An Observation of Human Comprehension Through Wood Joints Assembly of a Cube Puzzle

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Abstract. In Japan, cube puzzle toys are traditionally made of jointed wood. This paper explores the personal decision-making process necessary to correctly assemble a cube puzzle toy. Participants from Iwate Prefecture were divided into two groups, based on a questionnaire that assessed their skill level in assembling construction kits. The participants were presented with an unassembled toy and their actions, together with all of the conditions necessary for interpretation of the puzzle, were recorded with a VDO camera. As a result of the observations, new variables were developed to create three cube puzzle sets and customize the difficulty level associated with each puzzle. Furthermore, new information about how people define shapes was revealed during the observational stage of the study.

Keywords: Signifier · Physical constraint · Affordance

1 Introduction

The interlocking puzzle has been a popular toy around the globe for a very long time. The configuration and functional techniques associated with various puzzles have been developed by manufacturers, artisans, and researchers over many years [1, 2]. An important factor for toy developers to consider is why people do or do not understand the correct way to assemble a wooden puzzle without using color or markings to indicate the required solution. The origin of this consideration lies in the relationship between the burr and notch. However, we believe that the number of components and shape of the pieces are not the primary factors that confuse players who encounter a burr puzzle. In general, we assume that difficulty arises from a constellation of variables associated with the design stage of a puzzle.

To test this hypothesis, we propose a design method that considers three types of a cube puzzle with the same number of components. Different variables were used to create shapes that affect a player's perceptions. For our puzzle, we expected results to be connected with a phenomenal reciprocity between a player and strategies for assembling the cube puzzle. Our aim was to illuminate the process of understanding the correct way to assemble a puzzle. This paper discusses the techniques participants used to successfully complete cube puzzles, speculates how inferences were made about

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shapes, and explores how people contend with more difficult challenges. Data were derived from questionnaire answers and recordings made with a VDO camera.

Section 2 summarizes our design process, which applied variables to the manufacture of a cube puzzle toy. Section 3 explains our observational design and the objective of the questionnaires. The results of our observations are presented in Sect. 4. The article concludes with results of our observations regarding the design of a cube puzzle with discussing in our future work in Sect. 5.

2 The Design Process

This section describes the design process used to create three cubes of a puzzle toy. First, the traditional Japanese method was used to create the general shape of a cube puzzle. More than 200 different kinds of joints used in the manufacture of wooden furniture and structures may be incorporated into the puzzle. Second, we developed a method to create three types of a cube puzzle that has the same amount of components. However, different variables were implemented in order to create shapes that would influence a player's perception. Variables such as signifier, physical constraint, and affordance, from the fundamental psychological concepts posed by Norman [3], were applied during the design phase. However, we discovered a new way to use these variables in our research study.

In general, we opted for traditional techniques associated with Japanese joints to design the cube puzzle toy. We designed the core of the puzzle as a center burr in order to allow for joining with other notches. However, when they are separated by a single piece, most notches may not match with the core burr, as shown in Fig. 1.

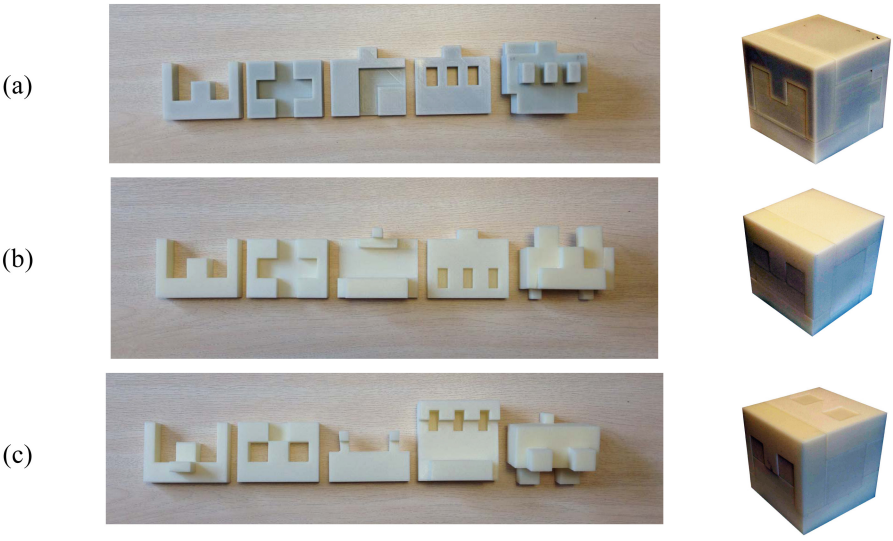

Fig. 1. The conventional version (a), the developed version (b), and the advance version (c) including a completed shape in three sets of cube puzzles.

Therefore, the first step of selection plays an important role in finding a signifier for the next step of the puzzle's composition.

The conventional version or a simple level designed by Tanaka [4] of the cube puzzle included a core with three burrs that matched a piece with three notches, as shown in Fig. 2. The unambiguous burrs and notches in this design made strong use of a signifier a clear cue was presented to the player. Furthermore, when the first side was completed, an even more salient signifier appeared on another side of the puzzle. This new variable, which is different from fundamental psychological conceptualizations, is necessary to navigate the correct construction of the puzzle.

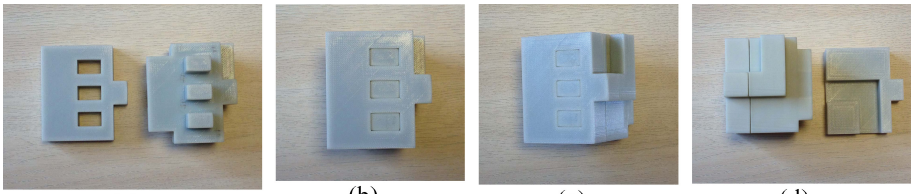

Fig. 2. (a) The first signifiers indicated by three burrs and notches. (b) Completed configuration of three burrs and notches. (c) The next signifier continuing to appear in another side. (d) New signifiers of next burr appeared to match another notch.

To design a cube puzzle of the developed version or a moderate level designed by the author, rather than use a signifier to compose a joint in the first step, we used another variable, "physical constraints," to limit the possible action between burr and notch. This variable generated moderate difficulty because it manifests as an ambiguous form. Therefore, players must interpret a shape and compose the correct configuration, as shown in Fig. 3.

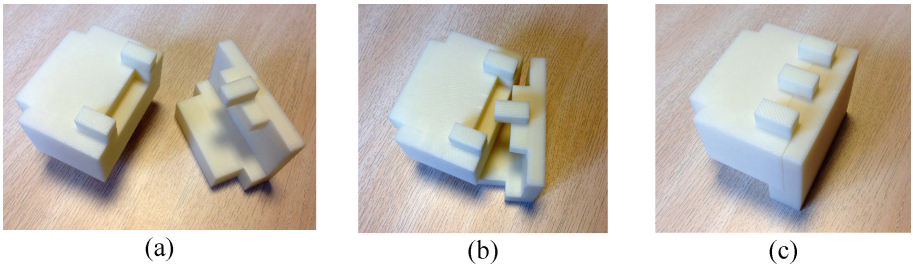

Fig. 3. From (a)–(c). A design using the "physical constraints" variable

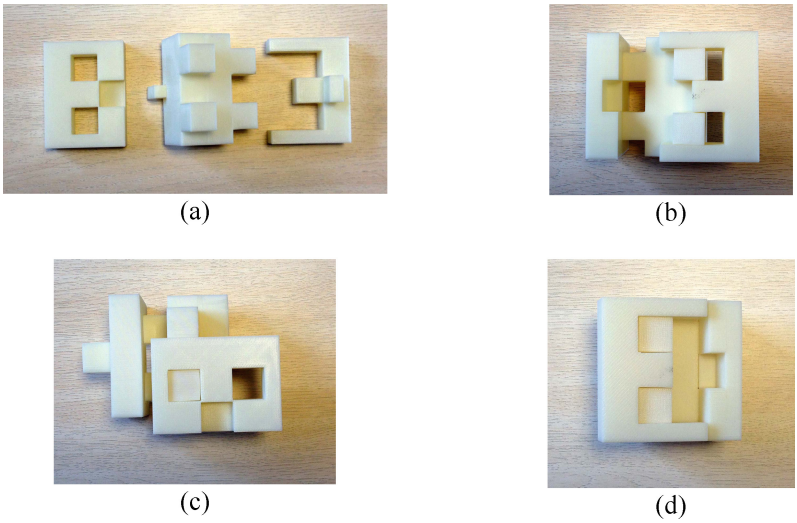

Fig. 4. From (a)–(d). A design using an "Affordance" allowing many possible actions to compose their items.

To design the advance version or a difficult level designed by the author, we introduced another variable, called "an affordance." This variable increases the possible actions of the puzzle's various components. In general, the burr-and-notch form is designed to serve as a joint in many directions, as shown in Fig. 4, but including additional variables—signifier, physical constraint, and affordance—allows for different levels of difficulty. This hypothesis is tested in the next section.

3 Observations

In this section, we describe the process and objectives of the questionnaire that was used in the first stage of the study.

Before testing commenced, 20 participants filled out a questionnaire intended to determine their higher and lower spatial abilities. The questionnaire was divided into three parts:

1. General Information (gender, age, nationality, course of study)
2. Specific Information (experience, type, and frequency of encountering assembly)
3. Participant Ability (three items)

- Inspired by the models of mental imagery developed by Shepard and Metzler [5], we tested for perceptual ability when an object was rotated to another position. We believe this measurement relates to the human ability to perceive and differentiate forms, as shown in Fig. 5.

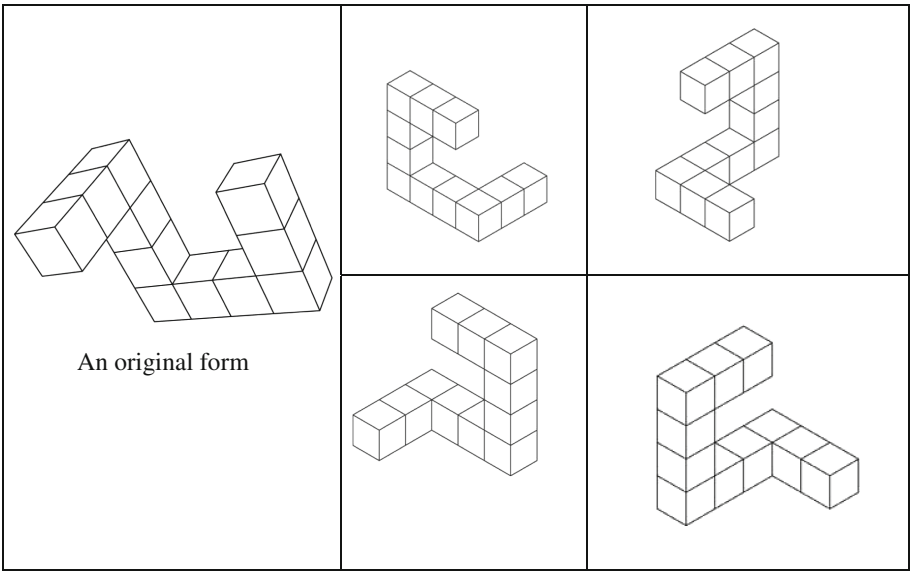

Fig. 5. Example of an identifiable form. Participants were required to choose true or false for each image.

- The correlation of burr and notch, which tests the ability to understand addition and subtraction made to a particular configuration. Participants were required to choose true or false for the forms shown in Figs. 6 and 7.

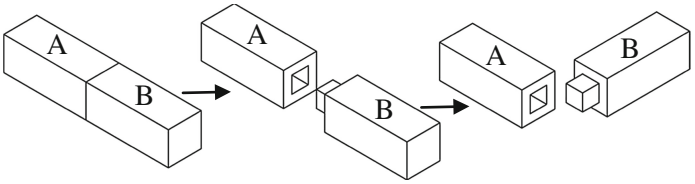

Fig. 6. Example of correlation assembly between part A and part B

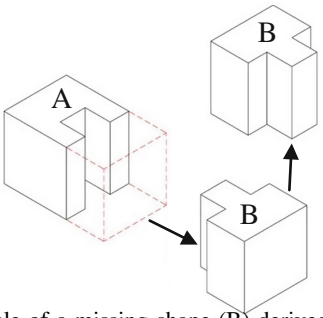

Fig. 7. Example of a missing shape (B) derived from subtraction (A)

- Predicting an absent form tested participants' abilities to define missing parts. This assessment related to the process of finding a signifier during assembly, as shown in Figs. 8 and 9.

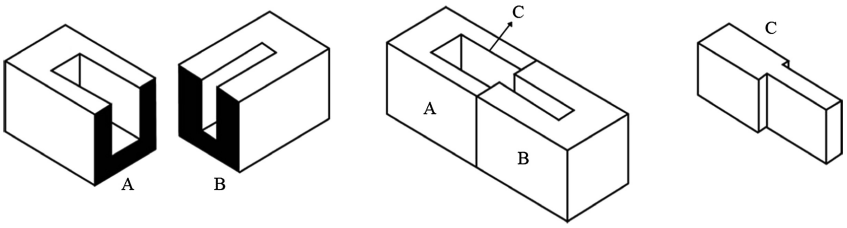

Fig. 8. Example of a void shape (C) derived from a combination of notches formed by part A and part B.

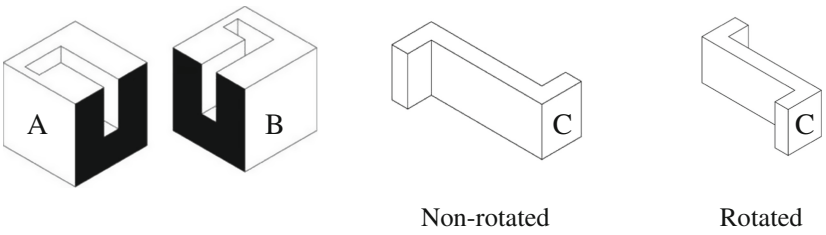

Fig. 9. Example of a void shape (C), which might be non-rotated or rotated, derived from a combination of notches formed by part A and part B.

Results of the questionnaire are detailed in the next section.

4 Results of the Observations

Before presenting the results of our observations, we offer a brief overview of the demographics, prior experience, and general ability of the participants.

Demographics. Of the 20 people who participated in this study, 8 participants were men and 12 participants were women. Participants ranged in age from 20 to 30 years old and hailed from Thailand, Japan, Taiwan, and China. All participants studied the fields of engineering, industrial design, or education.

Specific Information. Participants who studied engineering or industrial design had more experience solving puzzles than people who studied education.

Participant's Ability. The scale used to measure ability totaled 24 points. It can be divided participants into two groups which are the skillful and unskillful groups.

After completed a questionnaire, all participants composed three sets of cube puzzles. We recorded their actions by VDO camera. An average time of this experiment has shown in Fig. 10.

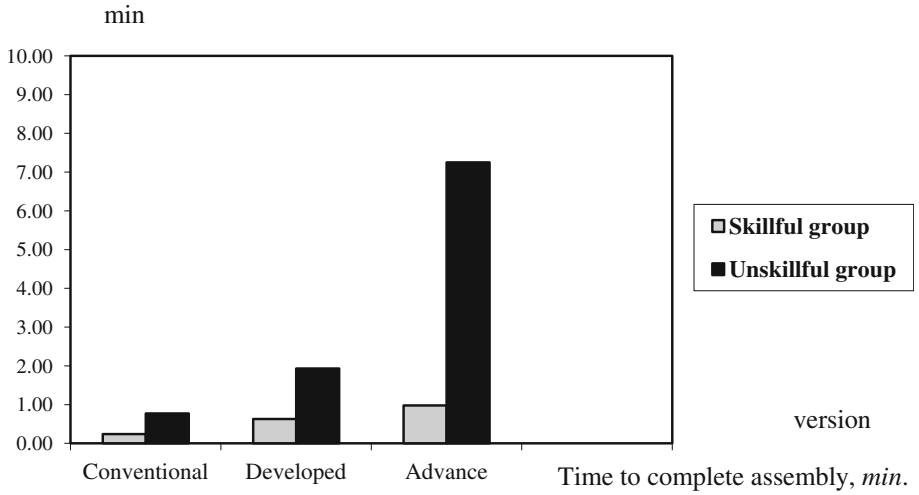

Fig. 10. Bar graph shows an average of assembly time between skillful and unskillful groups.

It's clearly seen in Fig. 10 that the average time of skillful and unskillful group of three cases are different. Skillful group spent time to compose less than unskillful group. However, the different time between skillful and unskillful group in developed and advance version are wider than in conventional version. It's interestingly that different time between skillful and unskillful in the advance version is dramatically wider than other two cases. Therefore, it was clear that the different variables (signifier, physical constraint, and affordance) affected the difficulty level of the three cube puzzles. Furthermore, Engineering and Industrial design students, a skillful group, spent a slight time to compose all sets of puzzles which received a high score from a questionnaire. On the contrary, Educational students, an unskillful group, spent a long time and received a low score from a questionnaire.

Table 1 shows an explanation of participant's behavior to investigate the causes that how participants define the shape and how develop more difficulty in their levels.

As a result, it can be concluded that a personal ability and the difficult levels of cube puzzle are important causes considered to why people do or do not understand the correct way to assemble a cube puzzle toy. Personal ability and the object are interacted with each other and reveal their perception-action activity that we can observe in a specific environment.

Table 1. Participant's behavior

Stage of assembly	Explanation of participant's behavior
Before assembly	-All skillful participants tended to consider the shape of an item before selection. -None of the unskillful participants considered the shape of all items before selection.
Start assembly	-For the conventional version, all skillful participants chose an unambiguous match of burr and notch.  -For the conventional version, most unskillful participants chose an unambiguous match of burr and notch, similar to participants in the skillful group.  -For the developed and advance version, at first, all skillful participants chose a complex shape, trying to match a burr and notch.   -For the developed and advance version, at first, most unskillful participants chose a simple shape and tried to match burr and notch.  

(*Continued*)

Table 1. (*Continued*)

Stage of assembly	Explanation of participant's behavior
During assembly	- For the developed and advance version, some skillful participants explored the complex shape, which had 3 notches, and then created 3 burrs derived from 2 pieces to forge a relationship. 
	-For the conventional version, some unskillful participants did not compose by following the signifier. 
	-For the developed and advance version, some unskillful participants started to compose a complex shape, but could not understand how to join the pieces.
Development of ability	-Some unskillful participants understood the relationship of the burr and notch better by trying to form a complex shape in the first stage of selection. -In contrast to initial observations, some unskillful participants started composing from a core piece earlier in the process. 

5 Conclusion

This paper explored why people do or do not understand the correct way to assemble a cube puzzle and how players define shapes when tasked with constructing a puzzle. We identified new variables that contribute to the difficulty of a puzzle tested by a small group of participants. However, the numbers of participants will be assured more accuracy. It may be explored new information about participant's behavior and expanded for other files of researches.

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