Journal for Geometry and Graphics
Volume 17 (2013), No. 2, 251–264.

# Errors Analysis of Mental Cutting Test Using Models Instead of Drawings as Presenting Problems

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**Abstract.** In the present study, we performed a modified MCT based on the hypothesis that if stereoscopic vision, which had been employed to give depth cues, was replaced with an actual object (model) and if subjects could rotate the model freely, they could understand three-dimensional images easily. In the investigation, a "predetermined-direction MCT" and an "arbitrary-direction MCT" were employed. The results were compared with those obtained for the perspective-based MCT. The comparison results are summarized as follows:

(1) The average score was higher by approximately 2 points and the accuracy rate was higher for 8 out of 25 problems in the predetermined-direction MCT than in the perspective-based MCT.

(2) Regarding problems, the accuracy rate of which increased, the relative position of the section and convexo-concave configuration of the solid body were correctly recognized in the predetermined-direction MCT. Thus errors occurring in the perspective-based MCT were confirmed to occur in the process of recognizing three-dimensional shapes and in the process of recognizing the relative position between the section and solid body.

(3) Compared with the perspective-based MCT, the average score did not increase for the arbitrary-direction MCT. In the arbitrary-direction MCT, as shapes were difficult to recognize in some problems due to the loss of horizontal/vertical-related clues, visible and obvious intersection points were used to try to generate section shape images. Thus, we observed that methods of drawing solutions or the problem-solving strategy peculiar to model observation were used.

*Key Words:* MCT, depth cues, predetermined-direction MCT, arbitrary-direction MCT

*MSC 2010:* 97U50

ISSN 1433-8157/$ 2.50 

# 1. Introduction

Recently, mental cutting tests (MCT [1]) have been used to evaluate the spatial cognitive ability in graphic science education. The standard MCT consists of 25 problems for which the full score is 25. In each problem, subjects are given a perspective drawing of a test solid which is to be cut with an assumed cutting plane. Subjects are asked to choose one correct cross section among 5 alternatives. There are two categories of problems in the MCT (Suzuki et al. [7]). One category is called *"pattern problem"*, in which the correct answer is determined by identifying only the pattern of the section. The other is called *"quantity problem"*, in which the correct answer is determined by identifying not only the pattern but also any quantity in the section, e.g., the length of the edges or the angles between the edges. It was shown by Saito et al. [4] that in order to solve the MCT problems, subjects go through 3 phases of information processing, which are,

(1) recognizing the solid from the perspective drawing,

(2) cutting the solid by the assumed cutting plane, and

(3) judging the characteristic quantity of the section, if necessary.

Based on results [2, 4] obtained using an MCT with perspective drawings (hereinafter referred to as the *perspective-based* MCT), the causes of errors occurring in each problem were analyzed. Consequently, it was revealed that MCTs could be used to evaluate the ability to *generate* three-dimensional images from drawings (the ability to recognize three-dimensional shapes and sections and the ability to generate section shapes) and *analytical* ability (the ability to clarify the qualitative difference between multiple options possessing the same pattern in quantity decision problems).

In order to verify this, we constructed the following hypothesis: If *depth cues*, which are insufficient in perspective drawings, are included in a solid body in MCT problems (hereinafter referred to as the solid body), the number of errors occurring in the generation of three-dimensional images would be reduced. Based on this hypothesis, new MCTs, in which the solid body is expressed using stereoscopic line drawings in a liquid crystal shutter system [11, 8, 9] or an anaglyph stereoscopic system [3] were developed. In the developed stereographic line drawing MCT, in which the binocular parallax was a depth cue, the accuracy rates obtained for quantity decision problems did not increase, although the scores obtained for some pattern decision problems did. Next, modified MCTs, in which problems were presented in the form of models [5] or photo-stereographics [6] were developed. By introducing shadow and tone as depth cues in addition to binocular parallax, a sense of depth, which might be visually obtained by presenting an actual object, was realized. Since the accuracy rates for some problems increased, the average score was significantly higher for the modified MCT than for the perspective-based MCT. However, the accuracy rates for many problems did not increase in the modified MCT. These results indicate that the "generation of section shapes", "processing of invisible parts" and "quantity decision problems" were not greatly affected by the introduction of stereographics. Therefore, presumption and examination processes were considered important in MCT solutions.

The above results were obtained by including various depth cues in the perspective-based MCT. However, the direction of the sight line (toward the solid body) in the modified MCT was the same as that in the perspective-based MCT. We assumed that if the solid body could be observed in an arbitrary direction by rotating the body, invisible parts in the body could be presumed, and consequently, the generation of three-dimensional images could be facilitated. Based on this assumption, we used a "rotated-view MCT (line drawings)" [10], in which the solid body could be rotated 180 degrees to the right and left around the vertical axis. We compared solutions to nine problems found in the perspective-based MCT and the rotated-view MCT. The average score increased significantly for the rotated-view MCT. However, when the section was rotated in the direction closest to the rectilinear view, the accuracy rate did not increase, except for a case where the questionable part in the solid body was clearly separated from the section. We found that subjects with low and medium scores could not intuitively image the shape of the solid body correctly. In many cases, these subjects drew solutions using two-dimensional elements, such as contours and parallels on the perspective drawing. They could not understand how to read projections and could not generate three-dimensional images from projections. The test results for subjects who could draw the correct solutions indicated that "viewing in an appropriate direction" was considered important in understanding three-dimensional shapes. In the rotated-view MCT, the solid body could be observed in an arbitrary direction. However, there were problems in the form of projections on a display, i.e., two-dimensional expression.

In the present study, we considered the characteristics of the modified MCT in constructing the hypothesis. The hypothesis was that if stereoscopic vision, which had been employed to give depth cues, was replaced with an actual object (model) and if subjects could rotate the model freely, they could understand three-dimensional images easily. Consequently, solutions would differ from those obtained for the perspective-based MCT. Based on this hypothesis, two types of MCT with an actual object (model) were performed. By presenting 25 problems related to the solid body in MCTs using models instead of drawings, we investigated changes in errors. In the investigation, a *"predetermined-direction MCT"*, in which the model was observed in a predetermined direction and the appearance of the model was similar to that in the perspective-based MCT, and an *"arbitrary-direction MCT"*, in which the model was observed in an arbitrary direction, were employed.

## 2. Materials and methods

### 2.1. Models

Each of the models used in this study consisted of a solid body and a section. The same models were used in a study conducted by Saito et al. [6], and those employed in the present study were created based on a cube with 65 mm edge length. They were made of chemical wood, and a light-grey pear-skin texture was used. A black leg of length 70 mm and with 6 mm diameter was installed between the solid body and a pedestal. The section created by Saito et al. was partially modified and used for the present study, where it was generated as a rectangular frame using a yellow PVC-covered wire of diameter 2 mm. On the pedestal, a white line was drawn, the direction of which was the same as that of the sight line, so that the appearance of the model was similar to that in a perspective-based MCT, and a blue seal was affixed to indicate the front. Figure 1 shows an example of the models.

### 2.2. Model-based MCT

In the present study, an individual room was used. In order to prevent a shadow of the frame indicating the section from appearing on a model, two lights directed toward the ceiling were placed approximately 1 m away from its right and left sides, i.e., indirect lighting was adopted. In addition, an original solution sheet was created in such a way that only solution options were printed. Of course 5 alternatives for each problem are the same as those used in perspective-

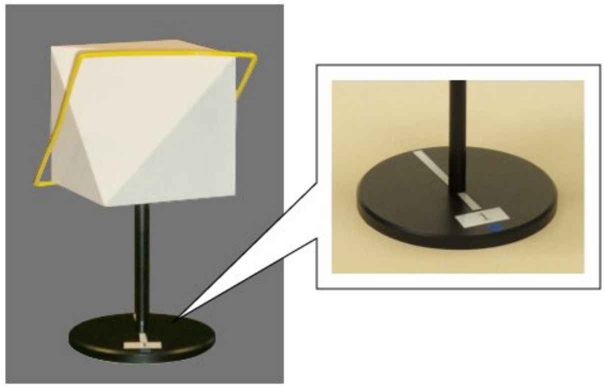


Figure 1: An example of the models used for MCT problems

based MCT i.e., original paper-and-pencil MCT. The predetermined- and arbitrary-direction MCTs were conducted between July and November 2010.

(1) Predetermined-direction MCT:
The models were placed one by one on a mark 30 cm away from the desk edge. A subject was orally instructed to sit in front of the blue seal on the pedestal and to observe the model along the white line, so that the appearance of the model was similar to that in the perspective-based MCT (the left photograph in Fig. 2).

(2) Arbitrary-direction MCT:
The models were placed one by one, and a subject was positioned in front of the blue seal on the pedestal of a model. The subject was orally instructed to observe the model in any direction under the condition of holding the leg of the model (the right photograph in Fig. 2).

The time limit of 20 min, which was set for the perspective-based MCT, was not applied to the predetermined- and arbitrary-direction MCTs, i.e., the subjects could give solutions freely. The models were presented to the subjects in the order determined by the investigator, and the subjects could not go back to the previous problem. A video camera was set to record the subjects observing the models and the time it took to give solutions.

### 2.3. Subjects

In the present study, 35 and 25 female students in Otsuma Womens University participated as subjects for predetermined-direction MCT and arbitrary-direction MCT, respectively.

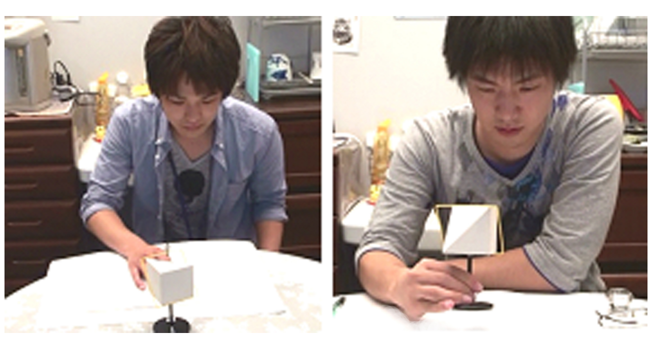


Figure 2: Photographs of the predetermined- and arbitrary-direction MCTs

### 2.4. Perspective-based MCT

Subjects for the perspective-based MCT belonged to the same department as subjects for the model-based MCTs; the perspective-based MCT was conducted in 2010 and 2011.

## 3. Results and discussion

### 3.1. Average score

Table 1 shows the average score. Figure 3 shows the score distribution. Table 1 also shows the results of a photo-stereographic MCT obtained by Saito et al. [6] for comparison. The average score of the predetermined-direction MCT was 13.46 and that of the arbitrary-direction MCT was 11.88; i.e., the average score was slightly higher in the predetermined-direction MCT than in the arbitrary-direction MCT ($P < 0.1$). Since the average score of the perspective-based MCT was 11.49, the average score was significantly higher only in the predetermined-direction MCT (score difference of 1.97) ($P < 0.05$).

A significant difference was observed in the average score between the photo-stereographic and perspective-based MCTs (score difference of 2.10) (Table 1). This difference was similar to that between the predetermined-direction and perspective-based MCT.

Table 1: Average score

| MCT | Average score | Difference | Persp. MCT 4) |
|---|---|---|---|
| Pre-MCT 1) | 13.46 | 1.97* | 11.49 |
| Arbi-MCT 2) | 11.88 | 0.39 | 11.49 |
| Photo-MCT 3) | 16.30 | 2.10* | 14.20 |

1) Predetermined-direction MCT
2) Arbitrary-direction MCT
3) Photo-stereographic MCT (Saito et al. [6])
4) Perspective-based MCT

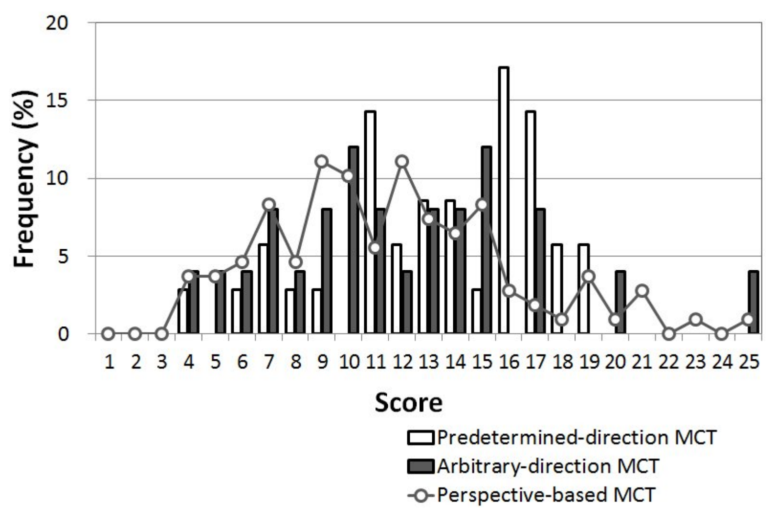



Figure 3: Score distribution

### 3.2. Accuracy rate of each problem

Figure 4 shows the accuracy rates of the problems in the predetermined- and arbitrary-direction MCTs, in the order of higher accuracy rates of problems in the perspective-based MCT. Table 2 shows significant differences in the accuracy rate between the predetermined- or arbitrary-direction MCT and the perspective-based MCT. This table also shows the results of the photo-stereographic and rotated-view MCTs for comparison.

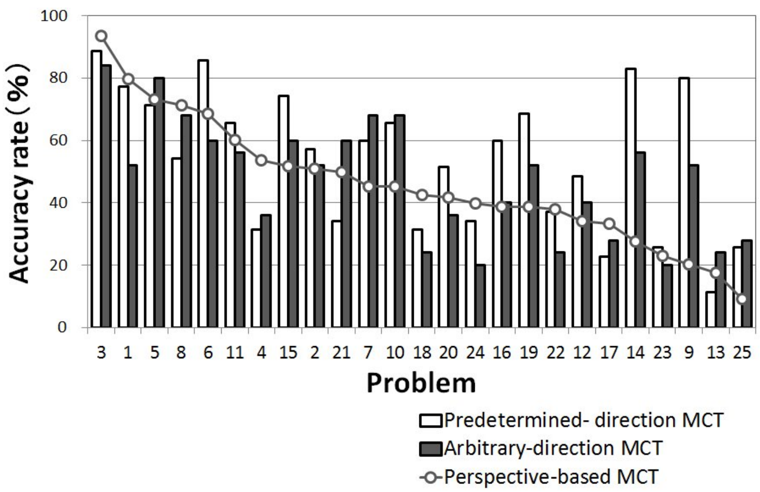



Figure 4: Accuracy rate of each problem

Table 2: Significant differences in the accuracy rate between the model-based MCTs and the perspective-based MCT

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Predetermined | | | | (*) | | * | | | ** | * | | | | ** | * | * | | | ** | | | | | | * |
| Arbitrary | (*) | | | | | | * | | ** | * | | | | ** | | | | | | | | | | | * |
| Photo-stereographic | | | | | * | | | | * | * | | | | * | | | | | | | * | * | | | |
| Rotated-view | | | | | | | | | | | | | | * | ** | | | ** | | | | | | * | |

(1) ** $P < 0.01$, * $P < 0.05$.

(2) (*) $P < 0.05$: problems, the accuracy rates of which were significantly higher in the perspective-based MCT than in the other MCTs.

(3) Filled cells represent problems that were not investigated in the study.

The accuracy rates of Problems 6, 9, 10, 14, 15, 16, 19, and 25 were significantly higher in the predetermined-direction MCT than in the perspective-based MCT. Moreover, the scores for Problems 9, 10, and 14 were significantly higher in the photo-stereographic MCT than in the perspective-based MCT, and this tendency agreed with that of the model-based MCTs. As shown in Table 1 and in Fig. 4, although the tendency observed in the predetermined-direction MCT was similar to that observed in the arbitrary-direction MCT, the increase in the accuracy rates tended to be smaller in the arbitrary-direction MCT than in the predetermined-direction MCT.

In contrast, the accuracy rates of Problems 4 and 1 were significantly lower in the predetermined- or arbitrary-direction MCTs than in the perspective-based MCT ($P < 0.05$).

The accuracy rates of Problems 1 ($P < 0.01$), 6, 9 and 14 ($P < 0.05$) were higher in the predetermined-direction MCT than in the arbitrary-direction MCT. As mentioned above, the average score was higher by approximately 2 and the accuracy rate was higher for 8 out of 25 problems in the predetermined-direction MCT than in the perspective-based MCT. The results obtained for the predetermined-direction MCT were similar to those obtained in the photo-stereographic MCT proposed by Saito et al.. In the photo-stereographic MCT, "binocular parallax", "shadow" and "tone" were introduced as depth cues in addition to "shielding" and "slight linear perspective", which were included in the perspective-based MCT. Therefore, the results obtained by Saito et al. were reproducible. However, the accuracy rates of some problems decreased, mainly in the arbitrary-direction MCT. The reason for this might be the observation of the model in an arbitrary direction.

### 3.3. Solution options

For some problems, the correct solution could be obtained more easily in the model-based MCTs than in the perspective-based MCT, as expected. However, the selection rates of unexpected errors were sometimes high in the arbitrary-direction MCT. The characteristics of solutions to the MCT problems observed when the model was presented are described below.

#### 3.3.1. Problems, the accuracy rates of which were increased by presenting the model

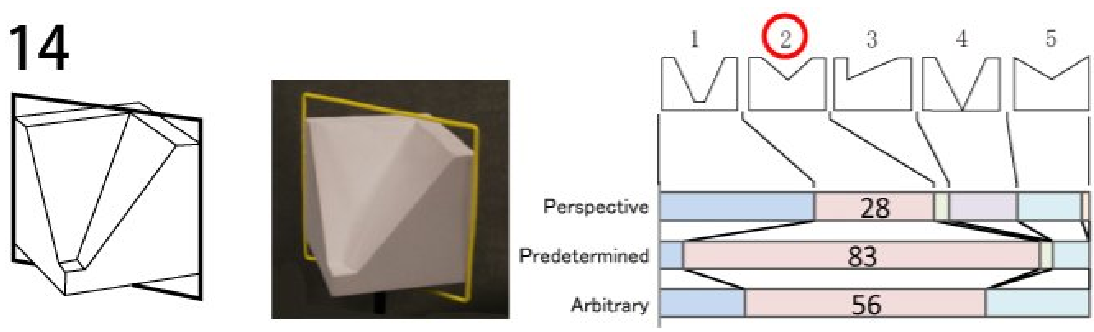



Figure 5: Changes in the selection rates of the solution options in Problem 14

**(1)** For Problem 14 (Fig. 5), the selection rate of the correct solution 2 significantly increased in the predetermined- and arbitrary-direction MCTs (circle in this figure represents the correct solution). In problem drawings in the perspective-based MCT, since the solid body and the lower part of the section contour line seemed to intersect, many subjects selected error 1. However, when the model was closely observed, the relative position of the section could be correctly understood. For Problem 10 (Fig. 6), since the concave part between the internal triangular pyramid and the vertical part at the right side could be easily recognized when the model was presented, the number of subjects selecting error 5 decreased greatly, and the selection rate of the correct solution 3 significantly increased. Thus, the relative position of the section against the solid body could be correctly recognized in some problems due to the appropriate presentation of the model.

**(2)** For Problem 9 (Fig. 7), the accuracy rate significantly increased in the predetermined- and arbitrary-direction MCTs compared to the perspective-based MCT. The greatest reason

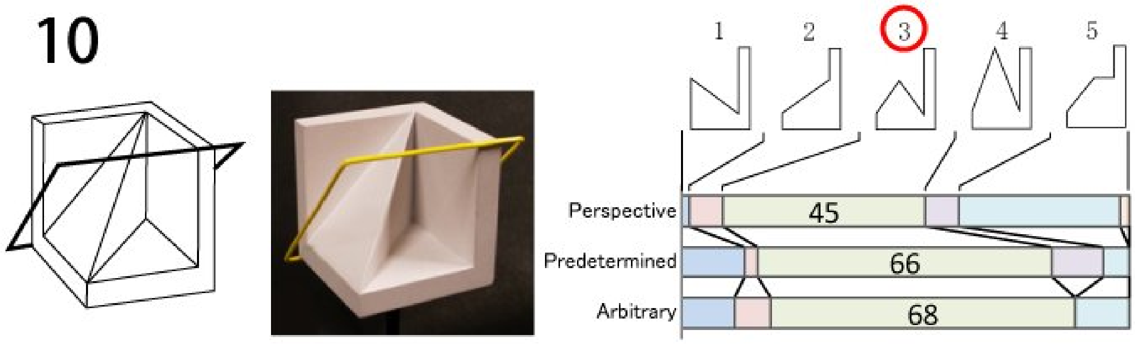



Figure 6: Changes in the selection rates of the solution options in Problem 10

for this was that error 4 was not selected at all when the model was presented. For Problem 13 (Fig. 8), although the accuracy rate did not increase in the predetermined- and arbitrary-direction MCTs compared to the perspective-based MCT, the number of subjects selecting error 3 largely decreased in the arbitrary-direction MCT. These errors possessed the shapes of cutting faces (expressed by the broken line in Figs. 7 and 8), which were imaged based on intersection points between line segments on the perspective drawing, while considering the problem drawing as a two-dimensional drawing in the perspective-based MCT. Since the number of subjects selecting these errors decreased in the model-based MCTs, to which depth cues were given, some errors in the perspective-based MCT were thought to occur in the process of recognizing the three-dimensional shape.

For Problem 9 (Fig. 7), the accuracy rate increased and the physical relationship between the solid body and the section became clear when the model was presented (Fig. 9 (a) shows the predetermined-direction MCT, and Fig. 9 (b) shows the arbitrary-direction MCT). However, the selection rate of error 3 also increased in the arbitrary-direction MCT. Error 3 possessed the shape of a cutting face (expressed by the broken line in Fig. 9 (c)); it seems as though the section was actually observed and the solid body was projected onto the section. When the subjects held the model in their hands, since they could observe the model in arbitrary directions, such as a direction from the back of the model and a direction perpendicular to the section, new misrecognition is considered to have been generated that was not often observed in the perspective-based MCT.

Through analysis of the changes in the solution selection rate due to the presentation of MCT problems using models, it was revealed that the relative position of the section and unevenness of the solid body were correctly recognized in problems, and the accuracy rates

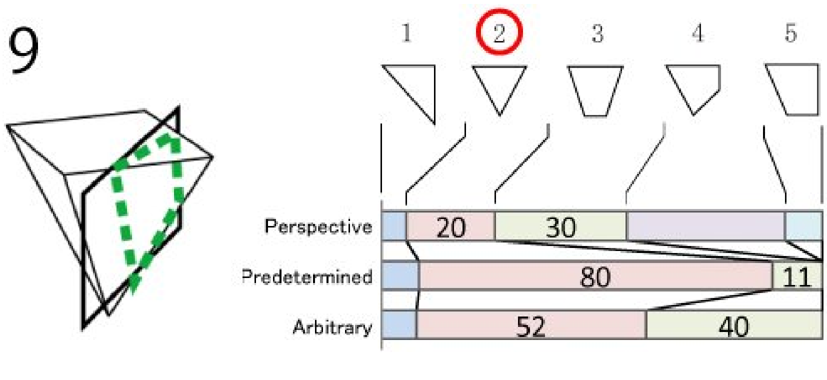



Figure 7: Changes in the selection rates of the solution options in Problem 9

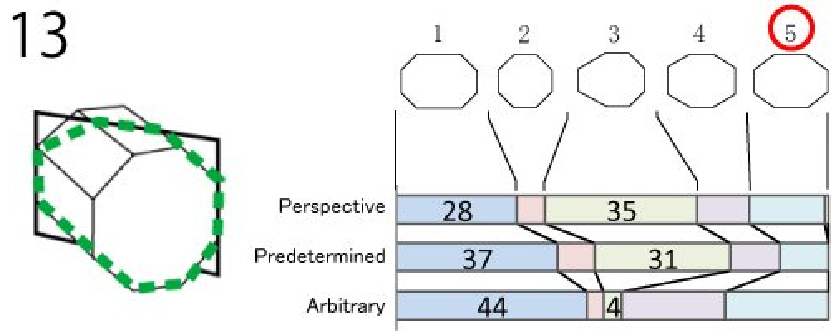
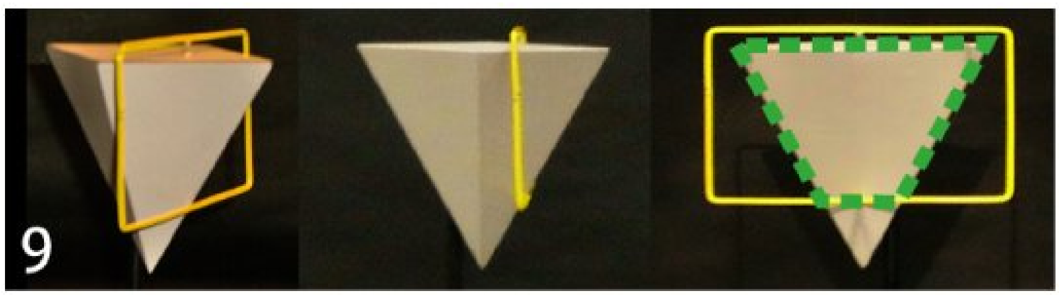



Figure 8: Changes in the selection rates of the solution options in Problem 13




(a) (b) (c)

Figure 9: Appearances of a model in Problem 9

increased. These results agreed with a study conducted by SAITO et al., which reported that some errors occurring in the perspective-based MCT were confirmed to occur in the process of recognizing three-dimensional shapes and in the process of recognizing the relative position between the section and the solid body. In the arbitrary-direction MCT, it was revealed that errors other than those occurring in the perspective-based MCT arose due to a "model" + "arbitrary rotation" phenomenon.

### 3.3.2. Problems, the accuracy rates of which were not increased by presenting a model

**(1)** For Problem 1 (Fig. 10), the accuracy rate was decreased by presenting the model. In particular, the accuracy rate was significantly lower in the arbitrary-direction MCT than in the perspective-based MCT by approximately 30 points, and the selection rate of error 1 was higher in the arbitrary-direction MCT than in the perspective-based MCT by approximately 20 points. As shown in Fig. 10, the shape of error 1 is a triangle. It seemed that the section shape image was constructed as if point A and B in Fig. 11 were directly connected by an edge. In the shape shown in error 1, points A and B were directly connected, as illustrated in Fig. 11. Although direct intersection points between the frame expressing the contour line of the section and the edge line of the solid body (points A, B, and C in Fig. 11, for example; hereinafter referred to as visible intersection points) were easy to observe, an intersection point between the (cutting) face existing virtually inside the frame and the edge line of the solid body, i.e., point D, could not be found or recognized because the intersection point did not directly intersect with the frame. Consequently, points A and B were directly connected by an edge, and a cutting face expressed by the broken line was imaged, as shown in Fig. 11. Error 4 in Problem 18 (Fig. 12) might have the same cause.

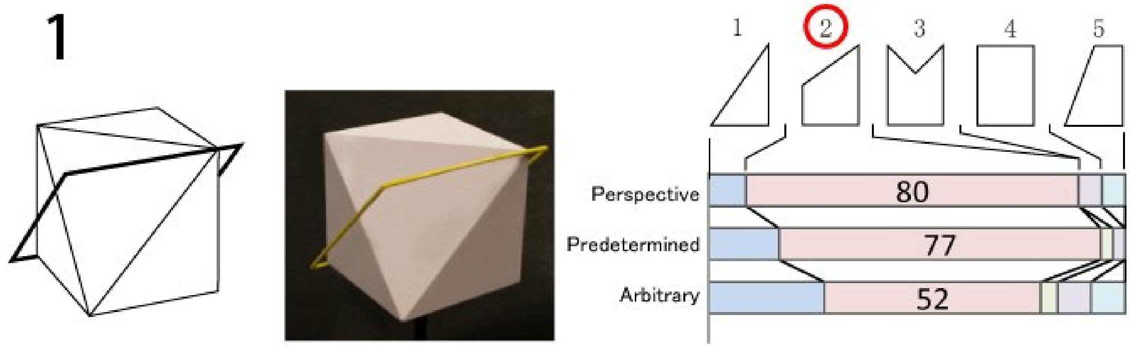



Figure 10: Changes in the selection rates of the solution options in Problem 1

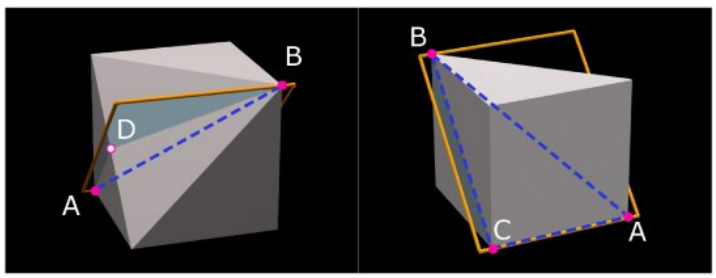



Figure 11: Visible and virtual intersection points between the solid body and the section

As mentioned in Section 3.3.1 (2), in the perspective-based MCT, intersection points between the edge line and the contour line of the section on a problem drawing (perspective drawing) were recognized (and sometimes misrecognized) as the apices of the cutting face in many cases. When a model was used in the arbitrary-direction MCT in which the model could be arbitrarily rotated, since a problem drawing (perspective drawing) was not given, a virtual intersection point such as point D in Fig. 11 could not be recognized as a fixed point. When a three-dimensional shape could not be clearly imaged, the subjects tended to create a cutting face centering on a visible intersection point without firmly recognizing the virtual intersection point such as point D. In other words, some subjects imaged a cutting face relying on visible intersection points on a problem drawing, regardless of whether a two- or three-dimensional image was presented, and selected the option which was the closest to the imaged cutting face.

**(2)** For Problem 18 (Fig. 12), the accuracy rate significantly increased in the rotated-view MCT, as shown in Table 2. The reason for this was that the back part of the pyramid in the

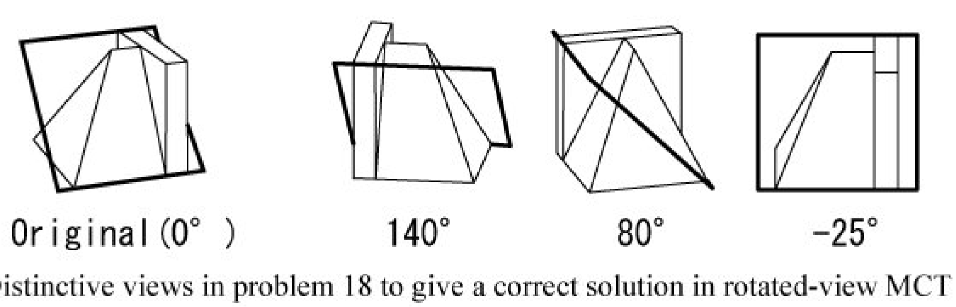



Figure 12: Rotated-views in Problem 18

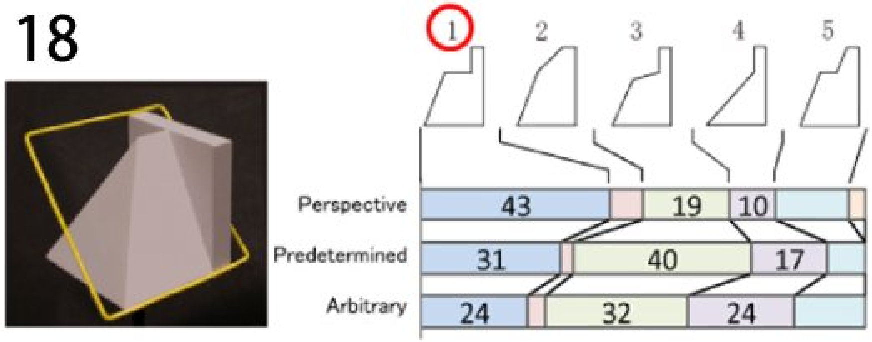



Figure 13: Changes in the selection rates of the solution options in Problem 18

problem, which was invisible in the perspective-based MCT, could be observed when rotating the model. However, the accuracy rate was lower in the arbitrary-direction MCT than in the perspective-based MCT by 19 points (Fig. 13), although models were allowed to rotate freely. Therefore, even if the number of clues for the solution was increased by observing the invisible part, as the horizontal/vertical-related clues possessed by the solid body were lost because the subjects held the model in their hands, subject couldn't find the correct solution easily. Consequently, the subjects imaged a cutting face by relying on visible intersection points and the selection rates of errors 3 or 4 actually increased.

**(3)** Error 1 in Problem 13 (Fig. 8) largely increased in the arbitrary-direction MCT. In this MCT, an appearance in which the linear elements in the cylinder in the problem were parallel to the frame expressing the section was strongly recognized. Consequently, subjects strongly identified the linearity of these elements, and the length of the cutting face, which was imaged to pass through the cylinder, was recognized to be longer than the actual length. This tendency was also observed in error 4 in Problem 2 (Fig. 14).

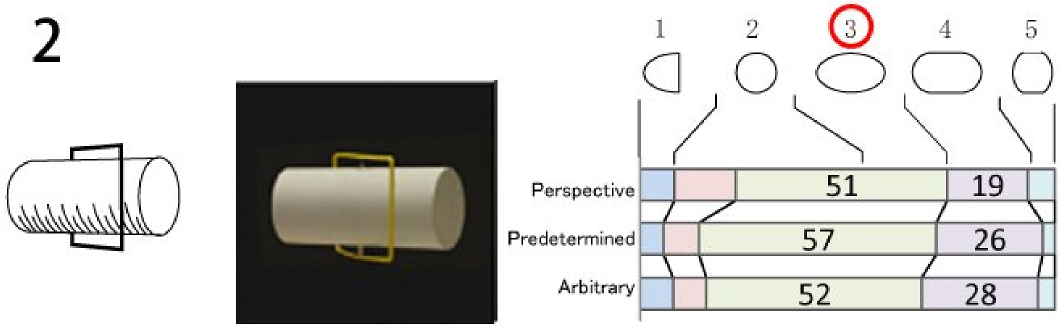



Figure 14: Changes in the selection rates of the solution options in Problem 2

**(4)** The model used for Problem 4 (Fig. 15) was a difference set of a cube and a cylinder. The selection rates of errors 1 and 4, in which the cutting face was expressed by a square, increased in the predetermined- and arbitrary-direction MCTs. Therefore, in the model-based MCTs, a cube and a cylinder were strongly recognized as a "square" and a "circle", respectively. Consequently, the subjects tended to image the cutting face based on the characteristic shape of the model, regardless of the cutting position.

The above-mentioned results (1) – (4) revealed that in problems where the accuracy rates were not increased by observing the model, errors due to the use of visible and obvious

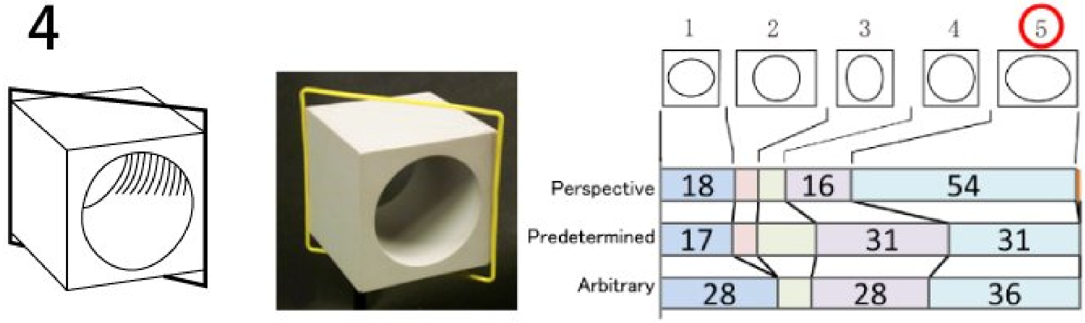



Figure 15: Changes in the selection rates of the solution options in Problem 4

intersection points occurred in the process of generating the image of a cutting face. For example, in the arbitrary-direction MCT, tactics of understanding the contour line of the solid body as the cutting face by observing the section from the front were adopted. Here, since the correct image of the cutting face could not be presumed, visible intersection points on the model were used. In the arbitrary-direction MCT, as pointed out in relation to the rotated-view MCT, although the accuracy rate was increased by observing the model in an appropriate direction in some problems, the correct image of a cutting face could not be created by observing the relative position of the section in an arbitrary direction, and the above-mentioned tactics were employed in some problems.

Many MCT problems used in the present study were designed based on a cube, in which a set of faces were horizontal and other faces were vertical (Fig. 16 (a)). Other MCT problems also possessed horizontal and vertical faces (axes) (Fig. 16 (b)). The subjects were considered to recognize three-dimensional shapes based on horizontal/vertical-related clues. In the arbitrary-direction MCT, by rotating a model in space, the subjects were released from the constraint of observing the model on the desk in a predetermined direction. However, shapes were difficult to recognize due to the loss of horizontal/vertical-related clues (Fig. 17), and consequently the above-mentioned tactics were employed in some problems. As shown in Table 1, the loss of horizontal/vertical-related clues prevented an increase in the average score due to the addition of depth cues, although a significant difference was not observed in each problem.

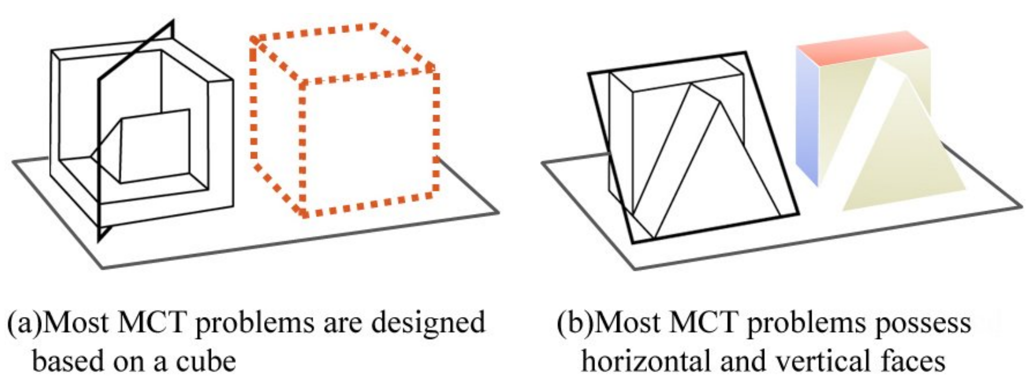



Figure 16: Most MCT problems possess horizontal and vertical faces

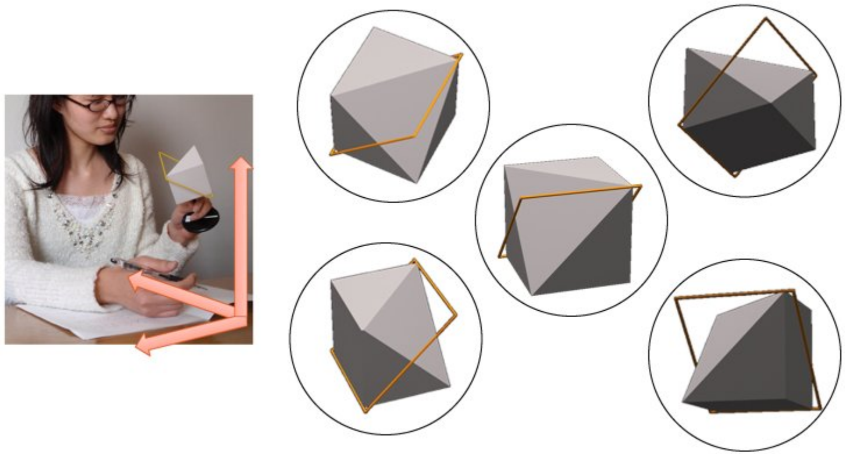


Figure 17: Loss of horizontal/vertical-related clues in the arbitrary-direction MCT

## 4. Conclusions

By presenting 25 problems related to the solid body in MCTs using models instead of drawings, we investigated changes in errors. In the investigation, a “predetermined-direction MCT”, in which the model was observed in a predetermined direction and the appearance of the model was similar to that in the perspective-based MCT, and an “arbitrary-direction MCT”, in which the model was observed in an arbitrary direction, were employed. The results were compared with those obtained for the perspective-based MCT. The results are summarized as follows:

(1) The average score was higher by approximately 2 points and the accuracy rate was higher for 8 out of 25 problems in the predetermined-direction MCT than in the perspective-based MCT. In particular, the results obtained for the predetermined-direction MCT were similar to those obtained in the photo stereographic MCT proposed by Saito et al.. In the photo stereographic MCT, binocular parallax, shadow, and tone were introduced as depth cues in addition to “shielding” and “slight linear perspective”, which were included in the perspective-based MCT.

(2) Regarding problems, the accuracy rate of which increased, the relative position of the section and unevenness of the solid body were correctly recognized in the predetermined-direction MCT. Errors occurring in the perspective-based MCT were confirmed to occur in the process of recognizing three-dimensional shapes and in the process of recognizing the relative position between the section and solid body.

(3) Compared with the perspective-based MCT, the average score did not increase for the arbitrary-direction MCT. In the arbitrary-direction MCT, shapes were difficult to recognize in some problems due to the loss of horizontal/vertical-related clues, and visible and obvious intersection points were used to try to generate section shapes. Thus, we observed that methods of drawing solutions peculiar to model observation were used.

## References

[1] Ceeb: *Special Aptitude Test in Spatial Relations*. Developed by the College Entrance Examination Board, USA, 1939.

[2] T. Saito, K. Makino, K. Shiina, K. Suzuki, T. Jingu: *Causes of Error in a Mental Cutting Test – Analysis of Problem Solving Process by the Use of Eye Fixations Data (2)*. Proc. 6th ICECGDG, Tokyo/Japan 1994, pp. 815–819.

[3] K. Nishihara, S. Nishihara, K. Chibana, K. Yoshida: *Effect of Hidden Line Removal on the Score of Mental Cutting Test Remodeled by Anaglyphic Representation*. Proc. 6th ICECGDG, Tokyo/Japan 1994, pp. 786–790.

[4] T. Saito, K. Shiina, K. Suzuki, T. Jingu: *Spatial Ability Evaluated by a Mental Cutting Test*. Proc. 7th ICECGDG, Cracow/Poland 1996, pp. 569–573.

[5] T. Saito, K. Suzuki: *Error Analysis on a Mental Cutting Test by the Comparison with a Real Solid Model Mental Cutting Test*. Proc. 4th China-Japan Joint Conference on Graphics Education, Dunghuang/China 1999, pp. 111–116.

[6] T. Saito, K. Suzuki: *Error Analysis of Mental Cutting Test by Using a Photo-Stereographic Mental Cutting Test*. Proc. 9th ICGG, Johannesburg/South Africa 2000, pp. 394–398.

[7] K. Suzuki, S. Wakita, S. Nagano: *Improvement of Spatial Problem Solving Ability through Descriptive Geometry Education*. Proc. 4th ICECGDG, Miami/USA 1990, pp. 442–448.

[8] E. Tsutsumi, K. Shiina, A. Suzaki, K. Yamanouchi, T. Saito, K. Suzuki: *A Mental Cutting Test on Female Students Using A Stereographic System*. J. Geometry Graphics **3**/1, 111–119 (1999).

[9] E. Tsutsumi, K. Yamanouchi, K. Suzuki: *A Mental Cutting Test Using Stereographic System Conducted to the Middle Scoring Group of the Test — Analysis of Response time* [in Japanese]. J. Graphic Science **34**, no. 4, 17–22 (2000).

[10] E. Tsutsumi, W. Ishikawa, H. Sakuta, K. Suzuki: *Analysis of Causes of Errors in the Mental Cutting Test — Effects of View Rotation*. J. Geometry Graphics **12**/1, 109–120 (2008).

[11] Y. Yao, T. Saito, K. Suzuki: *Analysis of Causes of Errors in a MCT through the Comparison with Stereographic MCT* [in Japanese]. Proc. 1996 Annual Meeting of Japan Society for Graphic Science, pp. 122–127.

Received September 22, 2013; final form October 29, 2013