

AR based Spatial Reasoning Capacity Training for Students

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Abstract: In this paper, we propose two methods to train students' spatial reasoning capacity using AR (Augmented Reality). The first method supports students for rotating spatial objects more easily with two AR markers. One marker is used for questions, on which several blocks and a landmark (with a shape of a chick) are displayed. The other marker is used for answers, on which blocks are moved freely. The layout of the blocks toward the chick is selected on the marker. The second method includes limitation of rotation on the marker using some Arduino based hardware. The second method supports students for rotating spatial objects partially. To validate the effect of the trained and resultant spatial reasoning capacity, we perform an experiment using the first method. The analysis results explain the spatial object recognition accuracy increases using the AR learning. To validate the effect of rotation angles, we perform other experiments using the second method. The analysis result shows the rotation angle of sixty degrees is the best for the training of spatial reasoning capacity.

1. Introduction

The spatial reasoning capacity is an ability to recognize objects in three-dimensional space. Objects' locations and conditions, which are shapes, angles and sizes, are recognized quickly and accurately by this capacity. Even non-existent objects are always imaged using the spatial reasoning capacity, too. Visual images can be controlled by cognitive operations in the same way for real objects.

Compulsory education includes the learning of spatial objects in some ages although the learning of the spatial objects has been decreased according to lighter curriculum promoted by the Ministry of Education in Japan. In the second grade of elementary school, children learn spatial objects for the first time as compulsory education [1]. First, children learn the basic objects, which are cubes and rectangular solids. These objects are shown in learning materials such as textbooks with a plane surface. Consequently, if they do not have spatial reasoning capacity so much, it is difficult to learn abecedarian arithmetic. In such case, they cannot understand spatial objects in junior high school. Moreover, selected specific general planes and equations for lines are given in mathematics of high school regardless of their intelligibility of spatial objects.

Children in old days mainly used to play with three-dimensional objects, such as building blocks, cat's cradle, puzzle links and plamodels. On the other hand, children in nowa-

days mainly plays in a plane, i.e. video games, rather than in the three-dimensional world. Spatial reasoning capacity is improved by strong awareness in the three-dimension space, for example, playing with three-dimensional objects. Opportunities of spatial reasoning learning have decreased in terms of play and education in general. Hence, special education for spatial reasoning capacity is needed in childhood.

In this paper, we propose some methods to train students' spatial reasoning capacity with using AR. In the AR environment, virtual objects are displayed even in floating and can be moved freely. Students with low spatial reasoning capacity can effectively learn by rotating an AR marker. To validate the effects of the trained and resultant spatial reasoning capacity, we perform some experiments and analyze them to model the learning phases.

2. Rotating blocks using AR

In this section, two methods to train spatial reasoning capacity are proposed. These methods support easy spatial object rotation for improving spatial reasoning capacity. We first explain the construction of an AR supporting environment. Then, we propose the first method to train spatial reasoning capacity and the second method with physical limitation of rotation.

2.1 Construction of an AR supporting environment

In this paper, we adopt AR to provide free spatial objects movement with displaying the corresponding virtual objects for students. AR markers are freely movable, and virtual objects on the AR markers are redisplayed according to their movement. Since we are interested in training spatial reasoning capacity, we use the marker based AR that provides the free movement of virtual objects for students.

The marker based AR supporting environment for spatial rea-

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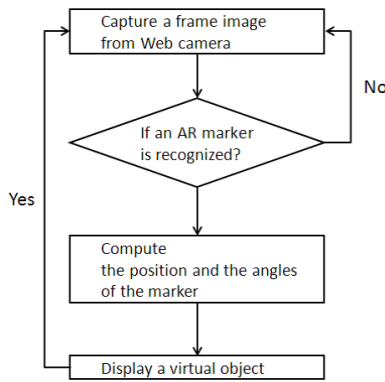


Fig. 1 Construction of the AR environment

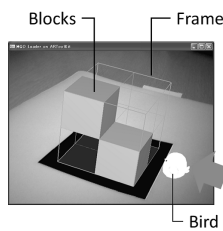


Fig. 2 A question marker

soning capacity is constructed as shown in Fig. 1. First, a frame image of video stream from a Web camera is captured to be displayed. Next, an AR marker is recognized in the captured image. Then, the position and the angles of the marker are computed. Finally, a pre-defined virtual object is displayed at the position with the angles. The AR marker receives events from user via keyboard to change the position and the angles of the virtual object.

2.2 Rotating virtual objects in the marker based AR supporting environment

In this subsection, we present a method to train students' spatial reasoning capacity with rotating virtual blocks in the above AR environment. This method requires two AR markers: for questions and for answers. On the question marker, several blocks, a landmark (with a shape of a chick) and box frames are displayed. Fig. 2 shows an example where two blocks and a landmark are displayed as a question. Up to 2³ blocks can be placed in the box frame. The number of blocks is selected using the keyboard. The layout of blocks is changeable in random. The landmark can be placed on the four directions.

On the answer marker, numbers of 1 to 4 are written. First, only the box frame is visible on the answer marker. A block is placed on the answer marker according to the keyboard input. The keyboard input is chosen from key 1 to 4. When a key is pressed, a block is placed on the same number of the answer marker. Fig. 3 shows examples of the key entries. When key 1 is pressed once, a block is displayed on the bottom as shown in Fig. 3(a). When the key is pressed twice, the block moves up as shown in Fig. 3(b). When the key is pressed three times, two blocks are displayed on the bottom and the top as shown in Fig. 3(c). When the key is pressed four times, the two blocks disappears and the key entries are canceled as shown in Fig. 3(d).

Fig. 4 shows two examples of answers. The layout of the

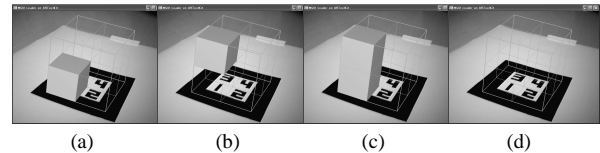


Fig. 3 Block placement ((a):One Click, (b):Two Clicks, (c):Three Clicks, (d):Four Clicks)

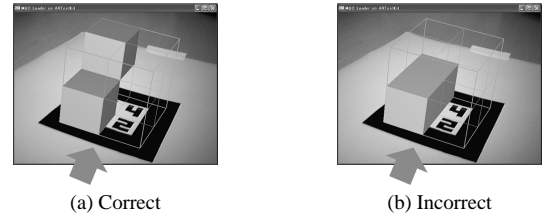


Fig. 4 Answer markers

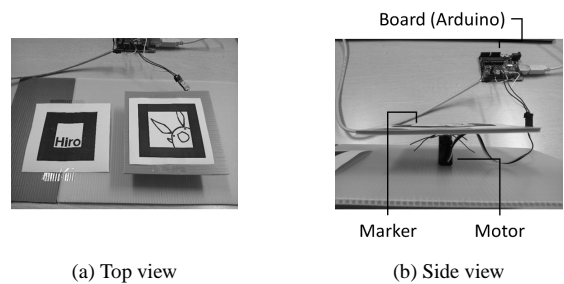


Fig. 5 Views of AR markers installed with the motor

blocks toward the landmark is selected on the answer marker. The correct and the incorrect layouts of blocks are Fig. 4(a) and (b), respectively. When the correct layout is given, the color of the displayed blocks is changed.

These blocks move synchronously with the marker. This method is applied to various rotations of blocks. When a given question is hard to be solved, the marker can be rotated physically with the displayed blocks so that the question becomes easier.

2.3 Improved version of the AR environment

The method described in subsection 2.2 does not take the rotation angle of the AR marker in account, and blocks can be observed from any direction. In this subsection, we improve the first method so that it provides analysis functions for the relationship between the angle and the learning efficiency of students.

The improvement to the AR environment is given by restricting the rotation of the AR marker supported by some hardware module. The hardware module consists of a fixed board (a plastic cardboard), a servo motor RB-001 and an Arduino Uno [2] based substrate. Arduino Uno is used as an A/D converter, which controls the servo motor, and is connected to the host PC via USB interface. Fig. 5 shows an answer marker and a question marker installed with the motor. Fig. 5(a) and Fig. 5(b) show the top and the side view, respectively.

We show the procedure to control the question marker.

- Step-1) Power down the motor
- Step-2) Compute the angle of the question marker
- Step-3) When the angle of the marker does not reach to a given threshold, go back to Step-2)
- Step-4) Start serial communication
- Step-5) Power up the motor

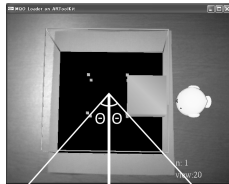


Fig. 6 A view of the angle limitation for a question marker

Step-6) Push back the marker

Step-7) Power down the motor and go back to Step-2)

In Step-1), the question marker can be rotated freely since the motor is off. In Step-2), to compute the angle of the marker, we get the marker coordinate (X_m, Y_m, Z_m) and the camera coordinate (X_c, Y_c, Z_c) . The two coordinates are expressed as

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} r_1 & r_2 & r_3 & t_x \\ r_4 & r_5 & r_6 & t_y \\ r_7 & r_8 & r_9 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix}, \quad (1)$$

where t_x , t_y and t_z are translation elements. $[r_1, r_4, r_7]^T$, $[r_2, r_5, r_8]^T$ and $[r_3, r_6, r_9]^T$ mean directional vectors of x-, y- and z-axis, respectively. Eulerian angles are computed with the directional vectors to be used for the marker angle. In Step-3), the marker angle is compared with a given threshold, which restricts the rotation of markers. When the marker angle reaches to the threshold, serial communication between the host PC and Arduino via USB is started in Step-4). At this point, Arduino is notified of the marker angle violation. So it turns on the motor in Step-5), and controls the motor so that the marker angle does not exceed the threshold in Step-6). When the marker angle becomes less than the threshold, Arduino turns off the motor and wait for the next marker angle violation in Step-7).

Fig. 6 shows a view of the angle limitation for a question marker. The location of the landmark is set to the right direction of the marker unlike in subsection 2.2. The angle limitation is defined as θ ($0 \leq \theta \leq 90$).

3. An experiment to validate the effect of the AR learning

To validate the effect of the trained and resultant spatial reasoning capacity, we perform an experiment using the method described in subsection 2.2. The method is implemented with AR-Toolkit [3] to provide an AR space. Objects in the AR space are displayed by using OpenGL [4].

According to Piaget's stage of cognitive development [5], four cognitive stages, which are a sensorimotor stage, a pre-operational stage, a concrete operational stage and a formal operational stage, are observed. The sensorimotor stage is the period of zero to two years old, where a hidden object can be recognized and the permanence of an object is acquired. The pre-operational stage is the period of two to seven years old, where limited intelligence is developed to symbolize objects so that make-believe games are played. On the other hand, thinking is done without logic. The concrete operational stage is the period of seven to twelve years old, where considerable intelligence is developed through logical and systematic manipulation of objects. Finally, complete intelligence, which is as competent as adults, is estab-

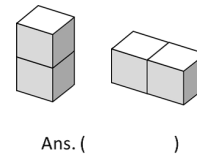


Fig. 7 An example of tests



Fig. 8 A view of the AR learning

lished in the formal operational stage at the age of twelve. The spatial reasoning capacity is developed by training. Since objects, which are generated in the method in section 2.2, are examined and logicized, children in concrete operational stage should be targeted. Therefore, in this experiment, we chose fifth grade pupils of an elementary school. The pupils are in the age of ten to eleven. In the fifth grade, there are 37 boys and 36 girls.

We start the experiment with the hypothesis that the method using AR does not affect the spatial reasoning capacity. The hypothesis is rejected later in this section.

The conditions of the AR learning are classified into three groups. The first group uses the method in Fig. 2, namely "with frame". The second group uses the question marker "without frame". The effect of box frames shown in Fig. 2 is validated by comparing these two groups. Finally, the group of "without learning" does not contain the AR learning phase to validate the effect of AR learning.

The experimental procedure is shown as follows.

Step-I) Paper test 1 (5 min.)

Step-II) AR learning (15 min.)

Step-III) Paper test 2 (5 min.)

In Step-I), the preliminary spatial reasoning capacity is measured using test 1. Fig. 7 shows an example of paper tests. The right-and-left objects are compared and the pupils determine if these objects are same or different. There are 80 questions in each paper test. The paper test 1 is to be completed within 5 minutes. Note that it is not necessary to answer all the 80 questions. In Step-II), the AR learning is performed in 15 minutes. The pupils of the "without learning" group wait 15 minutes without the AR learning. In Step-III), the spatial reasoning capacity is measured using paper test 2 in common with paper test 1. The effect of the AR learning is expected to be validated by this paper test when it is confirmed that Step-I) affects Step-III). These two paper tests are distributed at random.

In this experiment, laptop computers, AR markers and Web cameras are used for the AR learning. The AR markers are freely movable. Fig. 8 shows a view of the AR learning.

We analyze the results of the experiment. The spatial reasoning capacity is to recognize the overview of objects in the three-dimensional space quickly and accurately. The spatial object recognition speed is measured with the response rate (the rate of the response time in all questions). In addition, the spatial

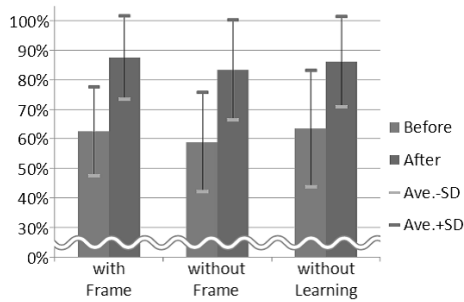


Fig. 9 The response rate

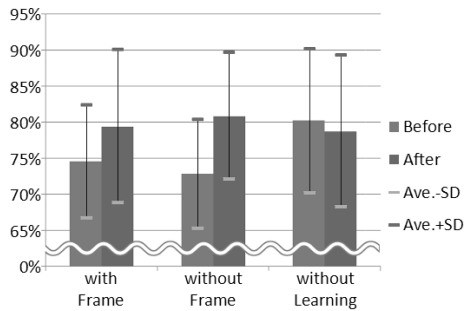


Fig. 10 The accuracy rate

Table 1 Two-way ANOVA

Condition	$F(2, 70)$	A response rate	An accuracy rate
	p	0.54	0.76
<i>before and after</i>	$F(1, 70)$	189.37	14.82
	p	< .001****	< .001****
Interaction	$F(2, 70)$	0.17	8.09
	p	0.84	< .001****

Significant level $p < .001****$

object recognition accuracy is measured with the accuracy rate. Fig. 9 and Fig. 10 show the average response rate and the average accuracy rate, respectively. ANOVA (ANalysis Of VAriance) is used to uncover the attributions and interaction effects. Table 1 shows the result of the two-way ANOVA. Here, F shows the proportion of within-group variance to between-group variance. p shows significance probability. * shows significance level. t is calculated with $\frac{\bar{X}-\mu}{\sqrt{U/n}}$, where n is the number of samples, \bar{X} is the sample average, U is the sample unbiased estimate of variance, and μ is the population mean. One attribution is the conditions for learning (learning with frame, learning without frame, and no learning). Another attribution is “before and after” (Step-I and Step-III)).

In the result of the response rate, “before and after” learning differs significantly ($F(1, 70) = 189.37, p < .001****$). Therefore, the spatial object recognition speed has the possibility to be improved by the tests. In the result of the accuracy rate, “before and after” learning differs significantly ($F(1, 70) = 14.82, p < .001****$). Interaction between “before and after” learning and the learning conditions also differ significantly ($F(2, 70) = 8.09, p < .001****$). Therefore, the interaction should be evaluated. The results of the simple main effect test are shown in Table 2 and Table 3. Significant difference is found in “before and after” learning within the “with frame” ($F(1, 70) = 8.135, p < .01**$) and the “without frame” ($F(1, 70) = 22.083, p < .001****$). So the AR learning affects the accuracy rate among “with frame” and

Table 2 The result of a post-hoc test for “before and after” learning

An accuracy rate	$F(1, 70)$	p
<i>with frame</i>	8.14	< .01**
<i>without frame</i>	22.08	< .001****
<i>without learning</i>	0.78	0.38

Significant level $p < .01**$, $p < .001****$

Table 3 The result of a post-hoc test for learning conditions

An accuracy rate	$F(2, 140)$	p
<i>before</i>	4.13	< .05*
<i>after</i>	0.32	0.73

Significant level $p < .05*$

Table 4 The result of a post-hoc test in “before” learning

An accuracy rate		t	p
<i>without learning</i>	- <i>without frame</i>	2.76	< .01**
<i>without learning</i>	- <i>with frame</i>	2.12	< .05*
<i>with frame</i>	- <i>without frame</i>	0.64	0.53

Significant level $p < .05*$, $p < .01**$

“without frame”.

The learning of “before” differs significantly ($F(2, 140) = 4.13, p < .05*$) in the learning conditions. The result of multiple comparisons in the learning conditions of the accuracy rate is shown in Table 4. The relationship between “without learning” and “without frame” shows significant difference ($t = 2.76, p < .01**$), and the relationship between “without learning” and “with frame” shows significant difference, too ($t = 2.12, p < .05*$). Therefore, it turns out that the group of “without learning” contains more examinees with high spatial reasoning capacity. Namely, the hypothesis is rejected. Thus, the effectiveness of the attribute “with frame” and “without frame” is validated.

As the result of the ANOVA, it is confirmed that the response rate is improved. However, the response rate is improved with any conditions and does not differ significantly. It means that the improvement is not affected so much by the AR learning but the habituation to the tests. Therefore, the spatial object recognition speed is not affected by the AR learning. The accuracy rate is improved by “before and after” AR learning. In the case of the accuracy rate, both of “with frame” and “without frame” are improved while the effect of the box frame is not observed. Thus, the AR learning affects the spatial object recognition accuracy.

4. Experiments for AR marker learning with angle rotation

To study the relationship between rotation angle and the learning efficiency of examinees, we perform other experiments as described in subsection 4.1. In this section, we first investigate the difference between the cases of fixed angle and variable angles for the AR marker by experiment. Then, we explain the experimental results to show the effect of the learning with rotating the AR marker.

4.1 Learning with limited angles

In this subsection, we perform an experiment to investigate the difference between the cases of fixed angle and variable angles. For the experiment, we have 42 examinees who are female students of our university. We start the experiment with the hypothesis that rotation angle does not affect the spatial reasoning ca-

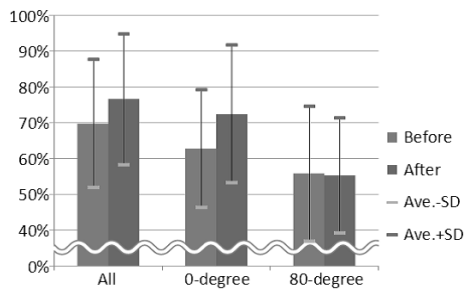


Fig. 11 The response rate in the improved version

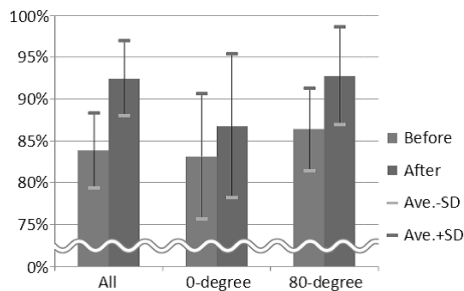


Fig. 12 The accuracy rate in the improved version

Table 5 Two-way ANOVA

Condition	F(2, 39)	A response rate	An accuracy rate
	<i>p</i>	3.86	2.57
<i>before and after</i>	F(1, 39)	< .05*	0.09
	<i>p</i>	12.60	50.85
		< .001****	< .001****
Interaction	F(2, 39)	4.12	2.74
	<i>p</i>	< .05*	0.08

Significant level $p < .05^*$, $p < .001^{****}$

capacity using the method of section 2.3. The hypothesis is rejected later in this section.

The experimental procedure is the same as in section 3. Therefore, just different parts are shown as follows. In step II), the method of section 2.3 is used. The conditions of the AR learning are separated into three groups to investigate the angle rotation effect. The three groups are as follows.

- “all” (zero, twenty, forty, sixty and eighty degrees)
- “0-degree”
- “80-degree”

The first group “all” has limitations of rotation angles (θ in Fig. 6) from zero (cannot rotate) to eighty degrees by twenty degrees. The second group “0-degree” is fixed θ zero degree. Finally, the group “80-degree” is fixed θ eighty degrees.

We analyze the results of the experiment. Fig. 11 and Fig. 12 show the average response rate and the average accuracy rate, respectively. Table 5 shows the result of the two-way ANOVA. One attribution is the conditions for learning (learning all, learning with 0-degree, and learning with 80-degree). Another attribution is “before and after” (Step-I) and Step-III).

As the result of the response rate, “before and after” learning differs significantly ($F(1, 39) = 12.60, p < .001^{****}$). Interaction between “before and after” learning and the learning conditions also differ significantly ($F(2, 39) = 4.12, p < .05^*$). Therefore, the interaction should be evaluated. The results of the simple main effect test are shown in Table 6 and Table 7. Significant difference is found in “before and after” learning within “all”

Table 6 The result of a post-hoc test in “before and after” learning

A response rate	F(1, 39)	<i>p</i>
<i>all</i>	6.89	< .05*
<i>0-degree</i>	13.91	< .001****
<i>80-degree</i>	0.04	0.84

Significant level $p < .05^*$, $p < .001^{****}$

Table 7 The result of a post-hoc test for learning conditions

A response rate	F(2, 78)	<i>p</i>
<i>before</i>	2.14	0.12
<i>after</i>	5.61	< .01**

Significant level $p < .01^{**}$

Table 8 The result of a post-hoc test in “after” learning

A response rate	<i>t</i>	<i>p</i>
<i>All</i> - <i>80-degree</i>	3.16	< .01**
<i>All</i> - <i>0-degree</i>	0.61	0.54
<i>0-degree</i> - <i>80-degree</i>	2.55	< .05*

Significant level $p < .05^*$, $p < .01^{**}$

($F(1, 39) = 6.89, p < .05^*$) and “0-degree” ($F(1, 39) = 13.91, p < .001^{****}$). So the rotation angle seems to affect the response rate in “all” and “0-degree”.

The learning of “after” differs significantly ($F(2, 78) = 5.61, p < .01^{**}$) in the learning conditions. The result of multiple comparisons in the learning conditions of the response rate is shown in Table 8. The relationship between “all” and “80-degree” shows significant difference ($t = 3.16, p < .01^{**}$), and the relationship between “0-degree” and the “80-degree” shows significant difference, too ($t = 2.55, p < .05^*$). Therefore, it turns out that the group of “all” gets considerable learning effects rather than “0-degree”. Namely, the hypothesis is rejected from the fact that the learning flow affects the spatial reasoning capacity. Thus, the effect of the attribute “all” and “0-degree” is validated.

In the result of the accuracy rate, “before and after” learning differs significantly ($F(1, 39) = 50.85, p < .001^{****}$). Therefore, the spatial object recognition accuracy has the possibility to be improved regardless of any rotation angle.

As the result of the ANOVA, the response rate is improved by the “before and after” AR learning. In this case, both of “all” and “0-degree” are improved from the view point of the rotation angle effect. Since this method is to have examinees to image object rotation with ninety degrees, “80-degree” is too much support for such object rotation in mind. Thus, the rotation angle affects the spatial object recognition speed. Furthermore, the accuracy rate is improved with any conditions and does not differ significantly. It means that the improvement is not affected so much by the rotation angle but the AR learning itself. Therefore, the spatial object recognition accuracy is not affected by the rotation angle.

4.2 Learning with various angles

In this subsection, we perform another experiment to study the effect of the AR learning with rotating the AR marker. The examinees are 16 female students of our university. The experimental procedure is shown as follows.

Step-i) Paper test 1 (5 min.)

Step-ii) Paper test 2 (5 min.)

Step-iii) Rotate the AR marker by θ in a random manner

Step-iv) AR learning (3 min.)

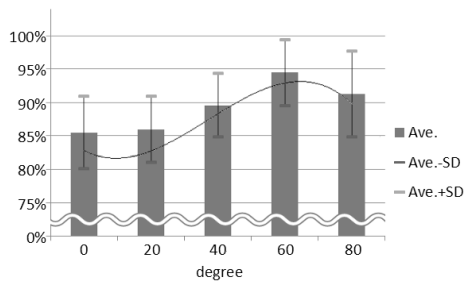


Fig. 13 The relationship between the rotation angle and the accuracy rate

Step-v) Paper test 3 (5 min.)

Step-vi) Terminate, if all angles are selected

Step-vii) Go to step-iii)

In Step-i), the preliminary spatial reasoning capacity is measured using test 1. The test is the same as in section 3. In Step-ii), the spatial reasoning capacity after the test 1 is measured using test 2. In Step-iii), the AR marker is rotated by zero, twenty, forty, sixty and eighty degrees in a random order only once. In Step-iv), the AR learning is performed using the method of section 2.3 for 3 minutes. In Step-v), the spatial reasoning capacity after the learning is measured using test 3. In Step-vi), when all the five angles are examined, the procedure is terminated. Otherwise it returns to Step-iii).

We analyze the results of the experiment to investigate which rotation angle is the most effective. To investigate the relationship between the rotation angle and the accuracy rate, a regression analysis is performed. Fig. 13 illustrates the average accuracy rate and a regression model [6]. This model is expressed as follows.

$$y = -0.12 * 10^{-5} x^3 + 0.13 * 10^{-3} x^2 - 0.22 * 10^{-2} x + 0.86$$

The effect of learning does not change from zero to twenty degrees. The accuracy rate increases for twenty to sixty degrees. Then the accuracy rate shows a gradual decline for eighty degrees. As pointed out in section 4.1, “80-degree” is too much support for such object rotation in mind.

In this experiment, “80-degree” improves the accuracy rate rather than “0-degree”. However, “0-degree” improves the accuracy rate rather than “80-degree” in section 4.1. This result contradicts the result in section 4.1. Therefore, we examine a one-way ANOVA test. One attribution is the rotation angle. In the results of the one-way ANOVA, the relationship among five rotation angles shows significant difference ($F(4, 56) = 8.99, p < .001****$). Therefore, a post-hoc test should be examined. The relationship between “80-degree” and other angles in the results of the multiple comparison is shown in Table 9. There are significant difference between “80-degree” and “0/20-degree”. In the experiment in section 4.1, other angles have no effect with “80-degree”. However in this experiment, the list of the learning is randomly generated, and the other angles are confirmed to be affected. Since the learning of “0-degree” does not support the rotation, the learning itself is difficult. Hence, we conclude that the learning of “0-degree” is an unsuitable angle.

As the result of the analysis, it turns out that the AR learning with sixty degrees as the limitation of angle is the most effective method.

Table 9 Multiple comparisons of angles

Degree	t	p
0 - 80	3.25	< .005***
20 - 80	2.98	< .005***
40 - 80	0.93	0.36
60 - 80	2.05	< .05*

Significant level $p < .05^*$, $p < .005^{***}$

5. Conclusions

In this paper, we proposed new methods to train students’ spatial reasoning capacity using AR. In the AR environment, virtual objects are displayed even in floating and can be moved freely. Students with low spatial reasoning capacity can effectively learn by rotating an AR marker. In the first method, if the rotation of a virtual object in mind is hard, the AR marker can be rotated by arbitrary angle physically. The second method has physical limitation of the rotation.

To validate the effect of the trained and resultant spatial reasoning capacity, we perform an experiment using the proposed method. As the result of the ANOVA, the accuracy rate is improved by “before and after” AR learning. In the case of the accuracy rate, both of “with frame” and “without frame” are improved while the effect of the box frame is not observed. Thus, the AR learning affects the spatial object recognition accuracy.

To study the relationship between rotation angle and the learning efficiency of examinees, we performed two experiments. First, we performed an experiment to investigate the difference among the cases of fixed angle and variable angles. As the result of the ANOVA, the response rate is improved by the “before and after” AR learning. In this case, both of “all” and “0-degree” are improved from the view point of the rotation angle effect. Second, we performed an experiment to study the effect of the AR learning with rotating the AR marker. The effect of the AR learning does not change from zero to twenty degrees. The accuracy rate increases for forty to sixty degrees. Then the accuracy rate shows a gradual decline for eighty degrees. From the result of the analysis, it turns out that the AR learning with sixty degrees as the limitation of angle is the most effective method.

In our future work, we plan to develop an AR tool to train spatial reasoning capacity for understanding 3D objects from opened-up cubes.

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