

Visualizing and Revealing the Difference of Learner's Thought Process and Question Solving Method

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Abstract—The objective of this study is to clarify the difference of each learner's question solving method and thought process as well as confirm the possibility of their visualization. In this study, we conducted an experiment with 13 participants. They were asked to categorize figures that varied in color, pattern, shape, and size into two groups. During the experiment, Participants' eye movements were recorded and their manipulation of figures were logged. The results showed that the participants could be divided into two groups according to the different question solving methods. Differences were observed between the two groups regarding the fixation time. However, no significant differences were observed between the two groups regarding the manipulation logs of figures. These results may suggest the possibility of visualizing the different thought process, as well as question solving method for each learner.

Keywords—*student centric education, thought process, Thinking Style, eye-movement*

I. INTRODUCTION

A. Research Background

Recently, in the field of education, there has been growing emphasis on enhancing the quality of learning by providing opportunities and environments tailored to the unique characteristics of each learner, with the aim of fostering a diverse range of talents and abilities [1]. To realize such an ideal state of learning, it is crucial for educators to teach based on learners' on characteristics [1]. However, there is currently no definitive consensus on which specific characteristics of learner, educators should focus on in their instruction [2].

Previous research has indicated that learners have various methods of understanding and reaching points of comprehension [3, 4]. This research suggests that it's essential for educators to tailor their teaching methods to align with the diverse ways of understanding [3, 4]. However, such as learners in the first grade who have just entered school, at stages where educators and learners have not yet had enough instructional sessions, it takes time for educators to discern a learner's preferred mode of understanding from the learner's behavior while learning. If learners are taught using methods that are appears to be complicated or unclear, potential issues could arise: requiring more time to grasp the content, not achieving thorough understanding especially when study time is limited. Given these perspectives, it is crucial for educators to instruct students in a manner that is easily understandable to them.

B. Research Objective

The objective of this study is to clarify the differences of the question solving method and thought process of each learner in order to identify each learner's way of understanding. As a means of achieving this objective, we considered visualization of each learner's question solving methods and thought process. Therefore, in this study, we will confirm the possibility of visualizing these question solving methods and thought process and explore visualization methods.

II. EXPERIMENT

The stimuli presented to participants, investigation of the participants' individual characteristics, experiment environment, and procedure are shown in II.A-II.D. This experiment was conducted with the approval of the University of Tokyo's Ethics Review Committee (Approval No. 22-416).

A. Stimuli to be presented

To determine the feasibility of visualizing question solving methods and thought process of the participants, a question was presented to the participants. It is known that there are individual differences in whether one is more likely to respond to color or shape[5, 6]. The question was created by authors because questions using figures can reveal differences in the different way of learners' questions solving method. TABLE I showed the parameters [color / pattern / size / shape] of figures. The task required participants to find as many classification criteria as possible. Participants were asked to come up with as many classification criteria as they could.

TABLE I. PARAMETERS OF FIGURES

appearance						
shape	circle	triangle	square	circle	triangle	square
color	blue	red	blue	red	blue	red
pattern	stripe	stripe	solid	solid	stripe	solid
size	height : 1cm width : 1cm			height : 5cm width : 5cm		

Fig. 1 shows an example of the screen displayed to participants during the experiment. The position of the figures was randomly displayed within the frame on the left side of the

screen (Palette) so that they did not overlap. To answer a classification criterion, the participants move the figures to one of the frames on the right side (Group 1 or Group2) to answer the classification criteria.

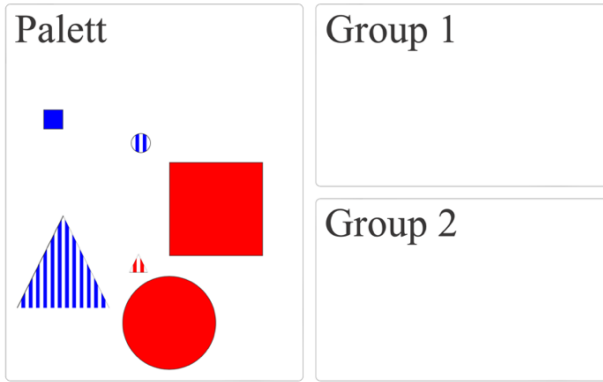


Fig. 1. Example of screen displayed to participants during the work

B. Investigation of Participants' Individual Characteristics

In this study, we examined the relationship between the participants' individual characteristics and their thought process during the question solving work. Therefore, we investigated the participants' Thinking Styles by using an existing questionnaire.

The term "Thinking Style" refers to the concept that individuals differ in how they organize, direct, and manage their own thinking activities. Thinking Style was proposed in the theory of mental self-governance by R. Sternberg (1988) [7]. This theory holds that styles of thinking can be understood in terms of constructs from our notions of government [7]. Thinking Style holds 5 categories and 13 items of thinking styles that are analogous to characteristics such as the form and function of government (TABLE II). Each thinking style is rated on a 7-point scale, with higher numbers indicating a higher tendency to apply. Note that the thinking style of one participant is not classified into one of the 13 categories, but rather each of the 13 items per participant represents the strength or weakness of the tendency. The Japanese version of the Thinking Styles Inventory was used in this experiment [8].

C. Experimental Environment

The experimental environment is shown in Fig. 2. The experiment was conducted face-to-face by a participant and an experimenter. The question solving task was conducted using a tablet (Apple iPad Pro 12.9 inch) placed in front of the participant. The eye movements of the participants during the task were also recorded using an eye-tracker (Tobii Pro Glasses 3). PC was used to explain the experiment and to answer the questionnaire, which is about the experiment.

D. Procedure

The following 1-6 explain the flow of the experiment procedure as experienced by the participants. 13 healthy male and female participants in their 20s to 50s participated in the experiment, all of whom did so of their own free will.

TABLE II. THIRTEEN CATEGORIES OF THINKING STYLE

Dimension	Style	Description
Functions	Legislative	Like to create their own rules.
	Executive	like to follow rules
	Judicial	Like to evaluate rules and procedures
Form	Monarchic	To be motivated by a single goal or need at a time
	Hierarchic	To be motivated by a hierarchy of goals, with the recognition that not all goals can be fulfilled equally well and that some goals are more important than others
	Oligarchic	To be motivated by multiple, often competing goals of equal perceived importance
	Anarchic	To be motivated by a potpourri of needs and goals that are often difficult for themselves, as well as others, to sort out
Level	Global	Prefer to deal with relatively large and abstract issues
	Local	Often like concrete problems requiring detail work
Scope	Internal	Tend to be introverted, task-oriented, aloof, socially less sensitive, and interpersonally less aware than externalists
	External	Tend to be extroverted, people oriented, outgoing, socially more sensitive, interpersonally more aware than internalist
Leaning	Conservative	Like to adhere to existing rules and procedures
	Progressive	Like to go beyond existing rules and procedures

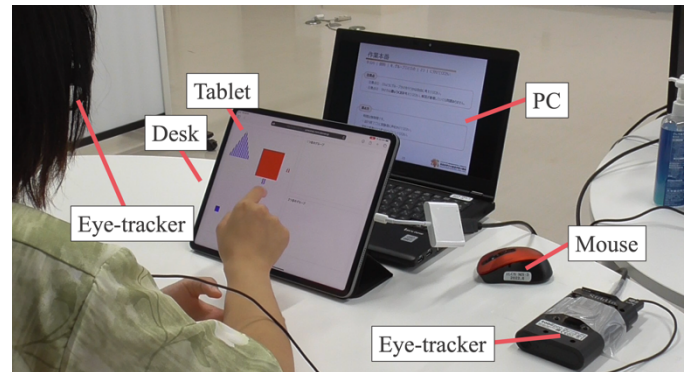


Fig. 2. Experimental environment

1. after receiving an explanation of the objective of the experiment, the participants gave informed consent and signed a consent form.
2. in order to clarify their thought process during the work, they were asked to speak out loud about what came to their minds (thought-speech). After receiving an explanation about thought-speech, the participants practiced thought-speech.
3. participants wore eye tracking devices.
4. after receiving an explanation about what the participants themselves would be working on, they practiced the task and answered on the actual question. During the task, they were instructed to "think freely about the classification criteria", "come up with as

many classification criteria as you can”, and “time is unlimited”.

5. after the task was completed, the participants were asked to describe specifically the criteria they classified for each of the multiple answers they performed.
6. after removing the eye-tracker, the participants answered questionnaires about the experiment and Thinking Style Inventory.

III. ANALYSIS AND RESULTS

In order to clarify the differences in question solving methods among participants, we analyzed the participants’ answers and the interview results in experimental procedure. In addition, to clarify the differences among each participant’s thought process and to confirm the possibility of visualizing the thought process, we analyzed eye movement data and figure manipulation log data. Furthermore, with the aim of clarifying the relationship between the question solving method and individual characteristics of each participant, we analyzed the relationship between the answers of the question and Thinking Style [8]. These results are shown in III.A-D. Note that 2 of the 13 participants were excluded from the analysis because their answers were not able to meet the instructions.

A. Participants’ Answer

A total of 97 answers were obtained from 11 participants. After organizing the obtained answers based on the classification criteria, the participants were classified into two groups. Fig. 3 shows the participant groups and example of answers. The top and bottom of each example in the Fig. 3 represents one answer of one participant.

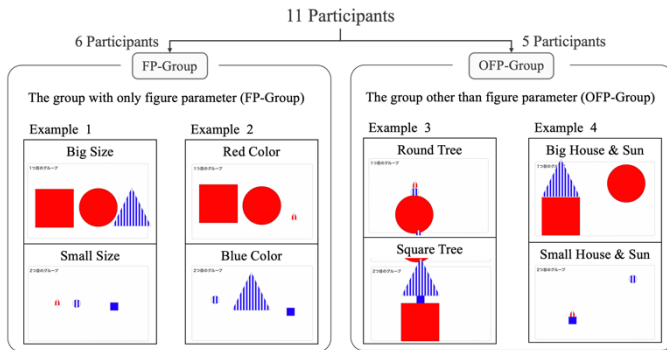


Fig. 3. The participant groups and example of answers

The first group gave answers that were related to the parameters as shown in TABLE I, such as color, pattern, size, and line or corner of the figure (6 out of 11 participants). The answers related to the figure parameters include [answers with only one parameter / answers with multiple parameters]. Here after, this group will be named as “the group with only figure parameter (FP-Group)”. The second group gave answers that were not only relating the figure parameters in addition to the answers related to the figure parameters (5 out of 11 respondents). Specifically, it includes four types of answers:

[answers related to the combination of figures / answers related to the characters / answers related to the visual impression of the figure / answers related to the positional relationship of the figure]. Here after, the groups will be named as the group other than figure parameter (OFP-Group).

B. Gaze Data

To confirm the possibility of clarifying the difference and visualizing of the participants’ thought process, we analyzed eye movement data during solving the question.

First, the data were preprocessed to remove gazing due to the ease of visibility immediately after the figure appeared on the screen. According to experimental studies of the human visual information processing process, it is known that it takes about several tens of ms per object to recognize objects of different colors, sizes, and orientations [9]. Therefore, we excluded data from the interval up to 1 s after the figure was presented, considering that gazing due to ease of visibility would occur.

Next, fixation points were extracted from the gazing point data. First, to remove saccades from the data, we set the threshold value of angular velocity 30 deg/s between adjacent frames. Then, we considered data that exceeded the threshold value as saccades and data that fell below the threshold value as candidate fixation points. It is known that in the state of showing interest in a specific object, fixation of 300 ms or longer are often observed [10]. Therefore, in this paper, we defined the fixation point as less than 30 deg/s and longer than 300 ms.

Additionally, we set seven areas of interest (AOIs): one for each of the six figures termed as figure area and one for the screen area where no figure was displayed, termed as the non-figure area.

Fig. 4 shows the result of the calculated percentage of fixation time in the figure and non-figure area for the AOIs.

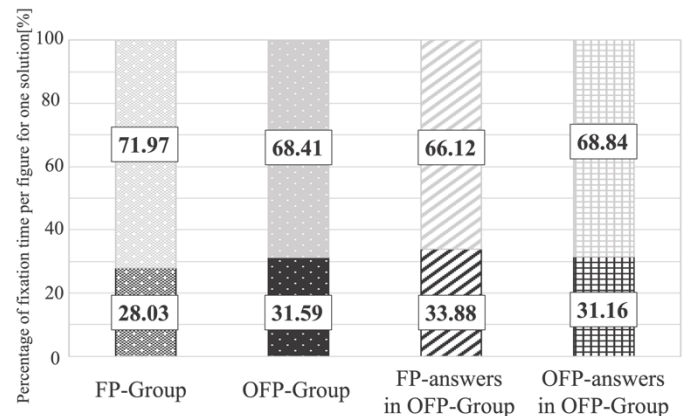


Fig. 4. Percentage of fixation time between figure and non-figure areas

Fig. 4 shows the followings from left to right: FP-Group, OFP-Group, answers with only figure parameters in OFP-Group (here after FP-answers in OFP-Group), answers other than figure parameter in OFP-Group (here after OFP-answers in OFP-Group). As a result, no difference was found in the percentage of fixation time among the 4 groups. These results

may indicate that differences in question solving methods do not cause distinctions between the percentage of fixation time in the figure and non-figure areas.

Fig. 5 compares the percentage of fixation time per shapes to the total fixation time of solving questions.

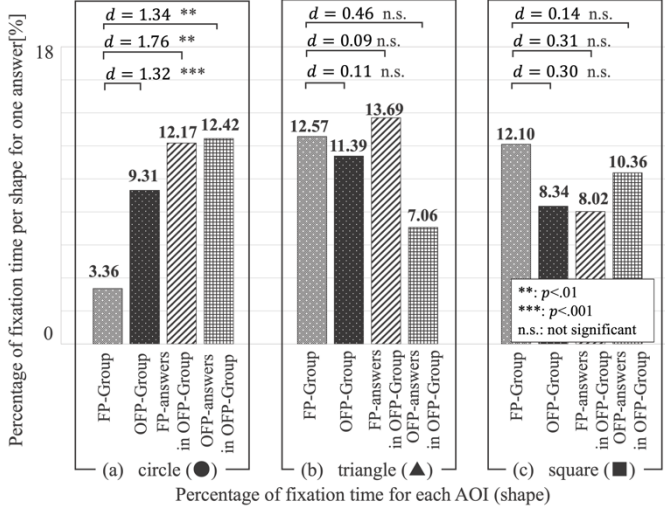


Fig. 5. Percentage of fixation time for each shape to the total fixation time for one answer

As shown in “a” frame in Fig. 5, the percentage of fixation time of the circle were compared between [FP-Group and OFP-Group], [FP-Group and FP-answers in OFP-Group], and [FP-Group and OFP-answers in OFP-Group]. As a result, there were significant differences respectively.

In addition, the percentage of fixation time of the circle, the triangle and the square in the FP-group was compared. There was significant difference between the circle and the triangle ($t(5) = -4.07, p = .01, d = 1.32$) (showed in FP-Group in “a” frame and FP-Group in “b” frame in Fig. 5). There was also significant difference between the circle and the square ($t(5) = -3.37, p = .02, d = 0.11$) (showed in FP-Group in “a” frame and FP-Group in “c” frame in Fig. 5). On the other hand, there was no significant difference between the triangle and square shapes (showed in FP-Group in “b” frame and FP-Group in “c” frame in Fig. 5). These results suggest that the percentage of fixation time for angular shapes was higher than for circular shapes in the group with only figure parameter group.

In addition, the percentage of fixation time of the circle, the triangle and the square in the OFP-group was compared. there were no significant difference between the circle and the triangle (showed in OFP-Group in “a” frame and OFP-Group in “b” frame in Fig. 5), the circle and the square (showed in OFP-Group in “a” frame and OFP-Group in “c” frame in Fig. 5), and the triangle and the square (showed in OFP-Group in “b” frame and OFP-Group in “c” frame in Fig. 5). This suggests that there is no difference in the percentage of fixation time for circle, triangle, and square shapes in the groups other than the shape parameter.

C. Manipulation log data for figures

To confirm the possibility of clarifying the difference and visualizing of the participants’ thought process, we analyzed manipulation of figures log data during figure classification task. At every 1 time stamp (120 fps), data on [coordinates of the finger on the screen / index of the figure being touched / center coordinates of the figure being touched] were constantly acquired while the finger was touching the figure. From the acquired data, the average movement distance, average movement time, and average movement speed per one answer were calculated for each of a total of six figures. The difference of x-component and y-component of the center coordinates of the figure between in the i frame and the $i + 1$ frame are ds_{x_i}, ds_{y_i} respectively. The moving distance of one figure is the following equation.

$$\sum_{i=0}^N \sqrt{(ds_{x_i})^2 + (ds_{y_i})^2} \quad (1)$$

Also, if the time difference between the time stamps in the i and $i + 1$ frames is denoted as t_i , the average movement speed per figure can be expressed by the following equation.

$$\frac{1}{N} \sum_{i=0}^N \sqrt{\left(\frac{ds_{x_i}}{t_i}\right)^2 + \left(\frac{ds_{y_i}}{t_i}\right)^2} \quad (2)$$

Based on these metrics, the average number of touches, average touch time, average movement distance, and average movement speed per figure per answer were calculated for both groups, resulting in TABLE III below.

TABLE III. GROUP COMPARISON OF LOGGED DATA PER FIGURE PER ANSWER

parameter	FP-Group		OFP-Group		Statistics
	M	SD	M	SD	
Touch count *	10.17	8.11	9.85	4.40	$p = .89, d = 0.02$
Touch time * [s]	0.89	0.27	0.88	0.26	$p = .95, d = 0.01$
Distance * [px]	568.86	68.58	603.48	88.03	$p = .49, d = 0.19$
Velocity * [px/s]	340.13	114.39	467.59	114.40	$p = .17, d = 1.48$

* Average per solution per shape

As a result, there were no significant differences between FP-Group and OFP-Group in any of the metrics. In addition, two types of manipulations were observed during the question solving process: moving the figure only within on the palette flame shown in Fig. 1 and moving the figure from the palette flame of Fig. 1 to one of the two frames (Group1 or Group 2) on the right side. The data in TABLE III contains a mixture of the

two types of data. To focus more on the pre-solution data, we extracted only the movements that move the figure only within the frame on the pallet, and calculated the metrics shown in TABLE III. As a result, there were no significant differences between FP-Group and OFP-Group in any of the metrics.

D. Mean Score of Thinking Style

From the results of III.A, we compared the mean scores of each Thinking Style between group A and group B (Fig. 6). As a result, a significant trend was confirmed for the Hierarchic style tendency ($t(7) = -2.12, p = .07, d = 0.39$). No significant differences were found for the other 12 items.

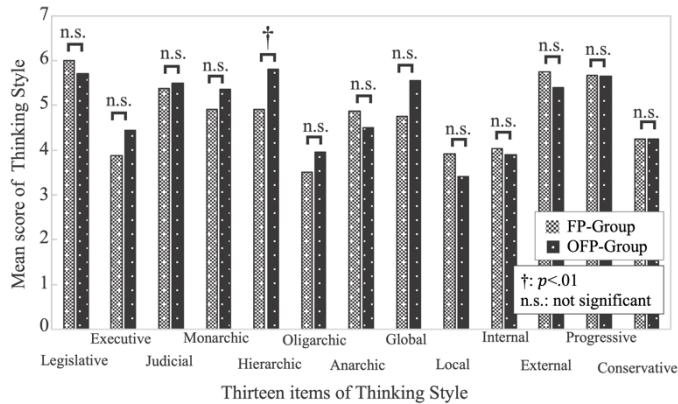


Fig. 6. Mean score of Thinking Style

IV. DISCUSSION

The results of III.A, two groups (the group with only the figure parameters and the group other than the parameter of the figure) were identified based on the different solution methods for one problem.

The results of III.B confirmed a significant difference between groups in the percentage of fixation time between circular and angular shapes in FP-Group and OFP-Group. According to previous research, it is known that those who prefer a confrontational conflict approach prefer angular shapes, while those who prefer a compromise approach prefer rounded shapes [11]. Based on these results, we hypothesized that the differences in solving approaches might be expressed in shape preferences, i.e., significant differences in the percentage of fixation time between rounded and angular shapes in the thought process.

On the other hand, it is possible that factors such as ease of visibility due to the color, patterns and corners of shapes may have influenced the percentage of fixation time for each figure. In this experiment, it was difficult to analyze the results after removing these factors. Therefore, it will be necessary to clarify the differences in question solving methods and thought process among learners by conducting experiments using shapes with limited parameters after removing colors and patterns. Based on the results of III.B., it is possible that the percentage of fixation time at each shape can be used as an indicator for clarifying the differences and visualizing the thought process of each learner.

From the results of III.C, no significant difference between groups was confirmed in the manipulation logs of figures in the groups A and group B. One possible reason for this is that the manipulation of figures may reflect the result of thinking rather than the thought process. Therefore, the manipulation logs of figures are considered not an appropriate mean to reveal differences and to visualize the thought process of each learner.

From the results of III.D, differences were identified in one item of thinking style depending on the different solving methods. This suggests that relationship between different solving methods and thinking styles might exists.

V. CONCLUSION AND FUTURE WORK

In this study, we conducted an experiment to categorize figures that varied in color, pattern, shape, and size into two groups in order to clarify the difference of each learner's question solving method and thought process and to confirm the possibility of their visualization. As a result, we confirmed the possibility of visualizing the different question solving methods and thought process of each learner and clarifying the differences between them.

In this study, the experiment was conducted on subjects over 20 years old. However, to realize a learning environment that matches the different comprehension methods of each learner in actual school education, it is necessary to conduct experiments with elementary school children and accumulate findings. Therefore, it is considered necessary to conduct experiments with elementary school children to verify the possibility of visualizing the solution method and the thought process leading up to the solution method for each participant and whether the differences can be confirmed.

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