.

Figure 3.3 describes how to use the rotate button to hide/show the graphic on the 3D cube puzzle by tapping at each icon button. In addition, they rotate 90 degrees and hide/ show each time. Thus, each step will give the participant examples on how to use this part of the application.

3.4.2 Assembling

The assembling part provides the participant instructions on how to start and assemble the actual cube puzzle by following the 3D cube puzzle; because it is an interactive application, it will show systematic instructions from the beginning until the end. The 3D cube puzzle and interactive application show which part of the cube puzzle should be selected first. After that, it shows which part should be assembled with other parts. When the participant completes the first step, he/she plays in the next step, that is, the same as the process in the first step until the last step. The assembling part is divided into four steps; each step uses the same method for assembling (as shown in Figure 3.4-3.7).

When the participant begins to assemble the parts, the screen of the smartphone shows the graphic image on the smartphone move to the left and the right. The participant has to move the smartphone and follow these graphic images, and the screen shows the 3D object part of the cube puzzle as a guide, showing the participant how to find the shape to put on another 3D object/shape. When they find the shape, the participant taps on the screen (as shown at the first image in Figure 3.4-3.7). After that, the screen shows the interactive 3D cube puzzle. Subsequently, the participant chooses the actual cube puzzle that is the same as the 3D cube puzzle. In this part, when the finger taps and releases on the screen, the 3D cube puzzle shows how to assemble (as shown at the second image in Figure 3.4-3.7), and an arrow will show the direction to assemble each part. Furthermore, the participant is required to assemble the actual cube puzzle following the interactive 3D cube puzzle. After the completion of this step, the participant proceeds to the next step and follows the application directions on how to assemble there. If the participant does not know which side of the cube puzzle should be connected with another side, while assembling in each step, the participant can use the smartphone's camera to point to the marker that sticks in each part of the actual cube puzzle. Then, the 3D cube puzzle will appear with the actual cube puzzle to guide the participant, on the side that should be connected to another side.

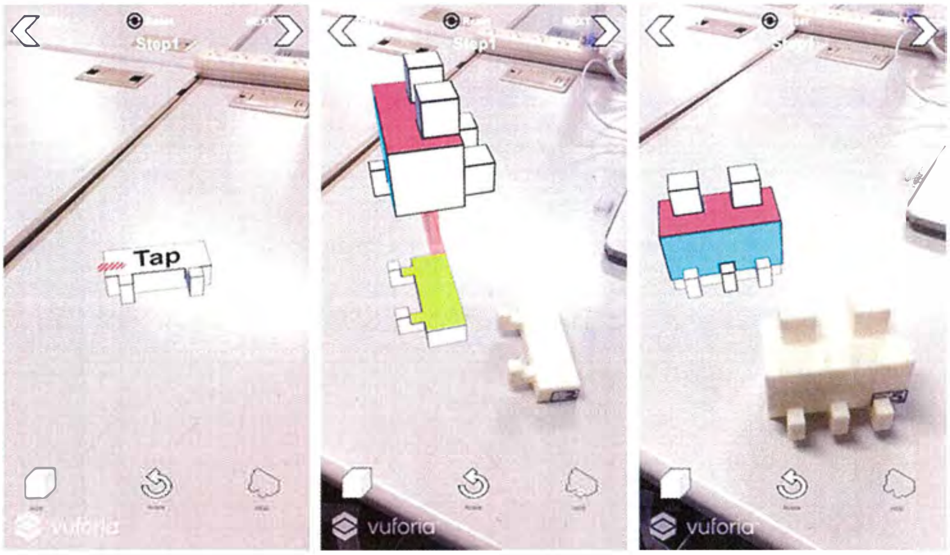

Figure 3.4 Step 1 of the Augmented Reality (AR) Application.

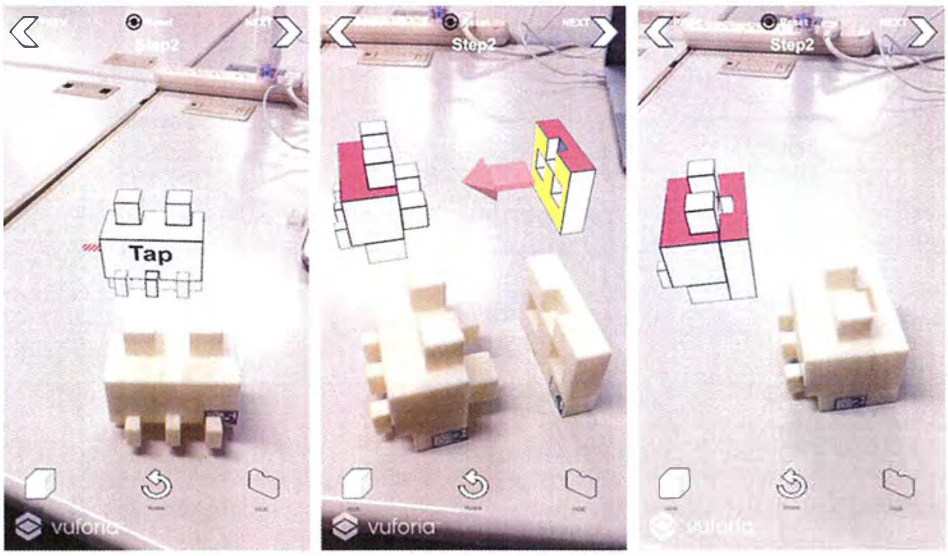

Figure 3.5 Step 2 of the Augmented Reality (AR) Application.

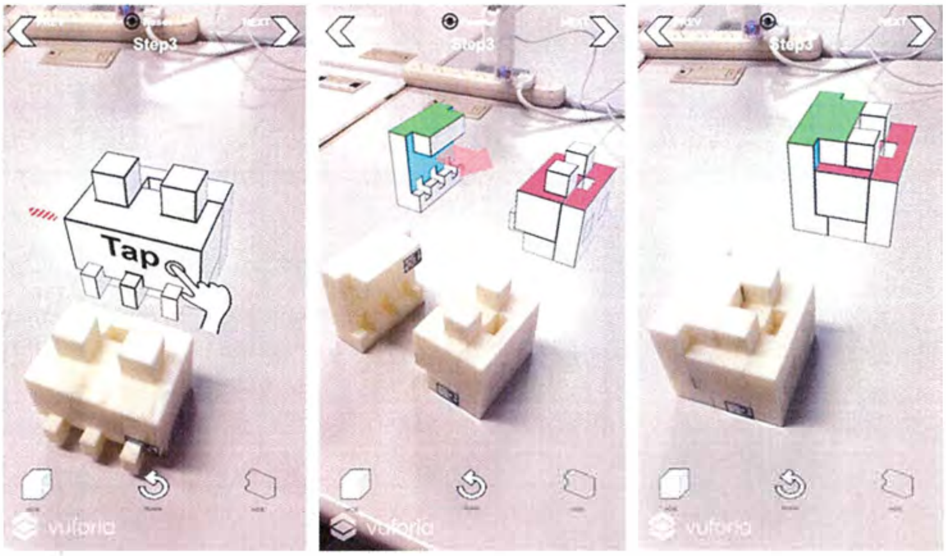

Figure 3.6 Step 3 of the Augmented Reality (AR) Application

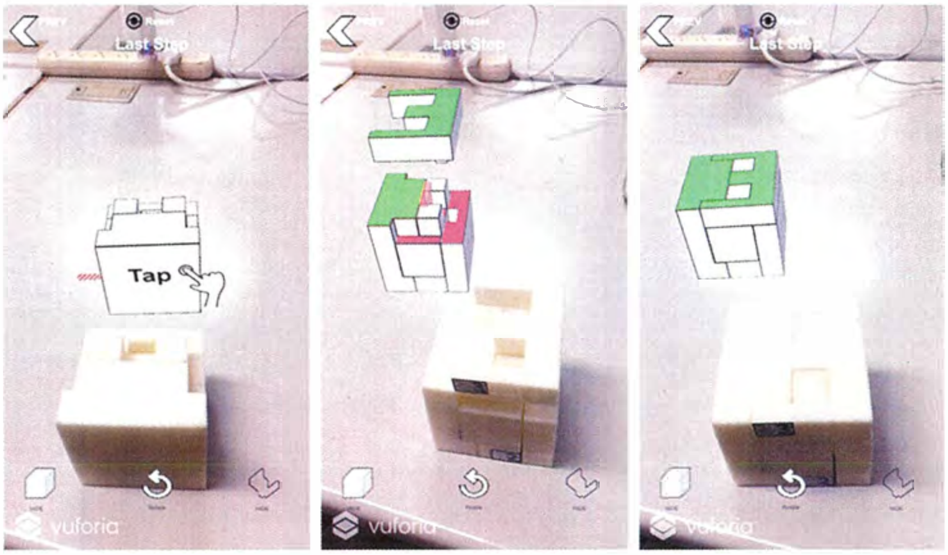

Figure 3.7 Last Step of the Augmented Reality (AR) Application

CHAPTER 4

ANALYSIS AND RESULT

4.1 Results

In this study, the author divided the participants into two groups: the design knowledge and non-design knowledge groups. Both of them were to follow the AR application to assemble the actual cube puzzle, even some people who had never assembled before. Thus, the results of this study were extracted from the time of learning the instruction, time to assemble the cube puzzle, the behavior of participants during the video recording, and the satisfaction survey form. Therefore, the different experiences and knowledge that show the average time of using the application and assembling in the two groups were different. Thus, the design group used an average time that was less than the non-design group (as shown in Table 4.1). When compared with an average time of previous work, the results showed that the average time of design and non-design were almost similar with respect to the average time of previous work that did not use this application (as shown in Figure 4.1). For the previous work, the longest time duration was caused by mistakes (more trials and errors), but this experiment used the time to teach the tester who observes the application's simulation. Hence, when compared with the average time of the interactive application [19], the result showed that the average time of design and non-design was less than the average time of the interactive application (as shown in Figure 4.1). This is because, to assemble the cube puzzle in the interactive application takes time when using the controller, and while assembling the 3D cube puzzle.

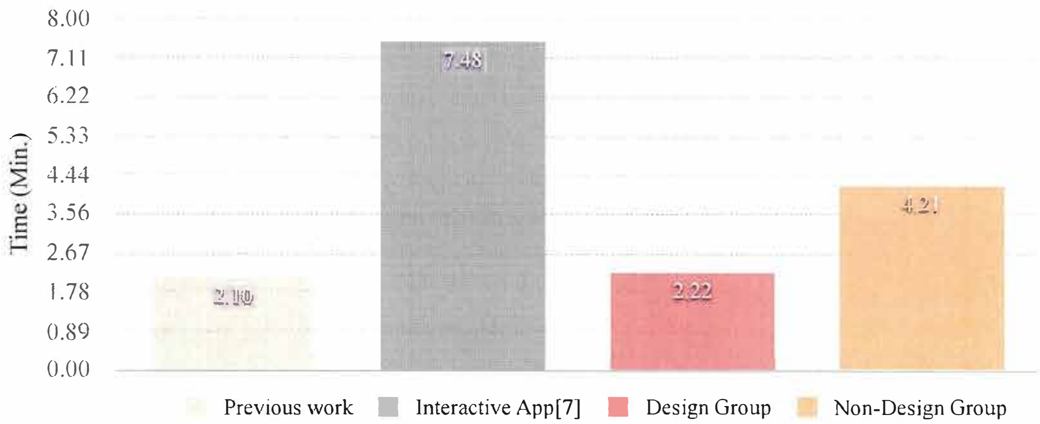

Figure 4.1 Comparison of Average Time with Previous Experiments

In particular, the behavior from the video recording shows that in the experiment, the design and non-design groups did not encounter errors or make mistakes while they assembled the actual cube puzzle when they followed this application. The assistance for the participant focused on the shape and profile rather than space and volume. The application also provided direction for the sides that should be connected. The graphic (as shown in Figure 4.2) helped the participant to easily see the different views of the 3D cube puzzle and to easily compare it to the actual cube puzzle. Therefore, both of them reduced mistakes in assembling of shapes with similar space and volume.

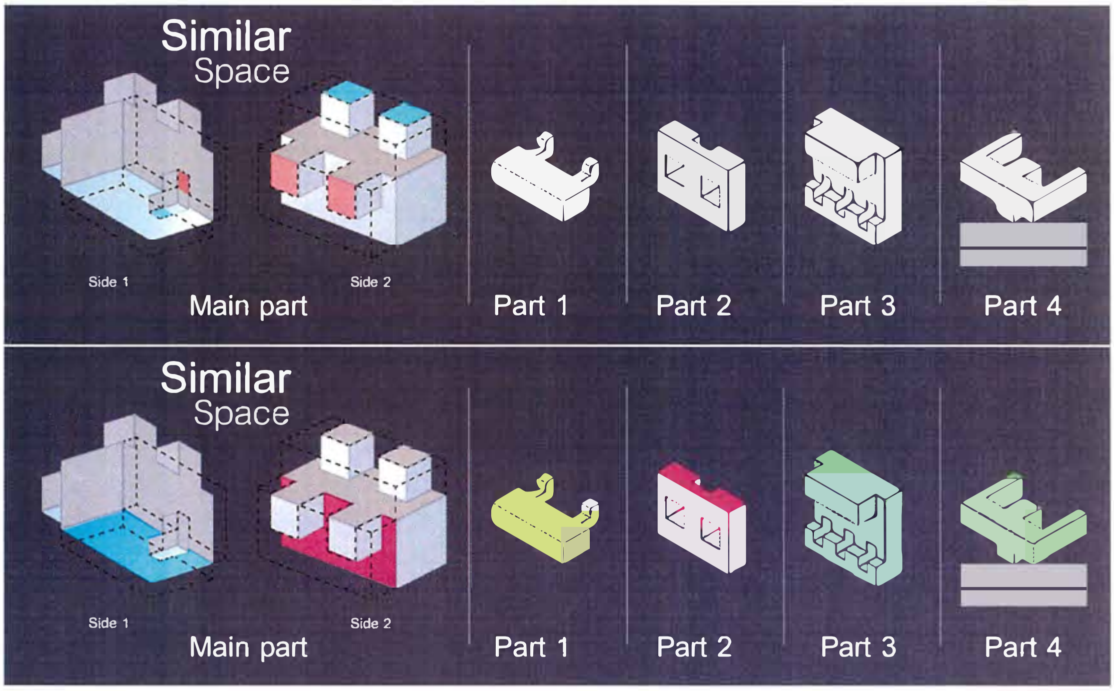

Figure 4.2 All Part of Cube Puzzle Compare with Graphic and Non-graphic

The satisfaction of this study had a range from -3 to +3, where -3 is shown as less helpful or very difficult to use, 0 as not helpful or normal to use, and +3 as very helpful or very easy to use. The tester was to fill a form after finishing the experiment to give feedback after using the AR application. The satisfaction average of the design group ranged from 2 to 3 and meant that the application was very helpful and easy to use. For the non-design group, the range was 1 to 2, meaning that the AR application was helpful and less difficult to use.

The p-value indicates that there is a significant difference between design and non-design for two groups of the average time of assembly $t(30)=-5.460$, $p<0.001$ are well below the 1% statistical significance level. It indicates that the design group has a probability of over 99% of the time to assembly less than the non-design group. But the average time of instruction $t(30)=-1.566$, $p=0.129$ that indicate there spent time for learning instruction no difference between design and non-design. Thus, this experiment did a satisfaction questionnaire to ensure that testers prefer to use the AR application to help assemble the cube puzzle easy to use and understand the 3d cube puzzle and graphic in the application. The t-test and p-value (as shown in Table 4.1) were App easy to use $t(30)=1.148$, $p=0.261$. Graphic help to assembly $t(30)=-0.349$, $p=0.730$. The 3D object shows how to assembly easy to understand $t(30)=0.664$, $p=0.512$. The 3D object appears when the scan marker at cube puzzle $t(30)=-0.265$, $p=0.793$. App help to assembly $t(30)=1.535$, $p=0.136$. The result was p-value indicate that satisfaction there is no difference between design and non-design.

Table 4.1 Comparison of Average Time, Satisfaction and P-value between Design and Non-Design

	DESIGN	NON-DESIGN	T	P-VALUE	H0
AVERAGE TIME (INSTRUCTION)	2m 56s	3m 24s	-1.566	0.129	No Difference
AVERAGE TIME (ASSEMBLY)	2m 22s	4m 21s	-5.460	<0.001	Reject Time Difference Design<Non-design
APP EASY TO USE	2	1	1.148	0.261	No Difference
GRAPHIC HELP TO ASSEMBLY	2	2	-0.349	0.730	No Difference
3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	3	2	0.664	0.512	No Difference
3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	1	2	-0.265	0.793	No Difference
APP HELP TO ASSEMBLY	3	2	1.535	0.136	No Difference

4.2 A Significant Multiple Comparison of the Design Group Satisfaction

Tests of the satisfactions of the design group p=0.003 per test were conducted using Bonferroni adjusted alpha levels. The significance level is 0.05.

Results indicated that average satisfaction of design group was significantly lower in the app easy to use (M = 1.7333, SD = 1.03280) than were those in both the 3D object show how assembly is easy to understand (M = 2.5333, SD = 0.51640), t(15)=-0.80000, p=0.024 and the app help to assembly (M = 2.6667, SD = 0.61721), t(15)=-0.93333, p=0.004. The the app easy to use was significantly no difference in the graphic help to assembly (M = 2.1333, SD = 1.12546), t(15)=-0.40000, p=0.162 and the 3D object appear when scan marker at cube puzzle (M = 1.4000, SD = 1.35225), t(15)=0.33333, p=0.638. (as shown in Table 4.2)

Results indicated that average satisfaction of design group was significantly no difference in the graphic help to assembly (M = 2.1333, SD = 1.12546) with the 3D object show how assembly is easy to understand (M = 2.5333, SD = 0.51640), t(15)=-4.0000, p=0.394, the 3D object appear when scan marker at cube puzzle (M = 1.4000, SD = 1.35225), t(15)=0.73333, p=0.062 and the app help to assembly (M = 2.6667, SD = 0.61721), t(15)=-0.53333, p=0.140. (as shown in Table 4.2)

Table 4.2 A Significant T-test for Multiple Comparison of the Design Group Satisfaction

DESIGN			T	P-VALUE
APP EASY TO USE	=	GRAPHIC HELP TO ASSEMBLY	-0.400	0.162
	<	3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	-0.800	0.024
	=	3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	0.333	0.638
	<	APP HELP TO ASSEMBLY	-0.933	0.004
GRAPHIC HELP TO ASSEMBLY	=	3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	-0.400	0.394
	=	3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	0.733	0.062
	=	APP HELP TO ASSEMBLY	-0.533	0.140
3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	>	3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	1.133	0.006
	=	APP HELP TO ASSEMBLY	-0.133	0.533
3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	<	APP HELP TO ASSEMBLY	-1.267	0.001

Results indicated that average satisfaction of design group was significantly higher in the 3D object show how assembly is easy to understand (M = 2.5333, SD = 0.51640) than the 3D object appear when scan marker at cube puzzle (M = 1.4000, SD = 1.35225), t(15)=1.13333, p=0.006 and the 3D object show how assembly is easy to understand was significantly no difference in the app help to assembly (M = 2.6667, SD = 0.61721), t(15)=-0.13333, p=0.533. (as shown in Table 4.2)

Results indicated that average satisfaction of design group was significantly lower in the 3D object appear when scan marker at cube puzzle (M = 1.4000, SD = 1.35225) than the app help to assembly (M = 2.6667, SD = 0.61721), t(15)=-1.26667, p=0.001. (as shown in Table 4.2)

4.3 A Significant Multiple Comparison of the Non-design Group Satisfaction

Tests of the satisfactions of the non-design group p=0.35 per test were conducted using Bonferroni adjusted alpha levels. The significance level is 0.05.

Results indicated that average satisfaction of non-design group was significantly lower in the app easy to use (M = 1.2000, SD = 1.47358) than the graphic help to assembly (M = 2.2667, SD = 0.96115), t(15)=-1.06667, p=0.022, the 3D object show how assembly is easy to understand (M = 2.3333, SD = 1.04654), t(15)=-1.13333, p=0.009 and the app help to assembly (M = 2.2667, SD = 0.79881), t(15)=-1.06667, p=0.036. The the app easy to use was significantly no difference in the 3D object appear when scan marker at cube puzzle (M = 1.5333, SD = 1.40746), t(15)=-0.3333, p=0.510. (as shown in Table 4.3)

Results indicated that average satisfaction of non-design group was significantly no difference in the graphic help to assembly (M = 2.2667, SD = 0.96115) with the 3D object show how assembly is easy to understand (M = 2.3333, SD = 1.04654), t(15)=-0.06667, p=0.750, the 3D object appear when scan marker at cube puzzle (M = 1.5333, SD = 1.40746), t(15)=0.73333, p=0.103 and the app help to assembly (M = 2.2667, SD = 0.79881), t(15)=0.00000, p=0.853. (as shown in Table 4.3)

Results indicated that average satisfaction of non-design group was significantly no difference in the 3D object show how assembly is easy to understand (M = 2.3333, SD = 1.04654) with the 3D object appear when scan marker at cube puzzle (M = 1.5333, SD = 1.40746), t(15)=0.80000, p=0.052 and the app help to assembly (M = 2.2667, SD = 0.79881), t(15)=0.06667, p=0.614. (as shown in Table 4.3)

Results indicated that average satisfaction of non-design group was significantly no difference in the 3D object appear when scan marker at cube puzzle (M = 1.5333, SD = 1.40746) and the app help to assembly (M = 2.2667, SD = 0.79881), t(15)=-0.73333, p=0.149. (as shown in Table 4.3)

Table 4.3 A significant T-test for Multiple Comparison of the Non-design Group Satisfaction

NON-DESIGN			T	P-VALUE
APP EASY TO USE	<	GRAPHIC HELP TO ASSEMBLY	-1.067	0.022
	<	3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	-1.133	0.009
	=	3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	-0.333	0.510
	<	APP HELP TO ASSEMBLY	-1.067	0.036
GRAPHIC HELP TO ASSEMBLY	=	3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	-0.667	0.750
	=	3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	0.733	0.103
	=	APP HELP TO ASSEMBLY	0.000	0.085
3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	=	3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	0.800	0.052
	=	APP HELP TO ASSEMBLY	0.067	0.614
3D OBJ APPEAR WHEN SCAN MARKER AT CUBE PUZZLE	=	APP HELP TO ASSEMBLY	-0.733	0.149

4.4 Average Time of Instruction

The average time of instruction was the time that users learned how to use the AR application. The instructions were explained systematically in a written form and were interactive. It also had examples for the testers to practice with, before assembling the cube puzzle. Therefore, the participant used some time to learn and practice the instruction, which was almost similar, even though they had different experiences.

4.5 Average Time of Assembly

The average time of assembly was the time used when the participant was assembling the cube puzzle by following the AR application. Therefore, this average time of assembling, the non-design group spent more time than the design group even they were learning the same information. Therefore, the design group could understand the shape and form better than the non-design group.

4.6 App Easy to use

The application was easy to use and this meant that all the functions in the AR application were easy to use and understand, for knowing how to assemble the cube puzzle. The participants of both groups felt it was a little bit difficult to use this application.

Because most of the non-design group never used the AR technology before, they had to get used to it to understand more than the design group.

4.7 Graphic Helps to Assembly

The graphic images helped in the assembly. This meant that the graphic images of the 3D cube puzzle that showed the difference of each side of the cube puzzle by the use of colors to let the tester clearly understand which side should be connected with another side. That meant that both groups thought the graphic could help in assembling the cube puzzle.

4.8 3D Obj Show How Assembly is Easy to Understand

The 3D Object showed how to understand and easily assemble the puzzle by the means of the interactive of a 3D cube puzzle. It showed the joining of parts of the cube while the participant was assembling. This showed that the 3D Object could be assembled very easily and was helpful to both groups' in their understanding and their reduction of mistakes made while working on the puzzle.

4.9 3D Object Appears when Scan Marker Points at Cube Puzzle

The 3D object appears when the scan marker touches the screen on the cube puzzle image. This means that the 3D image of the cube puzzle was displayed when they pointed the phone's camera to the marker/sticker that is stuck on the real cube puzzle. This helped the participant to reduce mistakes made when choosing the joints to assemble. That meant that the 3D object appearing when the scan marker was used, was helpful to the non-design group. The minimum score was because some participants in both groups thought the scan marker was not helpful as they were not familiar with its ability to manipulate graphic 3D cube puzzle image and 3D object.

4.10 App Helps to Assembly

There is an application help to the assembling, which meant that the AR application was helpful to the user when they assembled the cube puzzle. That meant that it was very helpful for assembling the cube puzzle.

CHAPTER 5

DIY FURNITURE ASSEMBLY USING THE AUGMENTED REALITY

5.1 Background and Inspiration

Based on the result of the previous experiment, we desire to use the advantage of AR technology for addressing and reducing the mistakes made in the assembly of DIY furniture or flat-pack design. In addition, 3D components with graphics can enhance cognitive assembly with the AR application. However, the cube puzzle in the previous experiment had only five shapes and sizes, unlike the DIY furniture or flat-pack design, which have several components with similar shapes and sizes.

The experiment conducted here was not aimed at studying the different experiences and knowledge of the design and non-design groups, such as that in the previous experiment. In addition, the AR application in the previous experiment had several instructions and button controllers, which confused the participants when using the application.

In this experiment, we decided to not use the standard DIY furniture or flat-pack design, such as a book shelf, table, or chair, as their components can be easily recognized and assembled. This experiment redesigns the AR application to be non-verbal, using lesser controllers, and having only the assembly part.

This experimental approach to studying cognitive spatial reasoning enhances the AR application to make it easy to understand. In this experiment, we created three types of AR applications, (i) non-graphic, (ii) b&w patterns, and (iii) symbols, and determined which type improved cognitive spatial reasoning of the participants the most and how it aided them to separate components with similar shapes and reduce assembly errors.

5.2 Proposed Method(s)

In this experiment, the participants were asked to assemble the actual-size Gerrit Rietveld Red and Blue Armchair design of 1918 [45] by following the step-by-step instructions provided by the AR application, using interactive 3D chair components in three types (non-graphic, b&w patterns, and symbols).

5.2.1. Participants

The participants included 30 University students (undergraduate and graduate) and staff aged around 20–45 years (12 men and 18 women). This age has a chance to buy and assembling DIY furniture by themselves because there was a good design and not expensive, they can afford it. In this experiment, the participants were divided into three groups, according to the AR application type, and comprised 10 participants each. In this experiment, the chair components were individually assembled by each participant.

5.2.2 Materials

The Gerrit Rietveld Red and Blue Armchair design of 1918 comprises 17 components of similar shapes and sizes and 10 of different ones (as shown in Figure 5.1), including front leg post (No.1), mid support post (No.2), back leg post (No.3), front stretcher support (No.4), mid stretcher support (No.5), back stretcher support (No.6), side stretcher rail (No.7), armrests (No.8), and two flat panels, which form the backrest (No.9) and seat (No.10). In this experiment, the chair was changed from the original red, blue, and black to look like a wood material (as shown in Figure 5.2).

The AR application included interactive 3D chair components (white and black outline) showing how to assemble the chair step-by-step. In addition, the AR application was divided into three types, (i) non-graphic, (ii) b&w patterns, and (iii) symbols, all of which had the same steps, interactive 3D chair components, and materials.

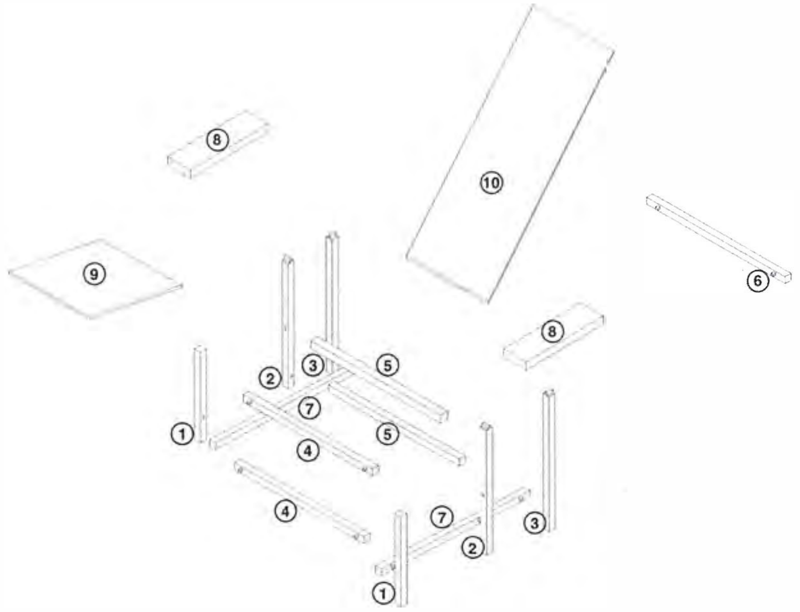

Figure 5.1 Ten Different Components of Gerrit Rietveld Red and Blue Armchair

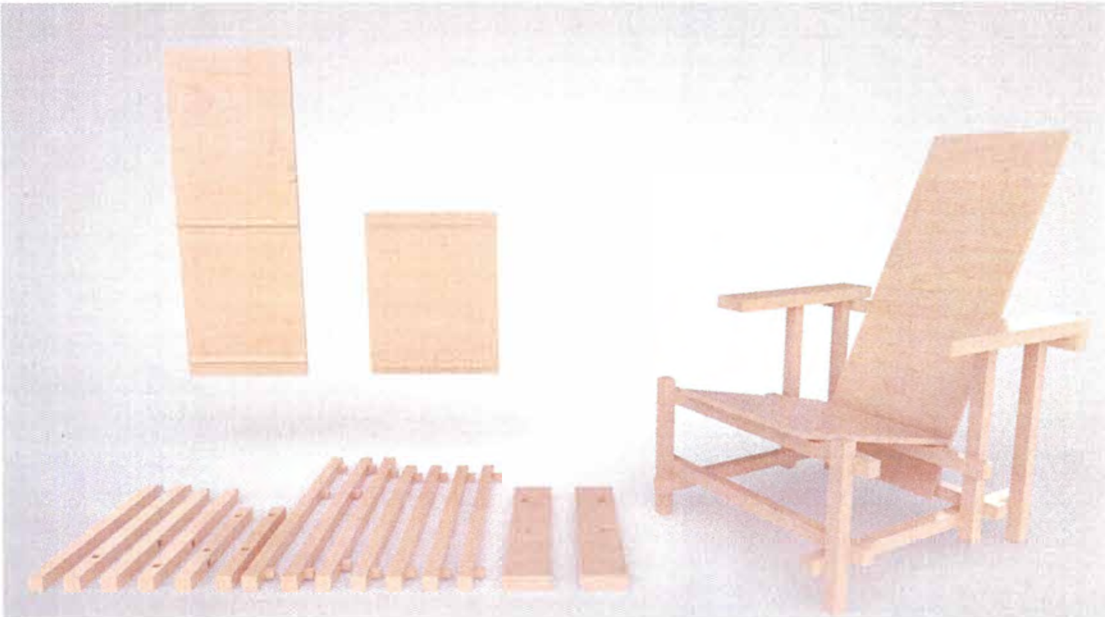

Figure 5.2 The Gerrit Rietveld Red and Blue Armchair with Wood Material

The non-graphic type had only interactive 3D chair components. In particular, this chair had 10 different types of components (as shown in Figure 5.1) and 9 components with different shapes and sizes, such as front & mid stretcher support (Figure 5.3).

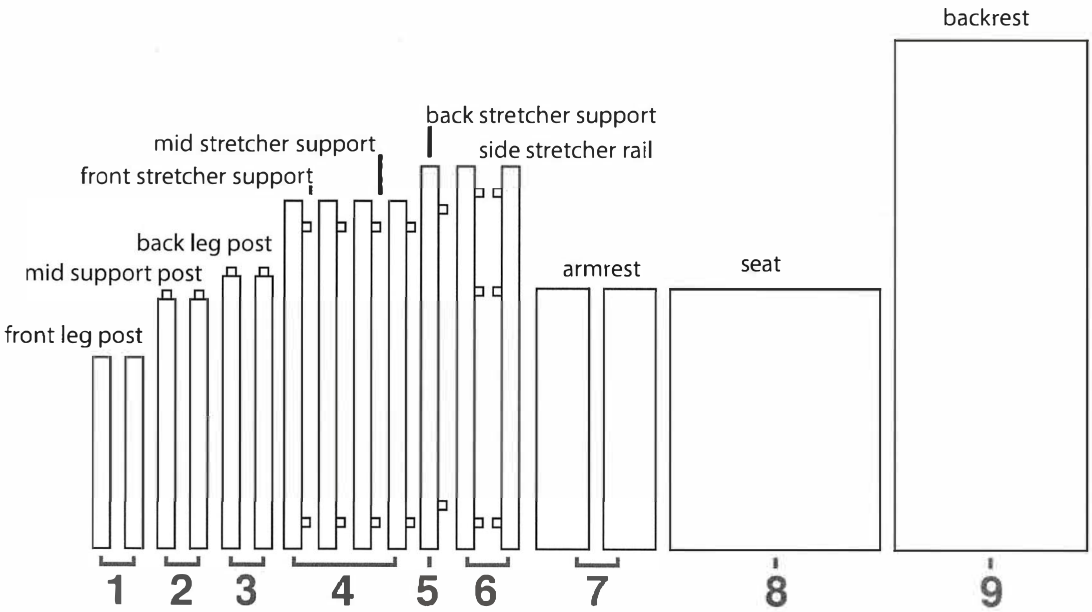

Figure 5.3 The 9 Different Shapes & Size of The Chair Components

The b&w pattern also had interactive 3D chair components. Additionally, 9 different b&w patterns (left black & right white, top black & down white, and middle black & side white) were stuck on each 3D and actual chair component. In particular, this chair had nine components with different shapes and sizes (such as front & mid stretcher support) stuck on some repeated b&w patterns and seven pairs with the same shapes & sizes, such as left & right armrests, front leg post, mid support post, back leg post, side stretcher rail, and front & mid stretcher support stuck on different b&w patterns (as shown in Figure 5.4).

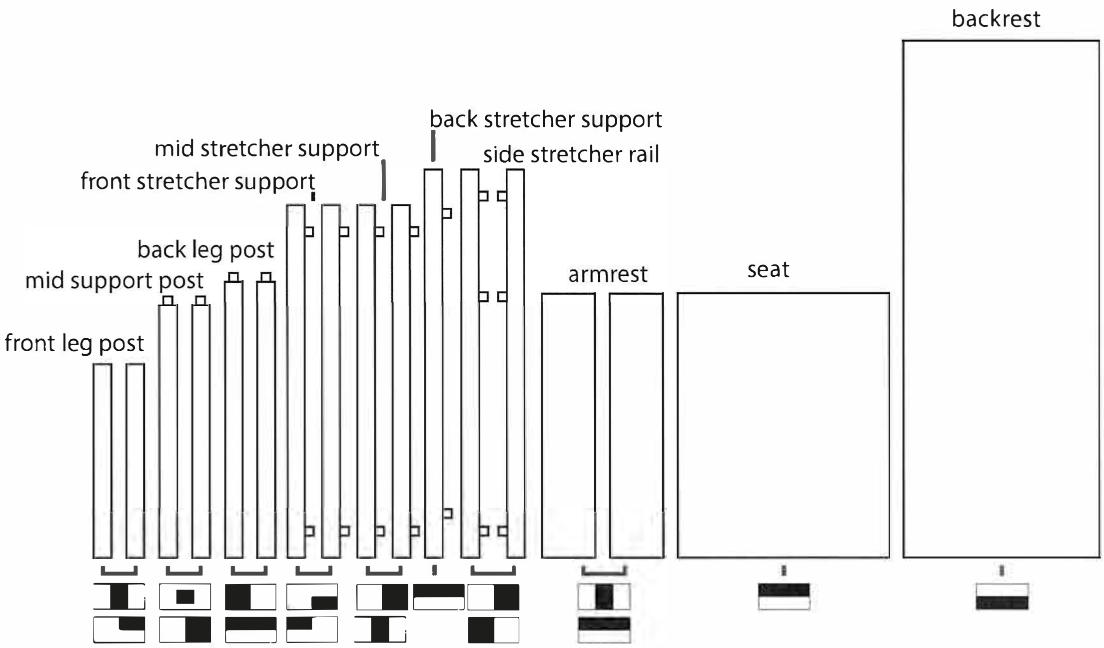

Figure 5.4 The b&w patterns with 9 different shapes & size

Symbols also had interactive 3D chair components. Additionally, nine different symbols (triangle, square, cross, circle, etc.) were stuck on each 3D and actual chair component. In particular, this chair had nine components with different shapes & sizes (front & mid stretcher support have same shapes & sizes) stuck on some repeated symbols and seven pairs with same shapes & sizes, such as left & right armrests, front leg post, mid support post, back leg post, side stretcher rail, and front & mid stretcher support, stuck on different symbols (as shown in Figure 5.5).

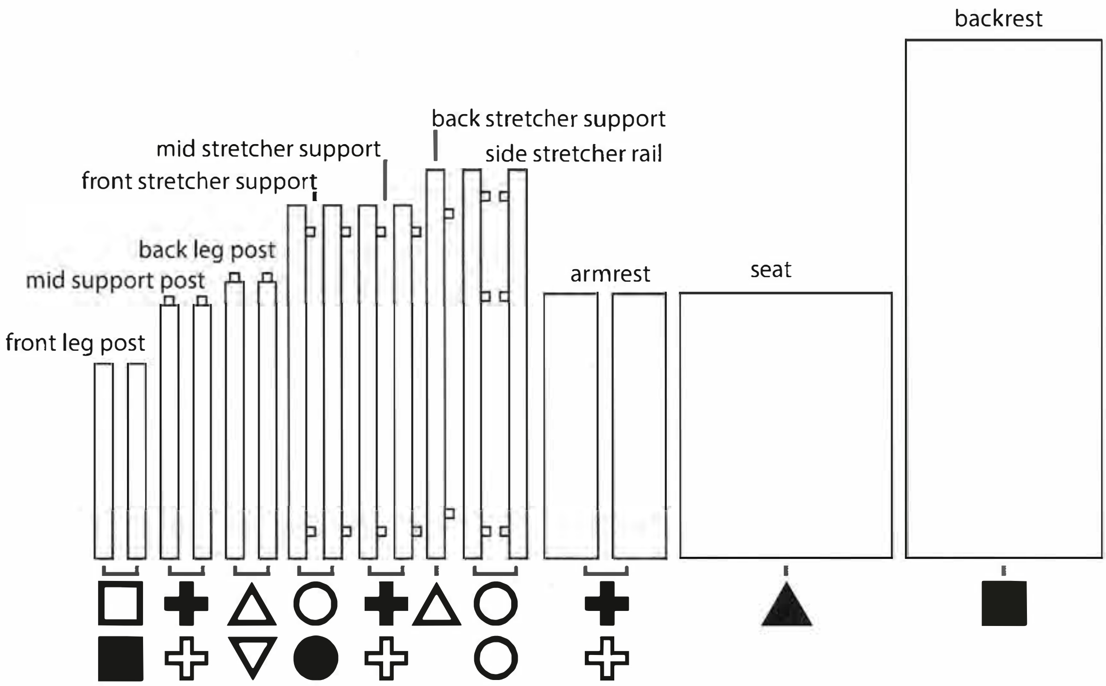

Figure 5.5 Symbols with 9 different shapes & sizes

A camera was used to record the individual behaviors of the participants assembling the chair components while they were following the steps given by the AR application until completion. Thus, the data comprised assembly time, thinking time, the number of mistakes made, and time is taken for fixing them.

Then, a satisfaction questionnaire was administered to the participants to rate their level of satisfaction for the application on a scale of 5 to 1 (5 is the easiest or helpful, 4 is easy and helpful, 3 is normal, 2 is difficult and not helpful, and 1 is the most difficult and least helpful) in terms of ease of use, helpfulness in assembly, and graphic (b&w patterns and symbols) help in assembly.

As in the previous experiment, in this experiment also, the participants were limited to use only smartphones.

5.2.3 Procedures

In this experiment, the actual chair components were individually assembled by the participants by following the step-by-step instructions of the application, and their assembly behaviors were recorded using a camera. The application comprised 3 types and 11 steps, and the participants in each group used each type for complete assembly of this Gerrit Rietveld Red and Blue Armchair.

In the non-graphic case, the participants had to assemble the actual chair components by following the step-by-step instructions using interactive 3D chair components. Therefore, this case did not have any graphics to help the participants assemble each component. Thus, the participants had to select the actual components, compare them with the 3D components, and assemble the 3D components the same as those shown in the AR application. In particular, such a study about 3D components in the AR application enhances spatial reasoning cognition when compared to similar shapes and different sizes of the actual components (as shown in Figure 5.6).

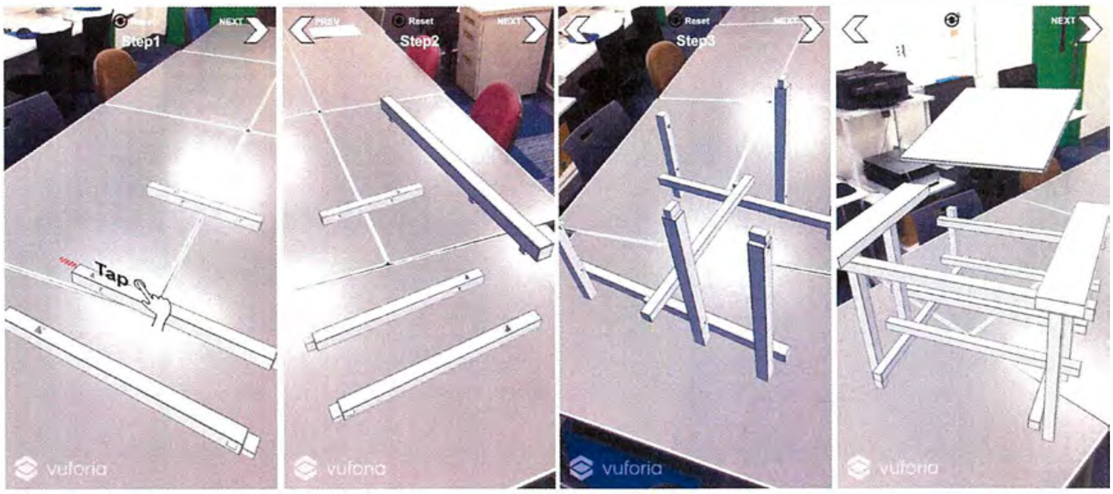

Figure 5.6 The AR Application with Non-Graphic

In case of b&w patterns, the participants had to assemble the actual chair components step-by-step, same as that in the non-graphic type. In particular, this experiment tricked the participants with the 9 different b&w patterns stuck at different positions for each 3D and actual component. Therefore, the participants had to select the actual components that had the same graphics, and assemble them in the same direction and position, as those of the 3D components shown in the AR application. In particular, this experiment focused more on how the b&w patterns enhanced cognition and direction with 3D components in the AR application (as shown in Figure 5.7).

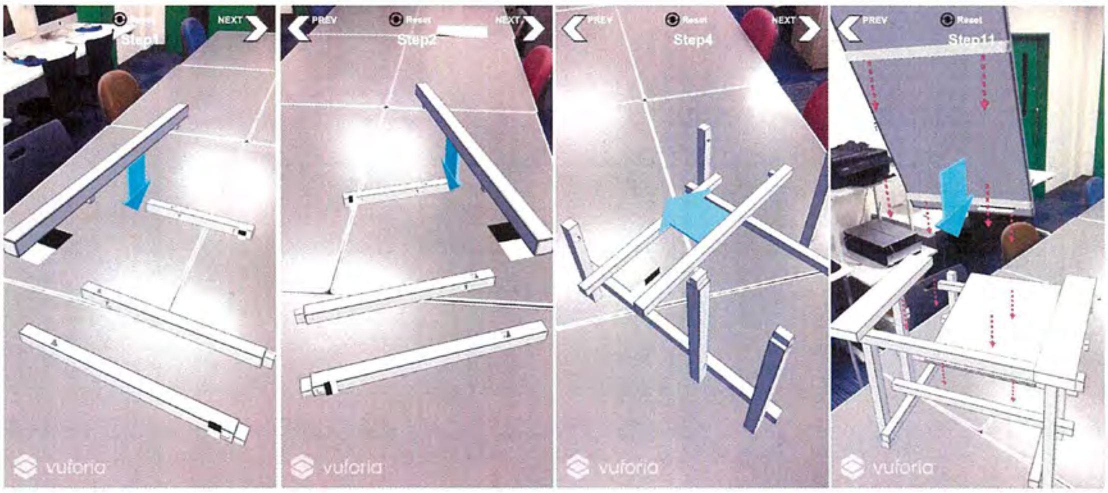

Figure 5.7. The AR Application with B&W Patterns

For the case of symbols, the participants performed the same procedure as that in the case of b&w patterns, with the b&w patterns changed to symbols. Thus, this experiment tricked the participants with the nine different symbols stuck on each 3D and actual component at different positions. Particularly, this group study focused on symbol cognition and direction. The participants had to correctly assemble using the same symbol, position, and direction as those in the 3D components shown in the AR application (as shown in Figure 5.8).

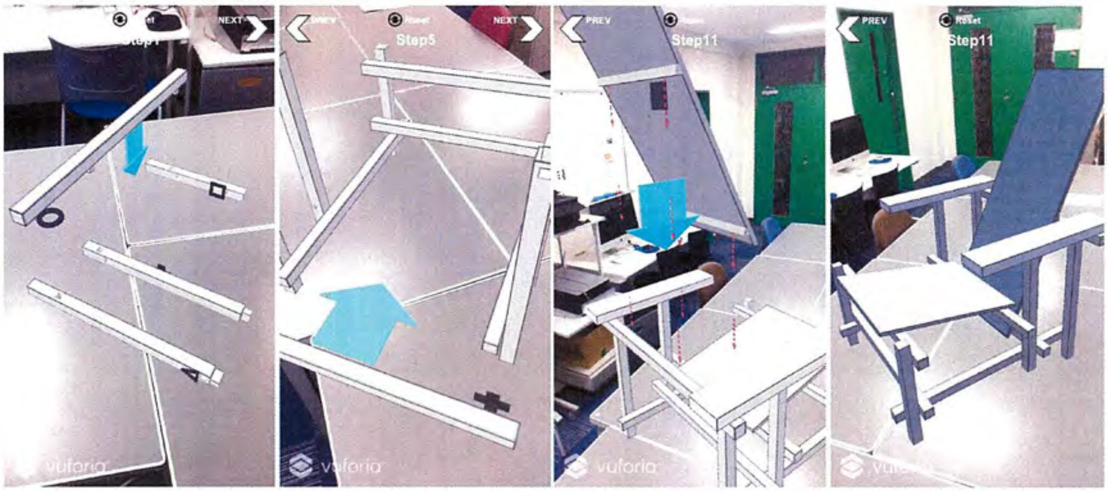

Figure 5.8. The AR Application with Symbols

In all three types, the participants performed the same assembling steps. (i) Each step had the same control. (ii) At the start of each step, the participants had to move the smartphone to the left, right, up, and down. Subsequently, the AR application showed the 3D chair components for finding the position to place them in the room. (iii) After finding the position, the participants had to tap on the smartphone's screen to lock the position of the 3D components. (iv) After another tap, the AR application showed interactive 3D chair components. In case of an application error, the participants were to tap the reset button at the top of the screen. Subsequently, the software would reset to the beginning of each step. When the assembly was finished, the next button at the top of the screen was tapped to go to the next step until the last step. The participants could move backward or forward on each step for fixing any assembling mistake by tapping the previous and next buttons at top of the screen (as shown in Figures 5.6-5.8). Therefore, this application had 11 steps, each of which guided the customer for assembling the different chair components.

Steps 1 and 2 involved assembling the right and left sides of the chair post (as shown at first and second image in Figure 5.6). The participants had to select four different actual chair components (front leg post, mid support post, back leg post, and side stretcher rail) which were the same as the 3D chair components shown in the AR application and assemble them accordingly.

In each of steps 3 to 11, the participants had to select one actual chair component same as the 3D chair component shown in the AR application and assemble it correctly at the same position as that of the 3D component.

Finally, after the participants had finished assembling the chair completely, they had to fill the satisfaction questionnaire. In addition, we checked individually if the components had the correct graphic (b&w patterns and symbol) direction and position. Subsequently, we determined their assembly behaviors, i.e., how long they took for assembly, how long they took for thinking, the number of times that they made mistakes, and the time they took for fixing them, from the captured videos.

5.3 Results

The experimental results indicate the difference and similarity of spatial reasoning among the three types of AR applications from two perspectives: assembly behavior and satisfaction questionnaire.

The p-value tests for satisfactions of the three types of AR applications were conducted using Kruskal–Wallis one-way ANOVA; the significance level was 0.05.

5.3.1 Assembly Behavior

The results of the assembly behavior indicate how the AR application helps the participants during assembly and reduces mistakes, in terms of wrong component and wrong direction selection, when assembling components with similar shapes and sizes.

5.3.1.1 Average Time of Assembly

The non-graphic type spent lesser average assembly time than b&w patterns and symbols, and b&w patterns spent lesser average assembly time than symbols; therefore, symbols spent the maximum average assembly time (non-graphic < b&w patterns < symbols). In particular, the difference in the average assembly time between non-graphic and b&w patterns was 1 min and 13 s, while that between b&w patterns and symbols was just 20 s, which was negligible (as shown in Figure 5.9).

There was no difference in the average assembly times (($M=6.4077$, $SD=2.02210$), $t(30)=2.550$, $p=0.279$) among the b&w patterns, symbols, and non-graphic cases (as shown in Table 5.1).

5.3.1.2 Average Time of Thinking

The average time of thinking spent by the non-graphic type was lesser than those spent by b&w patterns and symbols, and the average thinking time spent by b&w patterns was greater than or equal to that spent by symbols (non-graphic < b&w patterns ≥ symbols). In particular, the difference in average thinking time between b&w patterns and symbols was just 1 s, which is negligible (as shown in Figure 5.9).

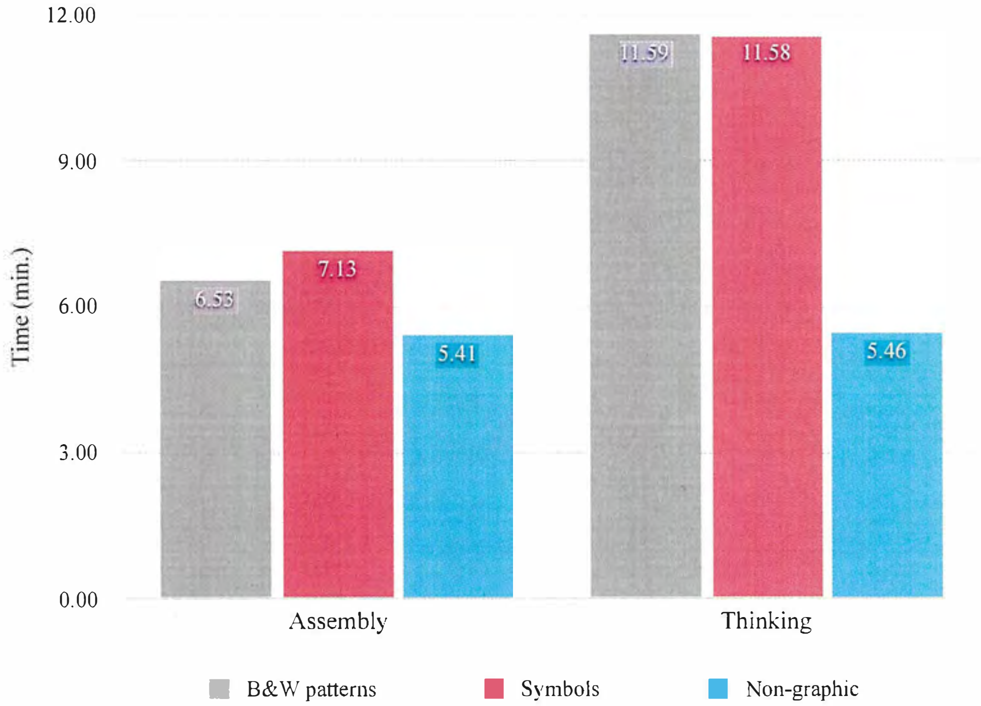

Figure 5.9. Comparison of Average Times of Assembly and Thinking

The p-value indicated that a significant difference in the average time taken for thinking for the non-graphic, b&w patterns, and symbols cases (($M=9.7043$, $SD=5.03617$), $t(30)=15.053$, $p<0.001$) (as shown in Table 5.1).

5.3.1.3 Average Mistakes & Fixing while Assembly

The average time spent on mistakes & fixing indicates the number of times mistakes were made and the time required in fixing them. The non-graphic type had an average mistake & fixing one time lesser than b&w patterns and symbols, both of which had the same average mistake & fixing of two times (as shown in Table 5.1).

The p-value of the average of mistake & fixing while assembly (($M=1.4667$, $SD=1.67607$), $t(30)=5.411$, $p=0.067$) indicated no difference among the b&w patterns, symbols, and non-graphic types (as shown in Table 5.1).

5.3.1.4 Average Number of Wrong Components

The average number of wrong components indicates how many components were wrong even after the completion of the assembly. The non-graphic type had an average of two wrong components, which is more than that for b&w patterns, which had one wrong component, which is less than symbols, which had two wrong components. Thus, non-graphic and symbols had the same average number of wrong components, while b&w patterns had the least (as shown in Table 5.1).

The p-value of the average number of wrong components ((M=1.5667, SD=1.30472), t(30)=7.523, p=0.023) indicated significant differences among the three types. Thus, the average number of wrong components for b&w patterns was significantly lesser than those for non-graphic and symbols (as shown in Table 5.1).

5.3.1.5 Average Number of Wrong Directions

The average number of wrong directions indicates how many actual components are not assembled in the same direction as that shown in the AR application even after the completion of the assembly. These data were available for only b&w patterns and symbols. The b&w patterns had an average of two wrong directions, which is less than that for symbols, which had three wrong directions (as shown in Table 5.1).

The p-value tests of the satisfactions of the average number of wrong directions were conducted on a normal distribution that used an independent T-test. In particular, the p-value of the average number of wrong directions, t(20)=-0.793, p=0.438. This indicates that there was no difference between the b&w patterns and symbols cases (as shown in Table 5.1).

Table 5.1 Comparisons among Average Assembly Time, Average Thinking Time, Average Mistakes & Fixing, and Average Numbers of Wrong Components and Directions

	NON-GRAPHIC	B&W PATTERNS	SYMBOLS	P VALUE
AVERAGE TIME (ASSEMBLY)	5m 41s	6m 53s	7m 13s	0.279
AVERAGE TIME (THINKING)	5m 46s	11m 59s	11m 58s	<0.001
MISTAKE & FIX (TIMES)	1	2	2	0.067
WRONG COMPONENTS (PART)	2	1	2	0.023
WRONG DIRECTION (PART)	N/A	2	3	0.438

5.3.1.6 A Significant Multiple Comparison of Average Time of Thinking and Average Number of Wrong Components

The p-value indicated that two factors (the average time of thinking and the average number of wrong components) had a significant difference among non-graphic, b&w patterns, and symbols. The multiple comparisons of the average time of thinking between non-graphic and b&w patterns ($t(30)=-3.477$, $p<0.001$) indicated that the b&w pattern was significantly higher than non-graphic. The multiple comparisons of non-graphic and symbols ($t(30)=-3.175$, $p<0.001$) indicated that the symbol was significantly higher than non-graphic. There was no significant difference between the b&w patterns and symbols ($t(30)=-0.227$, $p=0.281$) (as shown in Table 5.2).

The multiple comparisons of the average number of wrong components between non-graphic and b&w patterns ($t(30)=-1.193$, $p=0.233$) indicated no significant difference. Non-graphic and symbols ($t(30)=-1.443$, $p=0.149$) also did not indicate any significant difference. Between b&w patterns and symbols ($t(30)=-2.779$, $p=0.005$), the symbol was significantly higher than b&w patterns (as shown in Table 5.2).

Table 5.2 A Significant T-test for Multiple Comparisons of Average Time of Thinking and Average Number of Wrong Components

	H0	T	P-VALUE
AVERAGE TIME (THINKING)	B&W PATTERNS > NON-GRAPHIC	-3.477	<0.001
	SYMBOLS > NON-GRAPHIC	-3.175	<0.001
	B&W PATTERNS = SYMBOLS	-0.227	0.281
WRONG COMPONENTS (PART)	NON-GRAPHIC = B&W PATTERNS	-1.193	0.233
	NON-GRAPHIC = SYMBOLS	-1.443	0.149
	SYMBOLS > B&W PATTERNS	-2.779	0.005

The b&w patterns had the same average of mistake & fixing and thinking as symbols but much more than non-graphic, which did not have any graphic. The average number of wrong components and wrong directions were the least in each group. The result indicates that for the b&w patterns, the participants considered and recognized direction and shape & size. Therefore, they took time for selecting and assembling the same components as the 3D components. The graphic function helped the participants in fixing the wrong components while assembling, and also spent considerable time in comparison with the non-graphic function. The b&w pattern reduced the number of wrong components and wrong direction.

Symbols had the maximum values for an average of mistake & fixing, average assembly time, the average number of wrong components and wrong directions, except for the average time of thinking, which was lesser than that for b&w patterns by just 1 s (negligible). The result indicates that symbols helped the participants consider and recognize especially outstanding symbols. They took the same amount of time for selection and assembly as that for the symbols shown with 3D components. In particular, the participants did not spend time considering the direction and shape & size of the 3D components. Therefore, symbols increased the number of wrong components and direction when the assembly of the chair was complete.

On the other hand, the non-graphic function had the least values for the average of mistakes & fixing and the average assembly and thinking times. According to the result, the assembly cognition provided by interactive 3D components indicated that the non-graphic function enhanced the assembly skill of the participants. However, it had the maximum number of wrong components, same as that of symbols (as shown in Figure 5.10), because many of the chair components had similar shapes & sizes, which can easily lead to the wrong assembly, and the participants could not recognize the differences among the components. Therefore, the non-graphic function had the least values for mistake & fixing and thinking time in each group.

The results of assembly behavior indicate that after the chair assembly was complete, the non-graphic function had 5 of 10 participants (50%) who did not assemble the chair as the original, b&w patterns had 2 of 10 such participants (20%), and symbols had 6 of 10 such participants (60%); the data of 1 participant was erroneous. The most incorrectly assembled components were front & mid stretcher support, back stretcher support, and left & right armrests (as shown in Figure 5.10). In particular, the participants were always swift in assembling in the wrong position because the similar shapes & sizes tricked their spatial reasoning cognition. The AR application that had b&w patterns on components enhanced the spatial reasoning cognition more than the symbol and non-graphic functions. This reduced the number of incorrectly assembled components because the participants spent maximum time thinking. The graphic functions (b&w patterns and symbols) enhanced the assembly ability of the participants for components with similar shapes & sizes, which the participants fix when there is a mistake in assembling the components. Therefore, mistake & fixing also increased assembly time.

In particular, the graphic functions (b&w patterns and symbols) did not improve the direction ability. The participants did not consider the direction and position of the graphics shown on the 3D and actual components. Thus, the graphic functions could not help in understanding the left or right direction of the various similar components, such as front & mid stretcher support, back stretcher support, and left & right armrests (as shown in Figure 5.10).

5.3.2 Satisfaction Questionnaire

This section provides the average satisfaction of the participants' opinion and analyzes the difference or similarity from the following four perspectives: (i) ease of use of application, (ii) graphic's help in assembly, (iii) easy-to-understand assembly using 3D components, and (iv) help provided by the application in assembly.

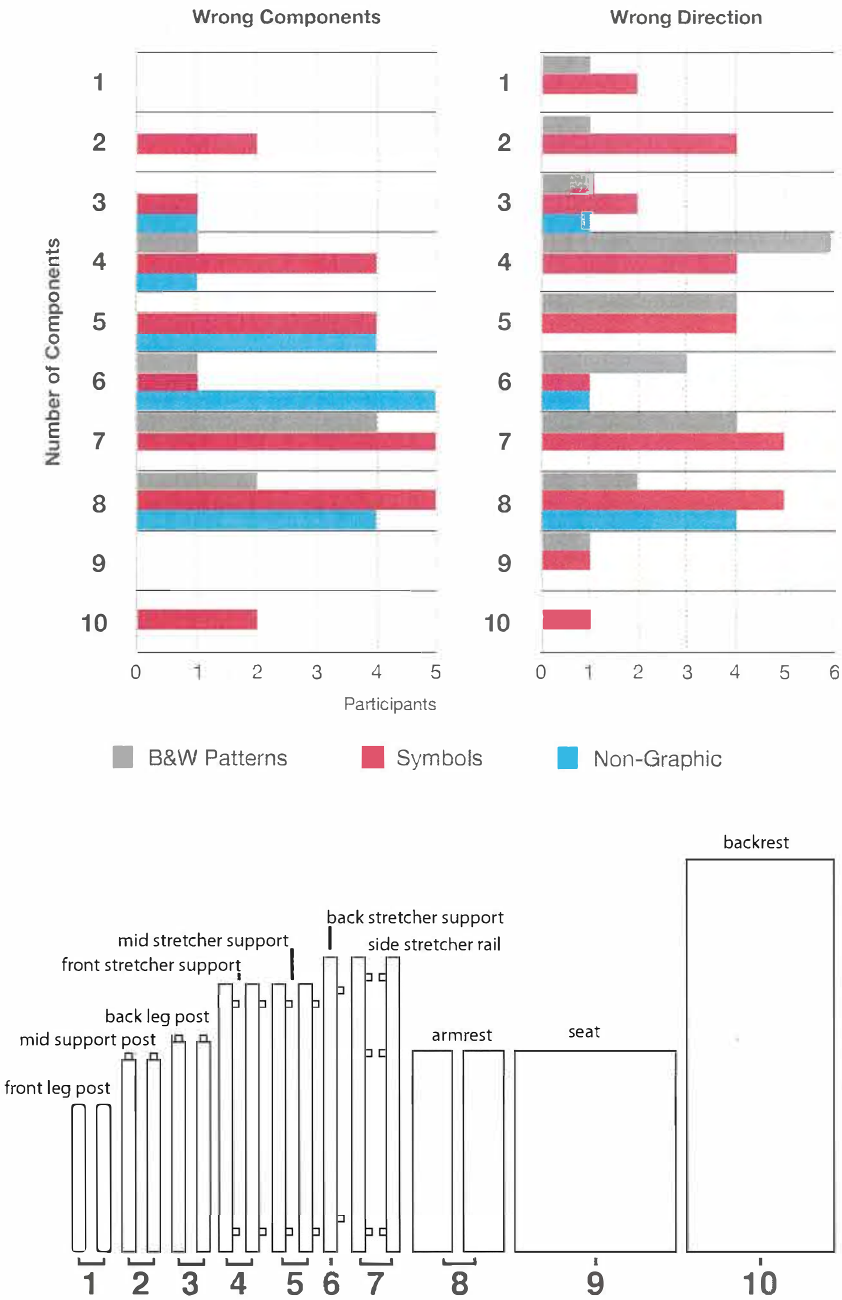

Figure 5.10 Participants obtained wrong components & direction

5.3.2.1 Ease of Use of Application

This implies that the interface and gesture in the application help the participants when assembling various similar shapes while following the steps provided in the AR applications.

According to the result, all three types obtained 4 points for the average of satisfaction (as shown in Table 5.3), which means that all three types of AR applications were easy to use for assembling the chair components.

The p-value ((M=3.9333, SD=0.86834), t(30)=0.216, p=0.898) showed no significant difference among the non-graphic, b/w patterns, and symbols (as shown in Table 5.3).

5.3.2.2 Graphic's Help in Assembly

This indicates that the graphic function (b&w patterns and symbols) helped the participant separate directions, positions, and components while assembling with the graphics stuck on the actual components by following those stuck on the 3D components in the AR application.

According to the result, the average of satisfaction was 5 points (as shown in Table 5.3) for 2 cases (except the non-graphic case, which has only the interactive 3D components), which means that the graphics in the AR application were the most helpful for discerning the direction, position, and similar shapes of the chair components.

The p-value tests of the satisfactions of the graphic help to assembly were conducted on a non-normal distribution using the Mann-Whitney U Test. In particular, the p-value ($t(20)=-0.223$, $p=0.823$) indicated no significant difference among non-graphic, b&w patterns, and symbols (as shown in Table 5.3).

5.3.2.3 Easy-to-Understand Assembly using 3D Components

This indicates that the interactive 3D components are easy to understand when assembling with the actual components by following step-by-step instructions in the AR application.

According to the result, the average of satisfaction obtained 4 points for all types (as shown in Table 5.3), which means that the interactive 3D components were easy to understand.

The p-value of the 3D components show how to assembly easy to understand (($M=4.1000$, $SD=0.88474$), $t(30)=1.571$, $p=0.456$) indicated no significant differences among non-graphic, b&w patterns, and symbols (as shown in Table 5.3).

5.3.2.4 Application's Help in Assembly

This indicates that the three application types (non-graphic, b&w patterns, and symbol) helped to assemble the several components with similar shapes and sizes.

As a result, the average of satisfaction obtained 5 points for b&w patterns and 4 points for non-graphic and symbols (as shown in Table 5.3), which means that the b&w pattern was the most helpful in assembly, but non-graphic and symbol were helpful too.

The p-value ((M=4.5000, SD=0.73108), t(30)=1.510, p=0.470) indicates that there is no significant difference between the non-graphic, b&w patterns, and symbols cases (as shown in Table 5.3).

Table 5.3 Comparison of Average Satisfaction

	NON-GRAPHIC	B&W PATTERNS	SYMBOLS	P VALUE
APP EASY TO USE	4	4	4	0.898
GRAPHIC HELP TO ASSEMBLY	N/A	5	5	0.823
3D OBJ SHOW HOW TO ASSEMBLY EASY TO UNDERSTAND	4	4	4	0.456
APP HELP TO ASSEMBLY	4	5	4	0.470

5.4 Discussion

The experimental results show that any graphic, such as b&w patterns or symbols, can stick on any position of the components. The participants consider only the graphics stuck on the components that are the same as those stuck on the 3D components in the AR application. Especially, the graphics that are easy to recognize and have similar styles, such as symbols, have the risk of leading to wrong assembly and direction.

The several 3D components that appear in the AR application, such as those in steps 1 and 2, confuse the participants while assembling more than one 3D component, such as that in steps 3 to 11.

It is very important for the patterns set for components before assembling to follow the AR application, for assembling various similar components. Compare with disorder patterns and orderliness patterns (as shown in Figure 5.11), conduct different spatial reasoning. The disorder patterns take more time and result in more mistakes for spatial reasoning cognition than the orderliness patterns while assembling the various similar components.

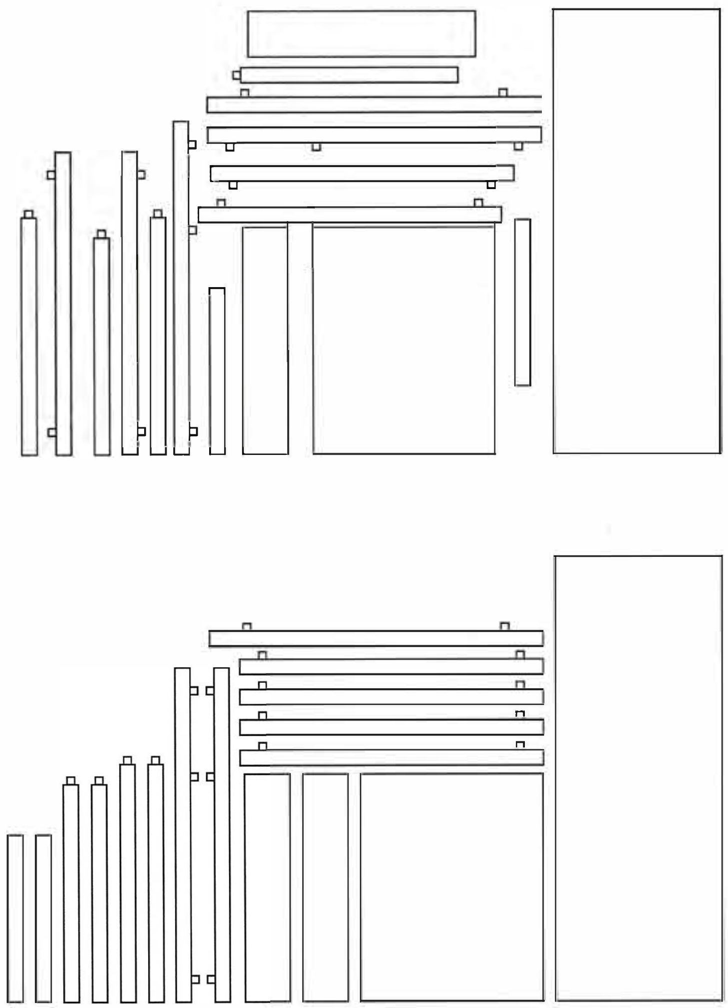

Figure 5.11 Disorder and Orderliness Patterns

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion and Recommendations

In this study, all participants did not make mistakes while they assembled the cube puzzle because they could compare the actual object and 3D objects by using the AR technology. The advantage of this technology is that it shows the 3D object and graphic in the same environment with the actual object, with the same actual size of a real object, which gave the advantage and solved the problem on the similarity of shape, space, and volume. The AR technology showed the people who could not imagine in three-dimensional forms, and how they were helped to see the 3D object, instead of imagining.

In this experiment, the graphic image was helpful to the non-design group because they spent an average time to assemble more than the average time of the design group. Particularly, the measure of time showed that some of the non-design group spent less time than the design group. This means that the graphic images helped them understand the shape and profile for the assembling cube puzzle (as shown in Figure 6.1). The participant did not see the space and volume when they assembling such in the previous work [18], [19] because when they assembled, they did not use their imagination. Thus, space and volume did not have any effect on them. This graphic image helped them to understand it. The participant just focused only on the shape or profile of the actual cube puzzle [46] and compared it with the 3D cube puzzle to help them choose parts of the cube puzzle without making a mistake. Even in the last step, where they had only one part of the cube puzzle, the non-design group still compared with the 3D cube puzzle when assembling. For some, the design group could assemble by themselves. Certainly, this experiment showed that the non-design group did not focus on space and volume while they were assembling the actual cube puzzle. They rather focused on the shape, and the profile, as if it was the same as 3D cube puzzle, and followed each step in the application.

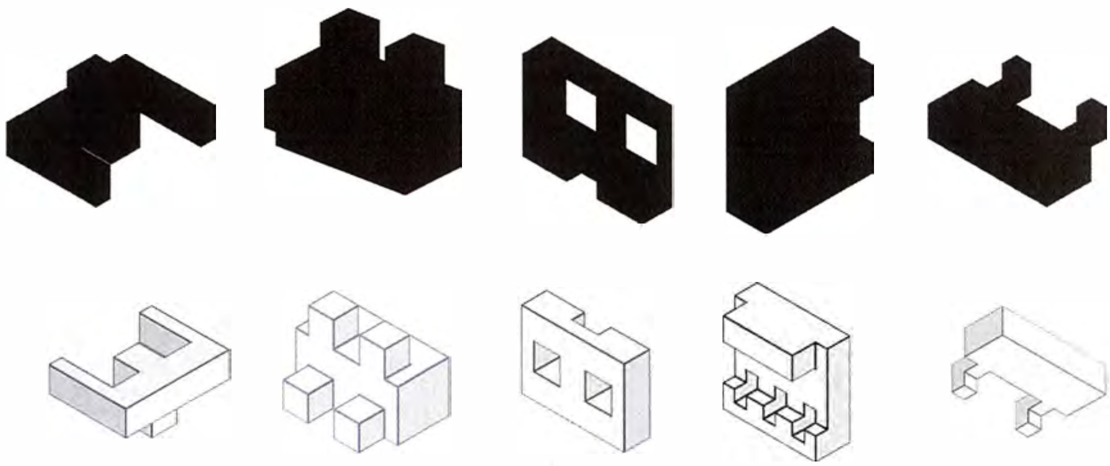

Figure 6.1 All Part of Cube Puzzle Compare with Shape & Profile

We recommend that some of the participants in both groups should consider that the AR application could have animation or video to explain how to use the application instead of instructions in text format. They will clearly understand how to use the application. For assembling the parts, the 3D object appeared when the scan marker pointed at the cube puzzle could not automatically hide. When they used this function the 3D object still appeared on the screen make them confuse while assembly the cube puzzle.

This study of the AR application will help in assembling puzzles by irrespective of the difference in experiences and knowledge. Thus, technology has merged different abilities altogether [47]. The application shows the image of 3D and interactive more clearly than the instructions in the paper. This will help people who cannot understand complicated image forms to understand more clearly by shape and profile. Therefore, the advantage of the AR technology provides the people the ability to focus on shape and profile for assembling rectangular shapes such as DIY Furniture or Flat-Pack Design.

6.2 Conclusion of DIY Furniture Assembly Using AR

In this experiment, non-graphic, b&w patterns, and symbols showed how the graphics enhance spatial reasoning and assist the AR application in easing assembly with the 17 similar shape & size components of the Red and Blue Armchair 1918 design by Gerrit Rietveld.

In particular, the results of assembly behavior indicated that the b&w patterns led to the maximum reduction in assembling of wrong components and direction. It also had the least number of participants who did not assemble the chair the same as the original (20%). In contrast, the symbol had the maximum number of incorrectly assembled components and incorrect directions, even more than the non-graphic function. It also had the maximum number of participants that did not assemble the chair the same as the original (60%), even more than the non-graphic function (50%). Hence, the variation in the graphics with 3D components influences assembling cognition and spatial reasoning. Thus, we have divided the conclusion into two parts: (i) b&w patterns & symbols and (ii) symbols & 3D components (non-graphic).

6.2.1 B&W Patterns & Symbol

The experimental result indicated that the two cases with graphics, that is, the b&w patterns and symbols cases, enhance spatial reasoning and assist the AR application in easing assembly. In particular, this experiment sheds new light on studying cognitive direction and position, how different graphics stick on different components and different positions in same shape & size of components, which can lead to correct assembly direction and position.

The symbols had different inner portions but similar shapes, such as solid triangle/ triangle outline, solid square/ square outline, solid circle/ circle outline, and solid cross/ cross outline, which made the participants focus on symbols more than that on the shape & size, direction, and position. Especially, they were tricked by similar shapes while assembling similar components. The symbol is outstanding and easy to look at while assembling the application, similar to the use of numbers in the manual of DIY furniture. Hence, most of the customers that follow the number make a mistake while assembling components with the same size and shape.

The b&w patterns that were different, such as left black right white, top black down white, and middle black side white, were provided to the participants for separating similar components. Different styles enhance cognitive spatial reasoning. Hence, the participants spent the maximum average thinking time while assembling for considering the b&w patterns and components and had the least values of average wrong components and direction.

6.2.2 Symbols & 3D Components (Non-graphic)

This experiment shows the results of two AR applications that have AR application with 3D components and the AR application with symbols different for an average of thinking time but similar in the average of assembly time, mistake & fixing, and number of wrong components.

In particular, the AR applications with 3D components provide assembly skill; the participants can completely assemble the components but cannot separate the various similar shapes & sizes, such as front & mid stretcher support and back stretcher support. Therefore, they have the maximum average number of wrong components, and half of this group (50%) did not assemble the chair as the original. Hence, the different shapes & sizes of 3D components enhance the participants' cognitive spatial reasoning.

The AR applications with symbols showed the maximum value for average assembly time and mistake & fixing but the average of wrong components and assembly the chair not same as original chair (60%), similar to the application with 3D components (50%). Therefore, the symbols reduce the assembly skill, even though the satisfaction is similar to that obtained for AR applications with 3D components.

In this experiment, we received recommendations from the participants regarding whether the AR application should or should not be improved for making it easier. (i) The interactive 3D components are the most useful in making the AR application easy to use. (ii) The shape & size of 3D components can improve the spatial reasoning to recognize the components during assembly. (iii) 3D components should have some color, rather than no color (white). Thus, color improves the spatial reasoning to recognize and compare the actual components with the 3D components. (iv) Graphics should have colors beyond just black and white.

6.3 Future Works

In this experiment, the technology of AR application can facilitate assembly tasks, enhance the spatial ability and error reduction. Therefore, both experiments provided the result that the most mistake assembling is similar shapes. The interactive virtual image is the key for error reduction, theirs replace the actual objects by indicating differently graphic or 3D objects [48]. Particular, the development of usage AR application for those who use it for the first time. Because there have various kinds of AR applications, the user spends time for the first time when using. Hence, the User Experience (UX) design for smartphone provide a perception of the application and increase the usage recognition [49]. The UX design facilitates the usage of the AR application, reduce confusing, everyone can use and user works together seamlessly [50]. In the next experiment will study UX design reduce confusion of the AR application.

APPENDIX A

SOFTWARE AND LAYOUT DESIGN

A.1 Software

The AR application created by several programs such as Unity [51], Vuforia [52] and 3D program. User interface (UI) and a graphic for 3D modeling were created for easy to use and 3D modeling that imitates the actual cube puzzle. Finally, Unity was combined with 3D modeling and UI to create the interactive and function in the application. Therefore, this application design for easy to use in one hand while assembling the actual cube puzzle (as shown in Figure A.1).

The 3D cube puzzle, we created a shaded to be more graphic by adding line and brightness colors for contrast with the environment and facilitate assembly (as shown in Figure A.2).

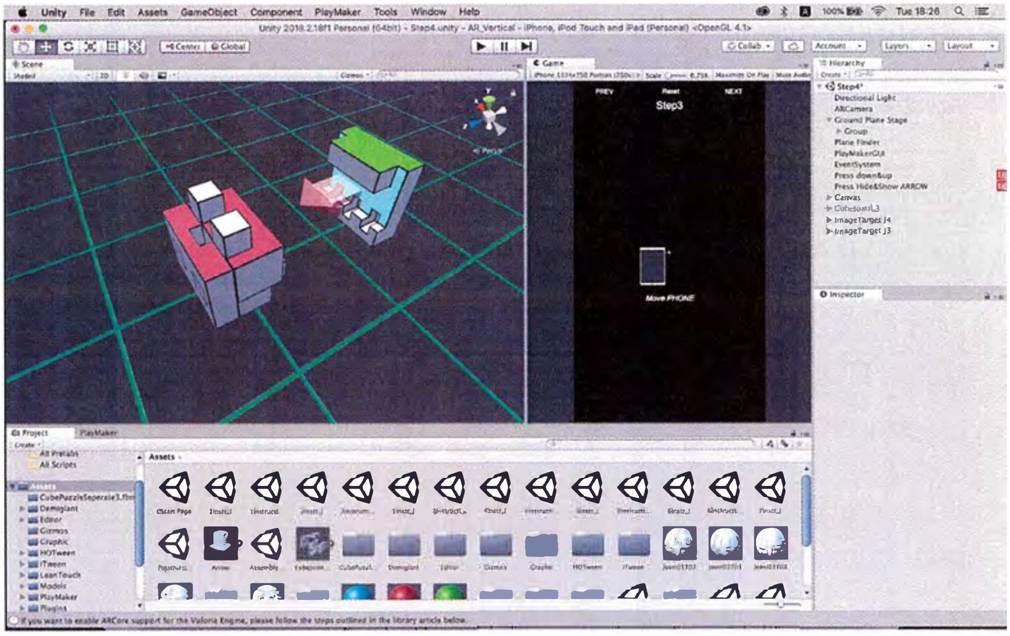

Figure A.1 The Software (Unity) Use for Create The AR Application

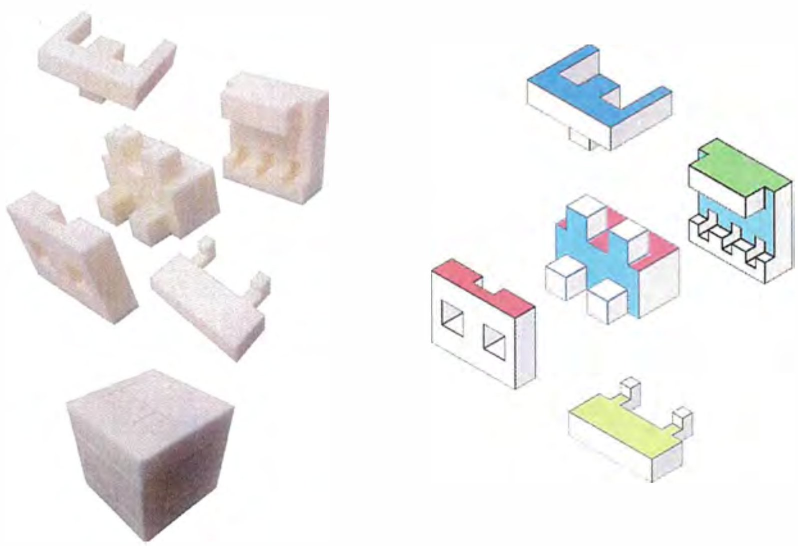

Figure A.2 The 3D Cube Puzzle Imitate The Actual Cube Puzzle

A.2 Application Lay-Out

This application was designed 2 layouts *"Horizontal and Vertical"* (as shown in Figure A.3). The first layout was designed to be horizontal, but this layout wasn't convenience for hold smartphones in one hand while using the application together to assemble the actual cube puzzle. Thus, the second layout was designed to follow the behavior when people use the smartphone in one hand. Finally, the layout was changed to vertical [53].

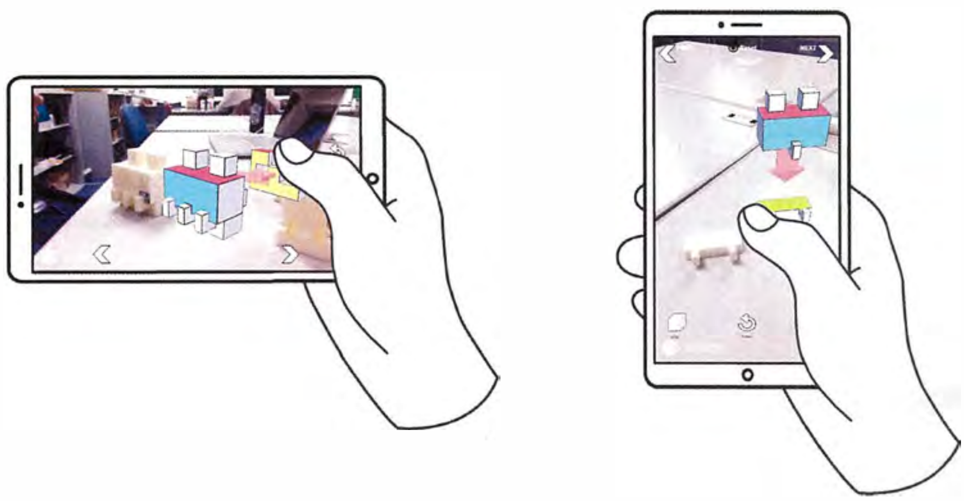

Figure A.3 Comparison One Hand Holding Smartphone with Horizontal and Vertical

APPENDIX B

RIETVELD CHAIR DRAWING AND OBSERVATION

B.1 Drawing of Rietveld Chair

In this experiment, provide the participants followed the AR application assembled the actual scale of Rietveld red and blue chair. Hence, this experiment has to make a real chair that each chair component should be similar to the 3D chair components. The AR application created the process of assembling by interlocking joint for each component instead of assembling by dowels to connect in each component. [54] Finally, we draw each component with the interlocking joint make the real chair (as shown in Figure B.1).

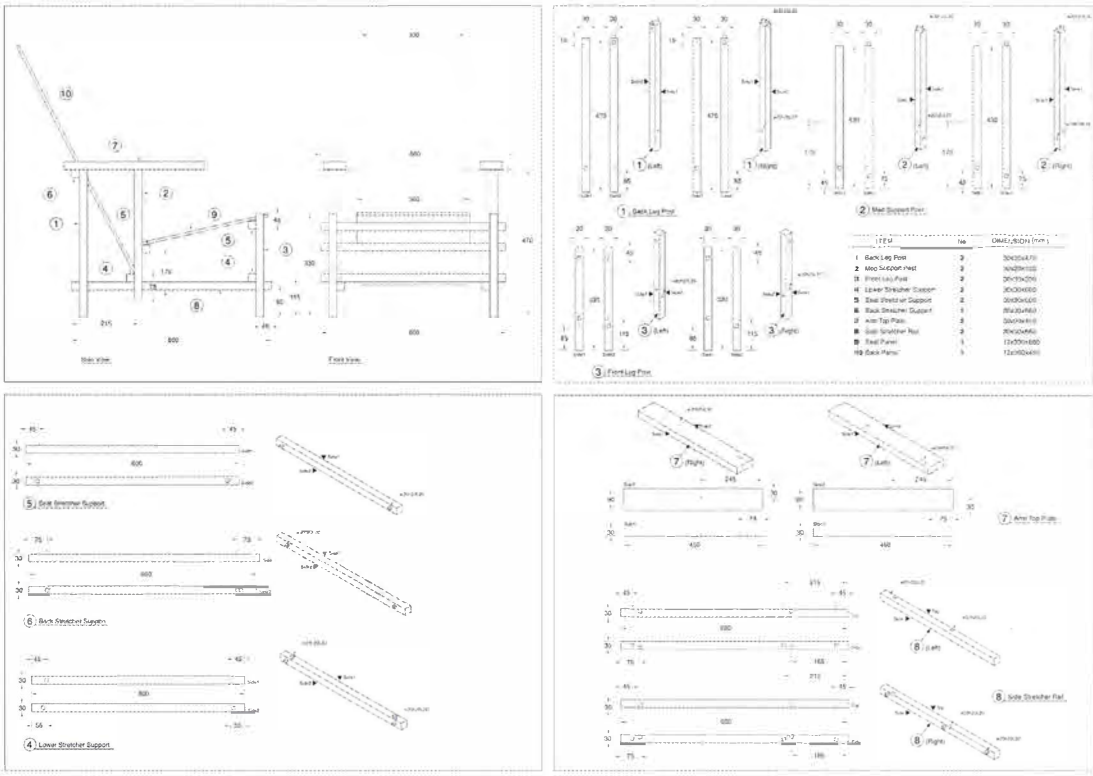

Figure B.1 Drawing of The Rietveld Chair with Interlocking Joint

B.2 Assembly Observation

In this experiment, observe the assembly behavior in a step by step while the participants follow the AR application. Particularly, thinking and assembling time when the participants use the application.

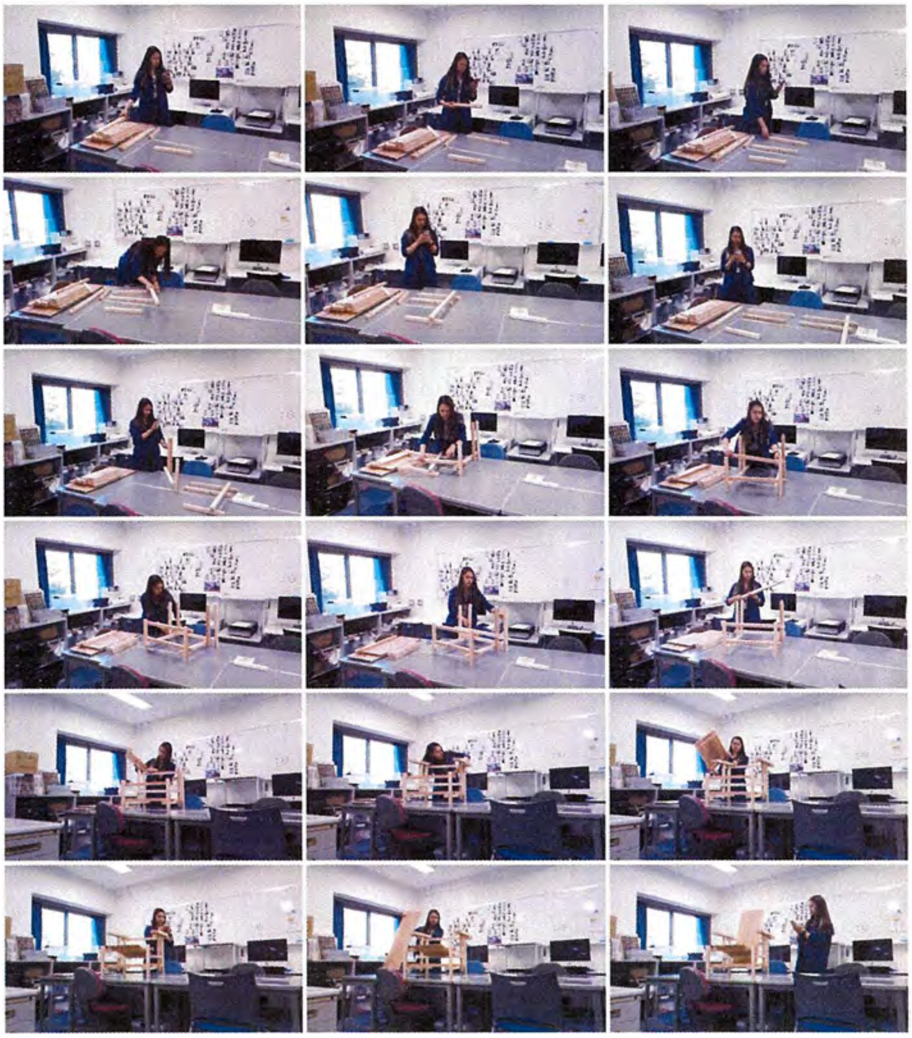

Figure B.2 The AR Application Assembly Observation

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