Joint, Space and Volume study by Interactive Cube Puzzle

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***Abstract*— This is a study of interlocking puzzle design that uses an interactive application instead of the normal assembly. The study investigates whether using an interactive application will help testers better understand an interlocking system of a cube-puzzle assembly than when using a normal assembly design. The proposed interactive application, which is easy to test, will make it possible for the tester to test a cube puzzle faster than the normal assembly method. Therefore, this research compares the average times of an interactive application and the normal cube-puzzle assembly[1]. The format of the assembly is the same as that of the normal cube-puzzle assembly. There is a difference between the joint and the three methods applied. This study provides instructions of the space and volume design and teaching materials by using an interactive application as a game that is simulated in different forms instead of using real objects.**

Keywords— Cube Puzzles; Space & Volume; Interactive Application; Interlocking puzzle design

I. INTRODUCTION

In the 21st century, the trend of society has been an increasing consumption of technology. We have become a digital society with the ubiquitous presence in developed countries of not just computers and large networks but also personal devices such as smartphones and tablets. Smartphones can do more than we think, and their power and connectivity have altered the behavior and lifestyle of people around the globe. Economists hold that there are three factors of production—land, labor, and capital—and some include "knowledge" as a fourth. In the 21st century age, there may be a fifth: digital technology. Applications that can run on multiple devices can enhance productivity and expand communication. For this to be possible, testing is key.

This study concerns an interactive testing application, and examines whether its interactive nature makes it more effective than the same application using a normal assembly design. The user interface (UI) of the application is simple and easy for consumers, and most of the commands are symbolic images that are easy to understand. Users—including children who have not yet learned to read—can immediately operate it without instructions. The UI design is attractive and eye-catching, which are features that make applications popular and widespread.

This research applied the interactive application technology to compare the proposed method with previous work on cube-puzzle assembly in an actual experiment. Therefore, the next step of the previous work is the use of interactive application instead of the normal assembly method. This author will highlight the differences and similarities of the results of the tester's assembly.

II. PROPOSED METHOD(S)

This author on puzzle interlocking design compares an interactive cube puzzle with the normal assembly cube puzzle. The instrument and assembly of this research simulates the normal assembly cube puzzles by analyzing 20 testers using an iPad for the two types of an interactive application. Type 1 is the color version and Type 2, the no color (white) version, is similar to previous work. Therefore, the researcher wants to compare the two interactive applications with the previous work. Therefore, an interactive cube puzzle application simulated human behavior when a tester was playing the normal assembly cube puzzles. A tester has to play all three levels, which are the same as the normal assembly cube puzzles and the time to complete the puzzle is measured. The researcher recorded the average times taken to complete the three levels for the two types of an interactive application with the previous work.

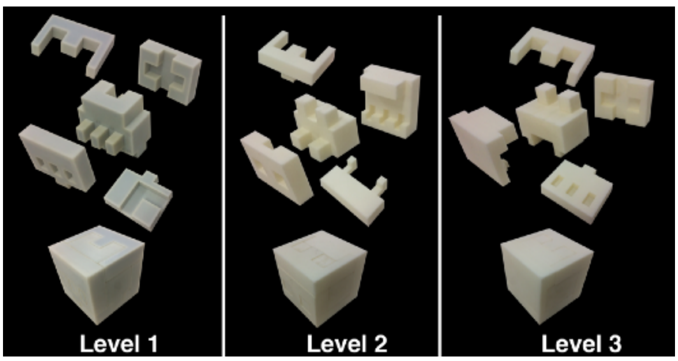

Fig. 1 Cube Puzzle of Previous Work.

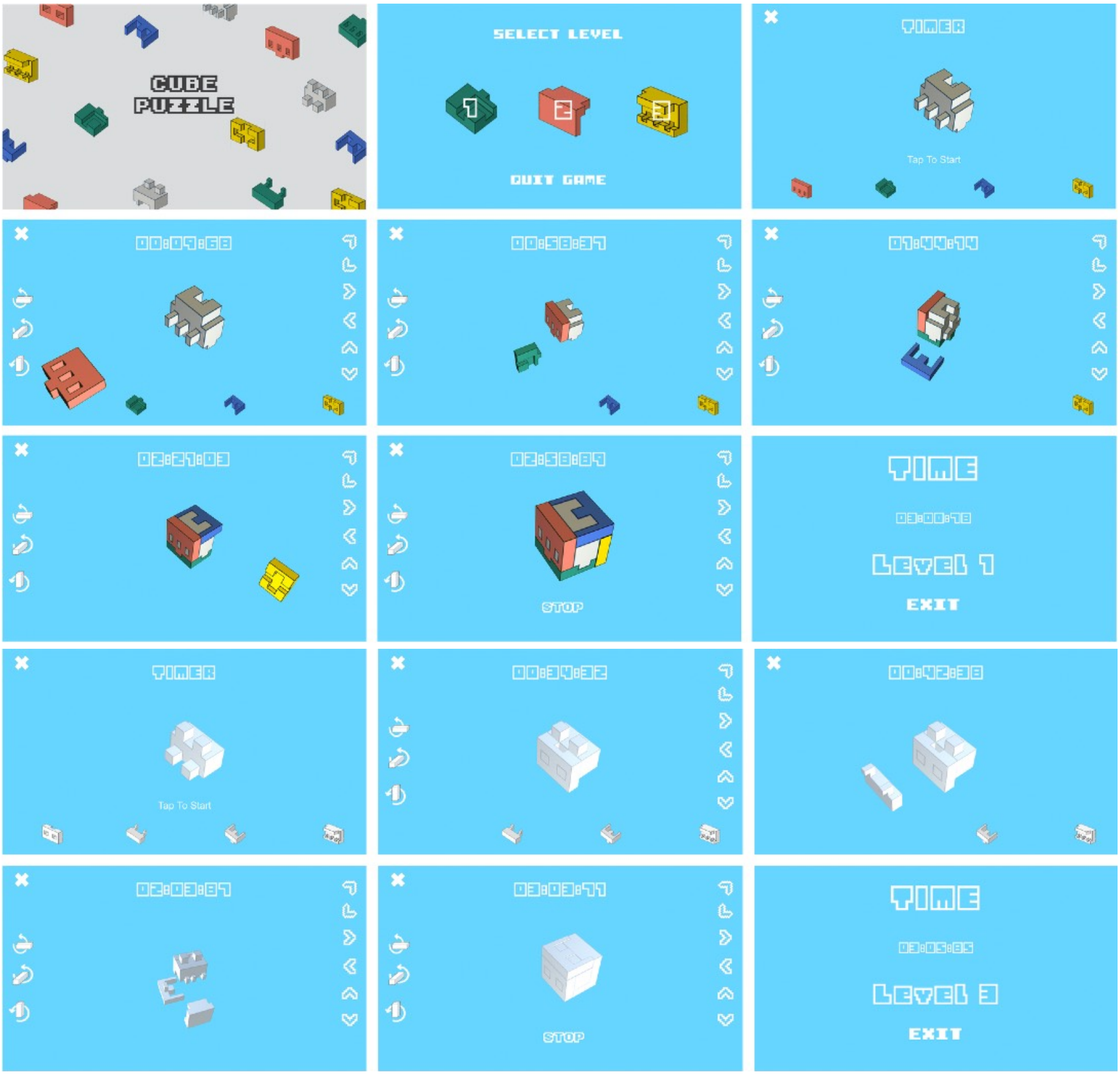

Fig. 2 Images of Type 1 is the color version and Type 2, the no color (white) version in interactive cube puzzle application

A. Subjects

There were 20 testers, including 15 men and 5 women, all aged between 18 and 30 years. Some testers had tested the previous work and others had not.

B. Materials

Based on the puzzle of the previous work, this study created two types of three-dimensional (3D) objects using the Program Cinema4D R18. The first type included color to make it look more interesting and easier to understand. The second type used no color. We imitated the previous work as closely as possible, then imported it into Unity as a program for creating games or applications. The test device was a 9-inch Apple iPad Pro running the Apple IOS.

We designed the graphics for the UI using the Illustrator CC 2017 program, and made the designs as self-explanatory as possible to enable the testers to understand and control the movements of the interactive cube puzzle in a manner as close to the actual movement as possible.

The control was divided into two types.

1) View Controller: Testers controlled the view using the following finger gestures.

- To rotate the Y axis, touch 2 fingers to the screen and rotate both fingers counterclockwise. The image will rotate the Y axis to the left. If you rotate the 2 fingers clockwise, the image will rotate the Y axis to the right.
- To rotate the Z axis, touch 3 fingers to the screen and rotate all 3 fingers counterclockwise. The image will rotate the Z axis to the left. If you rotate the 3 fingers clockwise, the image will rotate the Z axis to the right.
- To zoom, touch 2 fingers to the screen. Pinch them closer together to zoom in or spread them farther apart to zoom out.

2) Object Controller: Testers controlled the objects by touching icons on the screen. Control icons were arranged along three sides of screen. See Figure 2.

- The 3 icons along the left side controlled the rotation of each axis of the object. From top to bottom, the icons rotated the selected object 90 degrees on its X, Y, or Z axis respectively.
- The 6 icons along the right side controlled the movement of each axis of the object. From top to bottom, the icons moved the selected object on its X axis (left and right), Y axis (up and down), or Z axis (forward and back).
- The 4 icons along the bottom side selected the object to manipulate. Selecting an icon displayed the puzzle piece object in the center of the screen, and this piece could be manipulated using the icons at the left or right of the screen.

C. Procedures

The testing was divided into two sessions because there were two types of the interactive puzzle (Type 1 was the color puzzle and Type 2 was the all-white puzzle.) Each type had three levels. As in the previous study, the testers had to assemble the 3-D puzzle for all three levels while being timed.

There were tow testing sessions held two weeks apart (to allow the testers to forget the assembly pattern between sessions).

Session 1 session tested the Type 1 version following the same test pattern as the previous study, testing Levels 1, 2, and 3 and timing the assembly process.

Session 2 (two weeks after Session 1) tested Type 2 repeated the same test process but used the all-white version of the puzzle.

As in study, the position and layout of the puzzle pieces at the beginning of each test was random.

I. Comparison of The Average Time (Min.)

DESCRIPTION	LEVEL 1	LEVEL 2	LEVEL 3
Type 1 (color)	6.54	7.18	8.16
Type 2 (no color)	7.04	6.26	7.44

III. Results

In this study, the researcher recorded times for all 20 testers as they tested all three levels for the two types of the interactive cube puzzle application.

Type1 from the average time of the 20 testers (as shown in Table.1). It show that most testers can assembly puzzles. By the time in the order of difficulty as follows:

Type 1 tests. Table 1 shows the average time for the 20 testers to complete the Type 1 puzzle assembly for each of the three difficulty levels. For Type 1/Level 1, the average assembly time was 6.54 minutes. For Type 1/Level 2, the mid-level difficulty test, the average assembly time was 7.18 minutes. For Type 1/Level 3, the most difficult level, the average assembly time was 8.16 minutes. The following graph indicates the direction of the average test times.

[Level1 < Level2 < Level3]

Type 2 tests. Table 1 also shows the average time for the 20 testers to complete the Type 2 puzzle. It is evident that the average time required for the testers to compete the Type 2 puzzles was greater than the time for the Type 1 puzzles. For Type 2/Level 1, the average assembly time was 7.04 minutes (more than the 6.45 minutes for T1/L1). For Type 2/Level 2, the mid-level difficulty test, the average assembly time 6.26 minutes (less than the 7.18 minutes for T1/L2). For Type 2/Level 3, the most difficult level, the average assembly time was 7.44 minutes (less than the 8.16 minutes for T1/L3). The following graph indicates the direction of the average test times.

[Level1 > Level2 < Level3]

In this study, a comparison of the average time of completion for both types showed that most of the testers were faster on the Type 2 assemblies than on the Type 1 assemblies for difficulty levels 2 and 3, because the first time for the testers had to understand the controls of the interactive cube puzzle application. (see Figure 3).

It appears that the testers better understood space, joint, and volume with each subsequent test, except for when they switched from the color puzzle to the white puzzle; it seems that the average time went up between Type 1 and Type 2 because the testers had to get use to the interactive cube puzzle again when face with the all-white puzzle.

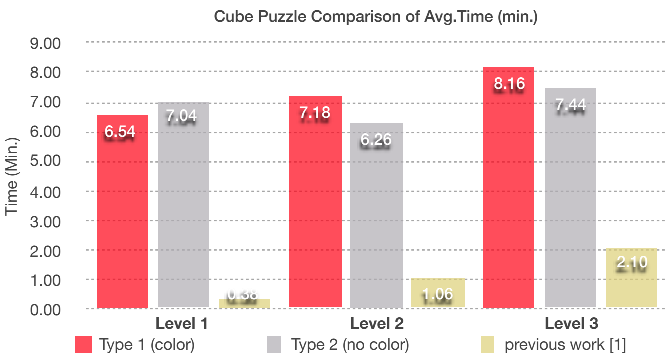

Fig. 3 Chart assembly cube puzzle comparison of average time

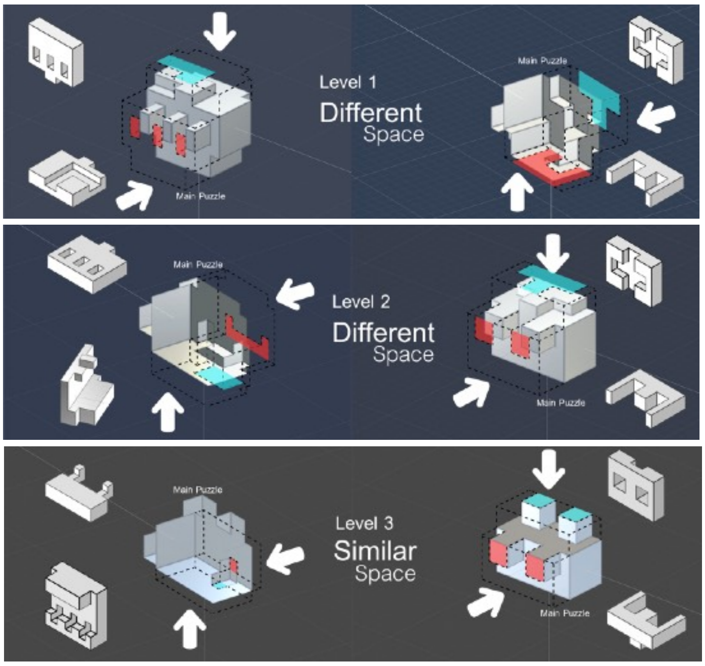

Fig. 4 Show different and similar space of each side cube puzzle for Level1, Level2, Level3

We also found similar results with the previous work (as shown in Figure 4) when testers assembled the interactive cube puzzles.

Difficulty levels.

- Level 1—Each side of main cube puzzle was a different shape. The tester could easily guess which sides should connect together. Level 1 required the least time.
- Level 2—Each side of main cube puzzle was a different shape, but one or two of the sides tricked the testers to confuse them during assembly. Level 2 required a bit more time than Level 1.
- Level 3—Each side of main cube puzzle was the same shape. This was the most difficult level because the testers could not easily guess which pieces had to connect. This level required more trial-and-error and reassembly, and therefore required the longest assembly times.

However, when the three difficulty levels were compared, the pattern of results was similar to those in the previous study, as the Figure 3 shows. In this study, however, the assemblies took more time overall than in the previous study because the testers had to understand the controls of the interactive cube puzzle application. (In the first study, the puzzles were assembled by hand.) However, the graph comparing the average times indicates that the testers in this study improved their times when using the interactive cube puzzle application, presumably as they became comfortable with the relationship between the UI and their understanding of space, joint, and volume.

The similarity in the results between this and the previous study showed that the testers using the interactive assembly were able to understand, recognize, and manipulate the puzzle pieces as if they were real. This study indicated that the interactive cube puzzle application can be used to teach the concepts of space, joint, and volume. This suggests that advanced assembly tests based on the interactive cube puzzle application could save production costs, transportation costs, and time. The application can also help many people learn or study at the same time since it can be accessed in the cloud from anywhere without having to install the program. Making it available in Windows, Linux, and Apple IOS platforms can reduce organizations' licensing costs. There would be no need for them to have a technical staff of their own since individuals customers could easily maintain and update the application.

IV. Conclusion and Recommendations

Type 1 and Type 2 are compared with the normal assembly cube puzzles when using the two types of an interactive application. Levels 3 takes the most average time for the tester to complete the puzzle. The second test with Type 2 in Level 1 has a greater average time than type 1 in Level 1. However, for the second test of Level 2 and Level 3, Type 2 takes less time than Level 2 and Level 3 for Type 1. Therefore, the time taken to complete the three levels is less when the tester is playing for the second time.

This application makes it easy for people to learn about and understand the concepts of space, joint, and volume. The human brain easily makes the connection between a real 3D puzzle piece and the digital portrayal of a 3D puzzle piece, and once they are familiar with the user interface, testers have no trouble manipulating the pieces as though they were real.

As a recommendation, since the tester was confused when playing this cube-puzzle application, the screen should have an X, Y, Z axis for the tester to easily understand on the screen movements. This application should have a tutorial or example to assist the tester on how to control and move the view. Type 1 and Type 2 are easier for the tester to recognize the shape and form of the cubes when using cube-puzzle application.

For this study, the results shown in Figure 3 comparing this study (interactive cube puzzle application) with the previous study (manual assembly) show that testing of this type could be done using interactive digital models rather than the real thing. This research required more time to create and test than the previous work, but fortunately the data is stored in one place and is easy to manage with no redundancy. The study does not require expensive high-performance computers or test equipment, and it will be easy to update to acquire new information on learning about and practice with space, joint, and volume.

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