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Investigating the Influence of Shape on the Assembly of an "Easy to Understand" Joint Cube Puzzle

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Abstract

In this study, we discussed an approach for identifying influences on assembly efficiency by adding various shape options to a joint cube puzzle. This study conducted a two-part experiment, In Part 1, we compared the time duration, numbers of errors, and numbers of rotate actions on the assembly of three shape options of a cube puzzle. Part 2 mainly discussed the observations of mental error behavior comparisons on each shape option. The two parts of the experiment involved 12 participants in total. The results indicated that adding the numbers of axial symmetry or curve figures to the joint puzzle can reduce visual interference and improve assembly efficiency. Further, we found that the geometric shape option had a lower error rate, while the curve option was associated with less time spent.

Keywords: Spatial Transformation, Wood Joint, Cube Puzzle

1 Introduction

Over the years, Ready-To-Assemble (RTA) furniture has evolved in terms of technology, design, and quality. It has proven to be stronger and easier to assemble than traditional furniture. Furthermore, due to reduced manufacturing and transportation costs, demand for it has recently increased [1]. However, the vast majority of frustrated users who do not have experience with technical assembly, even if an assembly manual is provided, will still get confused. Errors may easily occur during assembly because of the sets of simple similar shapes, which has been shown to seriously affect assembly efficiency.

In Asian regions, the joint interlocking technique has a long history among craftsman. It is characterized by easy-to-attach structures, and has widely been used in architecture, intelligence toys, and furniture manufacture. The joint was originally designed to be a conventional simple shape structure, considering it can be easy to fix and reassemble. However, because of this, the more complex the structure being designed, the greater the chance people will experience it as esoteric during assembly [2][3][4].

To make the spatial assembly task "easy to understand" in relation to the current simple shape furniture assembly issue, design methodology that produces an easily understood assembly joint needs to be developed. Therefore, this study aims to clarify "what kind of shape may impact its ability to be easily understood and the improvement of efficiency during the assembly task." To investigate this question, we developed methodology based on the shape of the joint cube puzzle, and conducted an experiment to observe the different influences on assembly behavior and efficiency by discussing the addition of various shape factors to a set of joint cube puzzles. By controlling the size, color, material, numbers of components, and difficulty of the puzzles, we sought to understand and verify why and how different shape variations stimulate and impact people's mental spatial transformational abilities during assembly. Therefore, we were able to apply the causes and relationships to the designations of the joint shape variations during the design process.

Prior studies related to the discussion of cube puzzle difficulty levels state that a close form, which lacks suggestions or signs for positioning, can guide participants in understanding how to assemble the cube puzzle in the next steps because it provides a boundary of space that is isolated from existing space. Moreover, the concept of "Cognition and Assembly" has been identified, which describes how different internal individual human characteristics such as age, working memory, or spatial problem solving ability influence cognition related to assembly [5]. In addition, other research states that reducing visual interference by giving assembly guidance with a spatially compatible design will improve assembly efficiency and reduce mental operating time [6].

On the other hand, elements like shape, size, color, and associations with objects were seen as the key elements used as clues impacting the assembly process. When visual information is limited, shape and size will be used as the main clues for finishing the assembly task [7]. However, these researchers did not state what kind of joint shape option or characteristic would improve assembly efficiency, or how it would impact assembly behaviors.

Therefore, based on these theories, it can be said that giving different shape options to the joint cube puzzle could provide and improve mental spatial cognition and give clues during assembly, as well as differentially impacting people's assembly behaviors. Moreover, clarifying the relationship

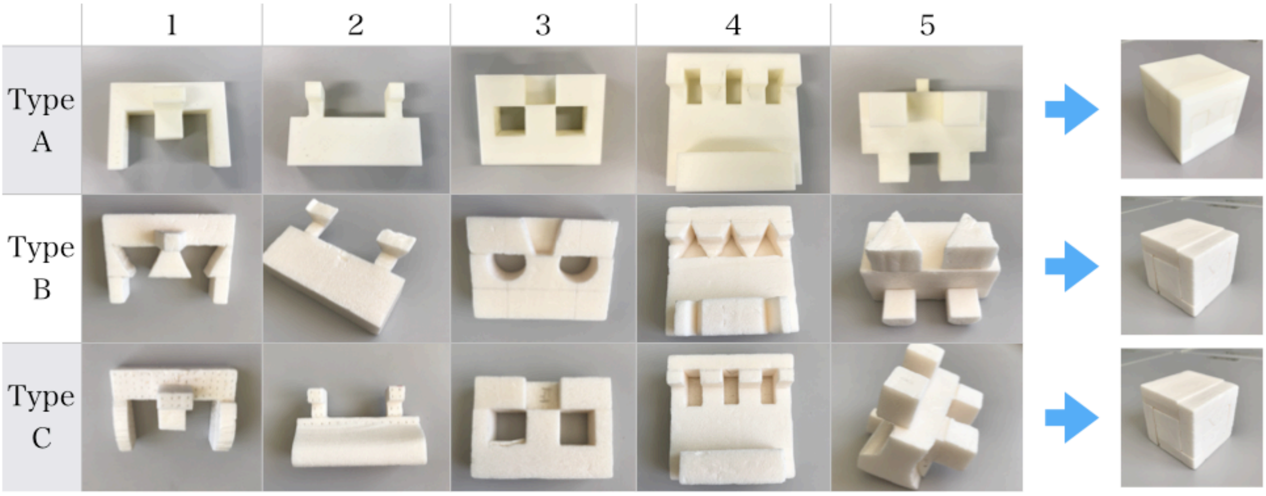

Figure 1: Various parts of joint member in Type A, Type B, and Type C.

between spatial compatibility and shape options will help increase efficiency and reduce mental errors during assembly.

2 Research Method

We conducted an observation experiment in order to verify the hypothesis. Three different shape variations of joint cube puzzles were developed. Based on previous research, we controlled all 3 models' sizes, numbers of components, colors, orders of assembly, and difficulty levels. There were three types of models (Types A, B, and C), as shown in Figure 1.

In the Type A cube puzzle, the shape options were set so that all the joints including edges, burrs, and notches appeared as a traditional rectilinear figure. For the Type B cube puzzle, we have set all joints, including notches and burrs, so that they are being built in close spaces in geometrically symmetrical figure shapes, consisting of axial symmetrical shapes like triangles and semi-circles. In the Type C puzzle, we basically kept the joint shape the same as in Type A; however, the close space joints' rectilinear figure was replaced by a curve. The radians of the two curves were set differently, so that the composition method depended on the users' curve radian recognition.

The three different shape options for the cube puzzle enabled people using different cognition and recognition methods that corresponded to each shape option to finish the assembly task. In this way, we were able to observe which option may reduce more assembly interference and how this would impact assembly behaviors in the coming steps.

Next, since the joint assembly cannot be shown in consecutive steps, the appearing joints can be discovered in two close space settings. The assembly and basic composition steps for the three types of models are shown in Figure 2. Close Space A consists of multiple connections, which means the first step is to find the missing separated burrs that must be placed in the right position to lock the angle or edge. Finally, all the missing burrs need to be simultaneously pushed into the bigger component. Close Space B contains several symmetrical burrs and notches that were produced for multiple assemblies, and it can be composed in many directions. The two close space settings increase the difficulty of the assembly and challenges all participants to solve the puzzles according to specific solutions.

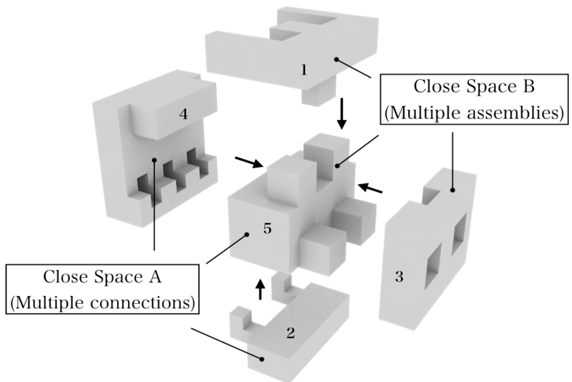

Figure 2: Basic Composition (Example of Type A).

Twelve participants who came from Japan, China, and Mongolia were asked to complete the experiments. During the experiment, the model's component layout was put on the desk in shuffle mode. In addition, because none of the models had any subsequent connections with each other, each participant was required to assemble only 1 of the 3 types of models on account of the controlled variable difficulty and order of assembly. Finally, 4 participants' assembly data were collected for each model. We classified all experimental data based on time duration and numbers of error, as shown below.

3 Discussion and Conclusion

In the first part of the experiment, in order to understand the different conditions being designed for the research instrument, the time durations during assembly of the three types of cube puzzles were statistically analyzed in Step 1, as shown in Figure 3. The assembly time durations were 261 Seconds, 146 Seconds, and 80 Seconds for Types A, B, and C, respectively. The geometric shape and curve models saved approximately 50% and 75%, respectively, of the assembly time compared to the original model.

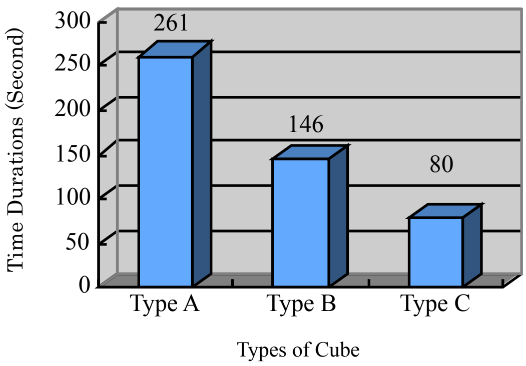

Figure 3: Average Time Durations Comparison.

Next, in Step 2, we aimed to better understand the shape of a joint characteristic by observing which shape option had the fewest errors. To this end, we collected the numbers of error, as shown in Figure 4. To get the error assembly data, we counted one error every time a participant attached the component to a wrong position. The results showed that both models were able to reduce errors over 50%, and they had lower numbers of misses compared to the original model.

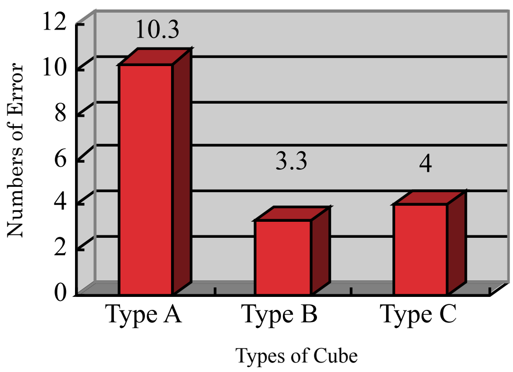

Figure 4: Average Error Numbers Comparison.

In Step 3, we sought to understand how much of the participants' spatial transformations had been used up during assembly. The rotate action numbers were also statistically analyzed, as shown in Figure 5. Unlike in Step 2, in this step we counted the rotate actions not only after the components were attached but also when the participants rotated them during observation.

However, in the next part of the experiment, we also compared the participants' main behaviors for all 3 models. Figure 6 and Figure 7 show the comparisons of Close Spaces A and B. During the assembly process, the participants could not easily predict which position had to connect in Type A.

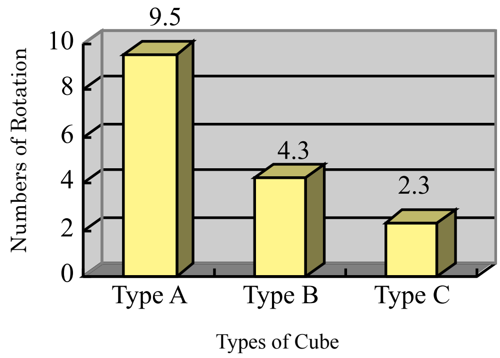

Figure 5: Average Rotate Actions Comparison.

This caused an increased number of rotate actions and resulted in several failed assembly attempts. Some participants even stopped trying to find other solutions. This task required more trial and error and re-assembly; therefore, assembly duration was increased [8].

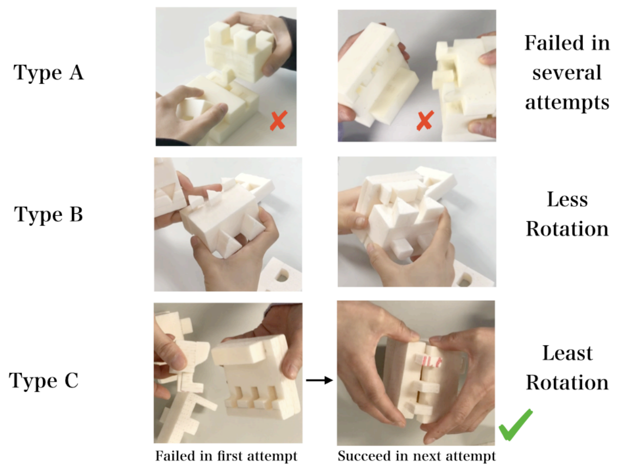

Figure 6: Behavior Comparisons of Close Space A.

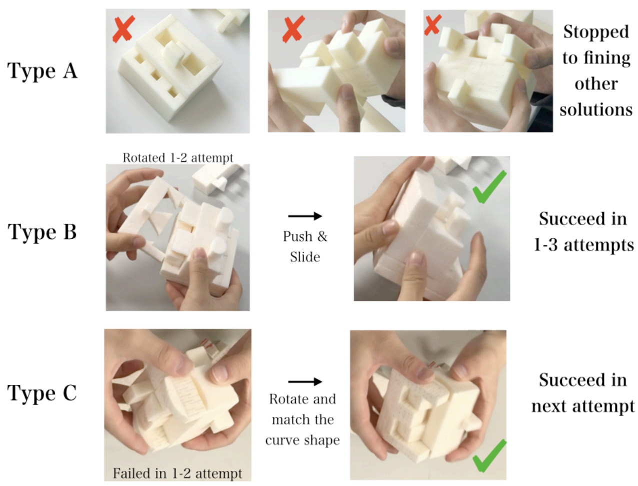

Figure 7: Behavior Comparisons of Close Space B.

However, for Type B, by observing the shape characteristics of the components, the participants were able to quickly and correctly recognize the shape characteristic that would fit, and they used this as a clue to finish the assembly in 2-3 attempts. For Type C, most participants failed in the first 1-2 attempts, but they soon recognized the curve after rotating, and they succeeded in attaching the curve shape to the right position in the next attempt.

During these observations, we found that both geometric and curve shape options being discussed could better deplete the cognition barrier, thus guiding participants to transfer their spatial abilities and use these options as clues to finish assembly. Next, we observed that the geometric shape had the lowest number of error, because definite direction of the components can help people in approach of finding the right position of the components in the next step. While the curve shape had over 50% fewer rotate actions and less time spent compared to the original rectilinear shape, which is also means transferred the shape characteristics to outline of the joint can be most easily classified and recognized. In other words, the impact on assembly behavior depends on the shape options being added to the joint.

Further, the results also appear to indicated that if we set the assembly task as Accuracy Priority, we need to keep people's spatial transformations and cognitions the same in the close space, and set compatible joint shape options and characteristics taking advantage of close space, so that it can be more easily matched and recognized for people to observing. On the other hand, if we set the assembly task as Speed Priority, it will be necessary to establish a shape characteristic that is different from the close space's shape, and transfer people's sight to the outline of the joint. More importantly, the shape characteristics being added, also need to be easily recognized, and is also necessary to shift people's spatial transformations and cognitions out of the close space as fast as possible in a lower mental operation load, otherwise it will delay the best timing for spatial transformation, result in mental rotate action will increase and mental operating time cannot be able to reduced.

4 Future Work

In this study, we have observed and discussed three shape options that differentially impact efficiency and assembly behaviors. However, we only discussed three shape options separately; therefore, we think it is necessary to conduct future research regarding the impact when Type B and C are combined to observe whether it reaches the limit point of the easily understood of assembly of the joint cube puzzle.

Secondly, during this study, we also noticed that some aging participants had trouble observing the component details because of physical aging difficulties. For this reason, we consider it important to discuss the impact of the relationship of size on cube puzzle assembly, including the puzzle's overall size and joint size. We noticed that the smaller the cube or the components, the more complex people will find the task during assembly; otherwise, people will find it more difficult to handle the components if their sizes are beyond the acceptable range.

Finally, although we have gained an understanding of what shape option may increase the efficiency of an assembly task, we did not take into the account the size factor. We think this may also affect assembly efficiency. Secondly, this study may also be helpful in constructing teaching material concerning volume calculations, since the shape of the puzzle is known to be difficult for children to work with. Therefore, this study is expected to provide a valuable reference for deepening the understanding of volume calculation. These aspects will be considered in our future research.

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