Basic Observation About the Difficulty of Assembly Wood Puzzle by Wooden Joint

Takamitsu Tanaka[1(✉)], Masao Tachibana[1], Thongthai Wongwichai[1], and Yen-Yu Kang[2]

[1] Iwate University, Morioka, Japan
{taktak, tatimasa}@iwate-u.ac.jp,
Pang_design@hotmail.com
[2] Kaohsiung Normal University, Kaohsiung, Taiwan
yenyu@nknu.edu.tw

Abstract. In order to understand the manner to develop what type of teaching material from wooden puzzle by combining the aspect of “easy to understand models” and “fun to assemble” for learning how to measure volume, this paper discuss about what is variable that impact to different degree of assembly difficulty in cube puzzle. The experiment is conducted by 3 characters of cube puzzle which have different condition such a picture print, many color, and no image or color. All puzzles were composed by third and sixth grade student. Each experiment spent 15 min for observation. It was designed for 2 times for observation and each time students experienced the different sizes to evaluate for difficult assembly. The result showed that the easiest in degree of assembly difficulty due to the large size. Further, since students found assembly difficult for shapes with deep joints, we notice that the color provided a helpful hint when selecting joints.

Keywords: Wooden joint · Interlock · Puzzle

1 About 3D Wooden Puzzles

Three-dimensional (3D) wooden puzzles are produced worldwide. Most are solid shapes based on cuboids and cubes. Since wood shrinks as it dries, the dimensions begin to differ from the designer’s original intention as the months and years pass after the user’s purchase. Above all, when fitting pieces of a wooden puzzle together, parts can be interlocked by employing an approach similar to configuring traditional wooden joints. However, while interlocking wood into complex wooden joint configurations may be appropriate for buildings not intended to be taken apart, it is not suitable for a 3D wooden puzzle intended as a toy. Therefore, wooden puzzles are assembled with simple wooden joints, allowing them to be disassembled repeatedly, and many are designed so that they can be easily put back together. However, as seen in Figs. 1, 2 and 3, most wooden puzzles are designed with simple wooden joints. Although some wooden puzzles have fewer parts, many are difficult to solve [1–3]. The author noted this fact during his experimental observation in 2012 [4]. One reason assembly is difficult is that while wooden puzzles possess the functions of a puzzle, they are often used as objets d’art.

S. Yamamoto (Ed.): HIMI 2016, Part II, LNCS 9735, pp. 589–598, 2016.
DOI: 10.1007/978-3-319-40397-7_57

There are 3D wooden puzzles, such as the one in Fig. 4, that blend the functions of a toy with those of art and design education. This puzzle is made of resin, and magnets hold the parts together, without wooden joints [5]. Painted in three colors, it is devised such that children can easily assemble it according to the shape of the pieces and their color. With this puzzle, children use its given form. As mentioned above, puzzles are mainly “3D wooden puzzles intended for adults” and “3D wooden puzzles incorporating educational functions intended for children.” This study aims to develop 3D wooden puzzles so that children can learn to calculate volume while having fun, utilizing shapes of wooden joints mostly built with straight surfaces such as cuboids and cubes, which are characteristic of 3D wooden puzzles. This paper includes basic observations in order to gain necessary information to effectively use wooden puzzles as teaching materials.

Fig. 1. 3D wooden puzzle designed by Gregory Benedetti

Fig. 2. 3D wooden puzzle designed by Hirokazu Iwasawa

Fig. 3. 3D wooden puzzle designed by Bill Cutler

2 Teaching Children to Calculate Volume: The Current Circumstances

In Japanese schools, the two methods of instruction for teaching children to measure volume are: “Instruction measuring volume with an instrument and expressing the volume” and “Instruction determining volume based on calculations.” Furthermore,

Fig. 4. 3D resin wooden puzzle for educational purposes

there are two subcategories under the latter: (1) learning formulas to determine the volume of a solid (such as cuboids, cubes, cylinders, pyramids and spheres); and (2) calculating the volume of complex figures that represent a combination of basic shapes (cuboids and cubes).

Students learn to calculate volume in fifth grade (elementary school) when they learn the concepts and units for measuring volume. During this time, they learn the concept of 1 cm^3, and quantify volume based on the number of 1 cm^3 cubes, which leads to the formulas for the volume of cuboids and cubes. In fifth grade, when students recall what they previously learned about area, they discover that volume can also be expressed in terms of the number of universal units. As a result, they are able to grasp this area of learning and compute volume in an integrated way. During instruction on volume, exercises are devised to find out how many 1 cm sided cubes it takes to fill a cuboid or cube. Through these exercises, students learn formulas such as the following: "volume of a cuboid = length × width × height" and "volume of a cube = side × side × side." In 2001, the National Institute for Educational Policy Research conducted a survey presenting problems to sixth grade students, asking whether they could "express the volume of the solid as a formula."

The percentage of correct answers was 79.5 %. The report of the Curriculum Implementation Survey for elementary and junior high schools pointed out that, "One example is actively adopting operational and experiential arithmetic activities, such as ones where solids of the size of a unit are prepared; students construct various cubes and cuboids by actually stacking and arranging them, then find their volumes. Students can understand the meaning of units and how to measure volume. Creating instruction that enhances students' feel for the size of volume is important."

The question on volume in the elementary school arithmetic section for the upcoming 2014 national survey is as follows. While the question is different than the one from 2001, which asked about units and measurement, the percentage of correct answers was 81.3 %. We can see that approximately 20 % of students were still unable to understand how to quantify volume. While the preceding manuscript mentions the current situation, whereby 20 % of students do not understand how to calculate volume, we believe this is due to inadequate teaching materials for calculating the volume of 3D objects. Textbooks are two-dimensional (2D), but in practice, students have to imagine 3D objects for calculations. While it is important to also learn problems from the textbook that are simply made 3D, in the next chapter "Observations," we decided to see what types of teaching materials were possible by combining the aspects of "easy to understand models" and "fun to assemble" for learning how to measure volume.

3 Observations

In order to understand the manner in which wooden puzzles balance the combination of the two aforementioned elements ("easy to understand models" and "fun to assemble"), we carried out basic observations on February 18 and 19, 2014.

We used three types of wooden puzzles for the observation, as shown in Fig. 5; they were made of ABS resin with a 3D printer and designed by us. Puzzle A was a wooden puzzle with pictures printed on the ABS resin. Puzzle B was painted such that the surfaces of pieces that come into contact with each other at the joints were the same color. Puzzle C was made of white ABS resin with a 3D printer and lacked any images or colors.

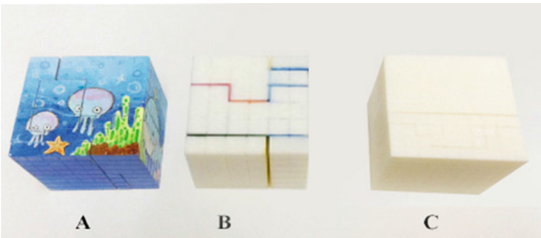

Fig. 5. The 3D wooden puzzles used during observations

However, the number of pieces and assembly methods of the three types of puzzles were designed based on the author's previous experience of the puzzle having nearly the same degree of difficulty. A professional designer performed the data design, based on 3D CAD. However, as seen in the comments in Tables 1, 2, 3 and 4, some students perceived difficulty due to size.

Over two days, third and sixth grade students were each given 15 min to put the puzzles together, for a total of two times.

Time and other details were as follows. We observed different students on both days. While third grade students have not yet learned how to measure volume, sixth grade students already have.

February 18, 2014:

"10:15–10:35 3 third grade students"
"12:55–13:10 3 sixth grade students"

February 19, 2014:

"10:15–10:35 3 third grade students"
"12:55–13:10 3 sixth grade students"

Table 1. February 18, 2014, first observation

Time (min)	Third grade, Student A	Third grade, Student B	Third grade, Student C
0–3	Works on Puzzle A. Has nearly constructed the form after 1 min, and completes after 2 min. Works on Puzzle C next, and finishes in about 30 s	Works on Puzzle B. It appears to be taking shape after about 1 min. However, afterward, student can be seen struggling and the puzzle remains incomplete	Works on Puzzle C. Begins to take shape in approximately 1.5 min, and is completed in 2 min. Next, works on Puzzle A. Assembles the pieces without any problems
4–6	Appears to struggle more with Puzzle B than the previous ones and remarks that the pieces are "difficult to insert." Completes this in approximately 2 min	Still unable to find pieces that fit after 5 min, exchanges for Puzzle C. Completes this in about 1 min	Completes Puzzle A in about 1 min 
7–9		Starts on Puzzle A after about 6.5 min, and is able to complete in about 2 min	Assembles Puzzle B last. Appears to have difficulty initially, but is able to complete it in about 2 min after figuring out a section
10–12	Responded that Puzzle C was the easiest as it had few pieces	Felt that Puzzle C was the easiest because the pieces were large	Responded that Puzzle C was the easiest as it had few pieces, the same response as Student A
13–15	Conversely, remarked that Puzzle B was complex and the most difficult	Puzzle B was the most difficult as it had difficult parts	Remarked that Puzzle B was the most difficult as its shapes were uneven, strange, and hard to figure out

Table 2. February 18, second observation

Time (min)	Sixth grade, Student A	Sixth grade, Student B	Sixth grade, Student C
0–3	Starts assembling Puzzle A very smoothly, and completes it after approximately 2 min. Begins assembling Puzzle C and finishes it in about 1 min	Works on Puzzle B. Assembles the corners during the first 3 min. Appears to be having difficulty	Begins assembling Puzzle C from the bottom up. Completes in about 3 min
4–6	Lastly, works on Puzzle B. Quickly assembles this one as with the earlier puzzles, and is nearly finished 	Work on Puzzle B is halted after 5 min, and we have the student assemble Puzzle C. Student smoothly assembles this, starting at the bottom, and completes it in a little over 1.5 min	Divides the pieces for Puzzle A into two groups, assembles them separately, and combines them at the end. Time required is about 1 min
7–9	Completes Puzzle B at the early 7 min mark	Can be seen assembling Puzzle A while looking at the pictures. Completes in less than 1 min	Completes Puzzle B in roughly 2 min
10–12		Attempts Puzzle B again. Remarks something to the effect that it might be possible to match pieces of the same color. Completes the puzzle with about 5 min remaining	
13–15	Selected Puzzle A as the easiest since it could be assembled by looking at the pictures. Responded that Puzzle B was the most difficult due to the myriad shapes of the pieces	Responded that Puzzle A was the easiest, for the same reasons given by Student A. Also stated that the most difficult was Puzzle B because comparatively, its parts had a lot of contours	Also responded that Puzzle A was the easiest for the same reasons. Selected Puzzle B as the most difficult due to the difference in the inner and outer colors

Table 3. February 19, first observation

Time (min)	Third grade, Student A	Third grade, Student B	Third grade, Student C
0–3	Can be seen assembling Puzzle A while looking at the pictures. Finishes in about 3 min	Assembles Puzzle B in sections	Begins to assemble Puzzle C, but appears unable to assemble evenly in sections
4–6	Works on Puzzle B. Student is seen tilting his head in confusion and appears to struggle with assembly 	After 5 min, pieces are still dispersed and far from resembling a cube. Student leaves it as is and moves on to Puzzle C	Incrementally taking shape in sections, but unable to complete. Next, student assembles Puzzle A 
7–9	Unable to complete the puzzle after 5 min, student trades it in for Puzzle C	Unable to complete it after 5 min, student trades it in for Puzzle A	Completes Puzzle A in about 2 min
10–12	Begins to assemble Puzzle C. After 1 min, the student is seen looking around	Student works on Puzzle A. Appears to assemble the puzzle by looking at the pictures. Completes in about 1.5 min	Begins assembling Puzzle B, but it shows no sign of taking shape
13–15	Nearing completion of Puzzle C. Completes after 14 min Responded that Puzzle A was the easiest because each part was large. Conversely, responded that Puzzle C was the most difficult because it lacked pictures and was uneven	Stated that Puzzle A seemed the easiest as it had printed pictures, making it easy to assemble. Puzzle B was the most difficult because it was painted with many colors and lacked pictures	Completes the puzzle with about 10 s remaining Also said that Puzzle A was the easiest as it had pictures printed on it. Stated that Puzzle B was the most difficult since it lacked pictures, had an uneven surface, and a lot of white space

Table 4. February 19, second observation

Time (min)	Sixth grade, Student A	Sixth grade, Student B	Sixth grade, Student C
0–3	Student can be seen assembling Puzzle A by looking at the pictures. Completes in about 1 min. Next, works on Puzzle B. Makes comments such as, “Uh-uh, no way…” Appears to find it difficult	Works on Puzzle B. Completes this in about 1 min. Works on Puzzle C next	Works on Puzzle C. Just as the student appears to have completed it, the student begins to disassemble and reassemble by trial and error. Completes in about 2.5 min. Works on Puzzle A next
4–6	Completes Puzzle B shortly before the 5 min mark. Student reassembles while waiting for the next puzzle	Has difficulty with 2 pieces remaining. Dismantles the puzzle for the moment	Completes Puzzle A in about 1.5 min
7–9	Works on Puzzle C. Gets a section to take shape, but is unable to make much progress	Completes Puzzle C Works on Puzzle A and completes in about 1.5 min	Assembles Puzzle B. Completes this in about 30 s
10–12	Finds some pieces that fit. Unable to complete it, student takes it apart again.		
13–15	Not much progress until the end, and time runs out, without being able to finish Felt that Puzzle A was the easiest as the pictures could be matched up, and responded that Puzzle C was the hardest as there were no patterns or colors, making assembly difficult	Responded that Puzzle A was the easiest for the same reasons given by Student A. Responded that Puzzle C, lacking any colors or pictures and complex in shape, was the most difficult	Also responded that Puzzle A was the easiest due to the printed pictures. Felt that Puzzle C was the most difficult because there were no colors to offer any hints

The three students each assembled all of the 3D puzzles (i.e., A, B, and C). We measured the time required for assembly. Upon completing the 3D puzzles, we interviewed the three students and asked them which puzzle was the easiest, which was the most difficult, and their reasons.

As C was clearly difficult, we stopped the students once 5 min had elapsed and then had them assemble A or B.

As a result of the observations, we found that Puzzle A, with the printed pictures, had a low degree of difficulty, except during the first observation on February 18, 2014. Additionally, we noted that even when presented with a complex structure, if students were able to recognize the rule that the surfaces of pieces were the same color where they meet, they were able to assemble the puzzle easily. However, since students found assembly difficult for shapes with deep joints (described by students as being “rugged,” i.e., uneven, in shape), we believe that the color provided a helpful hint when selecting joints.

4 Future Developments

Unlike planar materials, the size of teaching materials for measuring volume is important to students (i.e., when holding the object in one’s hand). Thus, the size of wooden puzzles must be determined from an alternative ergonomic perspective. We plan to create models resembling the same 3D objects found in textbooks, and perform an experiment on the differences between students who use 3D teaching materials versus those who learn by using traditional 2D textbooks.

The reason behind having professional designers devise the data of the 3D CAD was to understand under which types of processes modeling would occur. According to the designer, shapes were constructed by combining cubes or cuboids with each other, depending on the shape’s degree of difficulty. Another method was to take a large cube

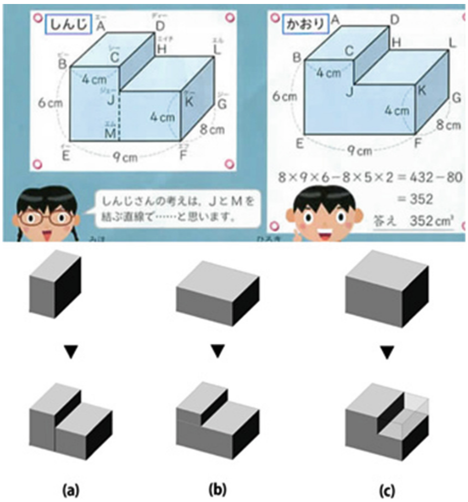

Fig. 6. Methods for solving volume calculation as shown in textbooks

or cuboid and subtract cubes and/or cuboids from it. These processes are the same as the basis for calculating volume that children learn in textbooks, as shown in Fig. 6 [6]. This figure shows that in textbooks, there is not just one method for calculating volume; rather, there are several. In addition, the 3D CAD data have all been recorded. In the future, we believe the 3D-CAD can be put to practical use as an application on tablets; for example, as shown in Fig. 7.

Fig. 7. Example of an application of volume calculation

Acknowledgements. We received support from Professor Masao Tachibana of Iwate University regarding the educational portion of arithmetic volume calculation, and from Mr. Ichiro Hirata of Hyogo Prefectural Institute of Technology regarding methods of observation. We also received support from Mr. Toru Sasaki and Ms. Eriko Yanagimura of the Elementary School that is attached to the Department of Education at Iwate University, undergraduate student Asami Kashiwagi, and graduate student Suleeporn Kamchompoo. Thank you, everyone.

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