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The Influence of Different Representations on Solving Concentration Problems at Elementary School

Chia-Ju Liu · Ming-Hsun Shen

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Abstract This study investigated the students' learning process of the concept of concentration at the elementary school level in Taiwan. The influence of different representational types on the process of proportional reasoning was also explored. The participants included nineteen third-grade and eighteen fifth-grade students. Eye-tracking technology was used in conducting the experiment. The materials were adapted from Noelting's (1980a) "orange juice test" experiment. All problems on concentration included three stages (the intuitive, the concrete operational, and the formal operational), and each problem was displayed in iconic and symbolic representations. The data were collected through eye-tracking technology and post-test interviews. The results showed that the representational types influenced students' solving of concentration problems. Furthermore, the data on eye movement indicated that students used different strategies or rules to solve concentration problems at the different stages of the problems with different representational types. This study is intended to contribute to the understanding of elementary school students' problem-solving strategies and the usability of eye-tracking technology in related studies.

Keywords Representations · Concentration concept · Science learning · Elementary school students

C.-J. Liu (✉)
Director of Neurocognition Lab, National Kaohsiung Normal University, 62 Shenjhong Rd., Yanchao, Kaohsiung 82444, Taiwan
e-mail: chiaju1105@gmail.com

M.-H. Shen
National Kaohsiung Normal University, 62 Shenjhong Rd., Yanchao, Kaohsiung 82444, Taiwan

Introduction

Many of our daily decisions and situations are related to science concepts. For instance, we decide what to wear by measuring and comparing day-to-day temperatures. Concepts of science are often related to intensive or extensive quantities, a concept best explained by Piaget (1952). Piaget defined extensive quantity as "the name given to any magnitude that is susceptible of actual addition." For example, time, weight, mass, and capacity represent extensive quantity because they can be gauged by measurements. Intensive quantity was defined as "the name given to any magnitude that is not susceptible of actual addition," such as temperature or concentration. These quantities often cause misconceptions in elementary school students.

The concept of concentration is especially difficult for elementary school students because it is complex, and students are used to perceiving concentration with their senses, which is not always effective or appropriate (Stavy and Tirosh 2000). Students must use scientific reasoning to understand the concept of concentration. For instance, students are given the following condition: "There were three cups of orange juice of the same concentration, and then the juice in two of them was poured into an empty new cup". The teacher then asked the students, "Now, is the juice in the new cup sweeter?" This problem is related to the concept of concentration. When students estimate the concentration of the solution, they may use different reasoning skills such as proportional reasoning of quantity or intuitive rules. This study aimed to investigate the development of proportional reasoning and the strategies used in solving concentration problems among elementary school students.

The development of proportional reasoning was extensively studied by Inhelder and Piaget (1958). They concurred that students must possess mathematical knowledge such as numerical relationships, numerical operations, and reasoning to acquire the concept of proportion. Stavy and Tirosh (2000) stated that the concept of proportion is widely used in the acquisition of both science and mathematics concepts needed in daily life. Proportion could be defined as an equality of two ratios, namely, $\frac{a}{b} = \frac{c}{d}$. Assessment tests of proportion are most frequently in the form of comparison of the two ratios. For example, one cup of sugar water consisted of 2 teaspoons of sugar and 3 teaspoons of water, whereas the other cup of sugar water consisted of 1 teaspoon of sugar and 3 teaspoons of water. Students were asked whether the concentration of these two cups would be the same. When students tried to solve the problem, they could represent the numerical relation in the form $\frac{2}{3} \square \frac{1}{3}$to reason which cup was sweeter. The $\square$ is for students to fill in the relationship between these two ratios: is $\frac{2}{3}$ is greater than (>), less than (<), or equal to (=) $\frac{1}{3}$? In fact, comparison is commonly used in our daily lives. Studies on students' development of their basic understanding and concepts of science are primarily focused on comparison tasks (Stavy and Tirosh 2000). Stavy et al. (1982) conducted a study on children between the ages of 6 and 10 with respect to their understanding of the concept of concentration. The children were asked to judge the sweetness (concentration) of a cup mixed with two cups of orange juice and one cup of water. It was found that a significant number of children claimed that the combined water was sweeter. Their reasoning was that "more water means more sugar" and, therefore, "more sugar, sweeter." This study suggests that children tend to use intuitive rules to explain and understand concentration.

In Taiwan, students in elementary schools are familiar with numerical computation. Therefore, different representations may affect students' problem solving when the problem is presented in text. The application of intuitive rules to proportional reasoning may be enhanced when the problems are presented in different modes or representations For example, students may apply the fractions or the ratios in their problem solving when the problems are displayed in graphic representations. The intuitive rule could be activated not only by obvious perceptual differences but also by salient differences between symbols associated with perceptual images (Stavy and Tirosh 2000). Hence, this study aimed to investigate the conceptual learning of concentration in different relations of quantities and representational types among third-grade and fifth-grade students.

Concentration is an abstract concept for elementary school students. In Taiwan's school curriculum, problems of concentration are usually displayed in various representations. Using different representations has been proven critical for the effective diffusion of science concepts (Ametller and Pintó 2002; Mathewson 1999). Many studies have suggested that scientists use different representations not only to promote student understanding of scientific phenomena but also to share and teach science knowledge in classrooms (Kozma 2003; Schnotz and Kulhavy 1994; van Sommeren et al. 1998). Furthermore, representations help students consolidate abstract concepts: representations can display multiple relationships and processes that are difficult to describe with text alone (Patrick et al. 2005). Therefore, employing different representations of the same concept can enhance students' thinking processes in their acquisition of science knowledge. To further understand students' problem solving processes using various representations, the method of eye-tracking was adopted for this study.

Just and Carpenter (1984) proposed the eye-mind hypothesis, that is, they found that there is a correlation between what a person is looking at and what he/she is thinking. Based on this eye-mind hypothesis, Anderson et al. (2004) hypothesized that eye movement could be studied to understand cognition. It was determined that when students are solving problems, different types of representations (textual or graphic) lead to and engage different cognitive mental processes (Kozma and Russell 1997; Kozma 2003; Seufert 2003). Students with little prior knowledge were found to focus on surface visual features of a representation to build their understanding of a concept (Seufert 2003). However, representations may lead to misconceptions being formed by students (Hegarty et al. 1991; Linn 2003). Furthermore, students with little prior knowledge were less able to transform representations to their understanding of a given concept (Kozma 2003; Kozma and Russell 1997). These various methods of cognition, according to the eye-mind hypothesis, can be detected through eye-tracking technology. Many researchers have used eye tracking to investigate the viewing of graphics and text (Hegarty et al. 1991; Rayner et al. 2001; Tai et al. 2004). Hence, eye-tracking technology was adopted for this study to distinguish the assistance and obstacles associated with different representations, and their effects on students' problem solving. By recording students' eye movements, eye-tracking technology allows for the identification of the exact location of their point of gaze, thus indicating acquisition-assisting graphic representations for students as they engage in the learning of science (Slykhuis et al. 2005).

This study intended to determine how students perceive concentration problems and which strategy they might adopt to solve those problems. Researchers have not yet come to an agreement on the correlation between the display of problems (in graphic or numerical representations) and the problem-solving strategies used by students. Steffe and Parr (1968) have found that the design of a problem on concentration is not related to students' problem-solving strategies. Noelting (1980b), however, argued that students

Table 1 The sample and quantity relation of three stages of problems

Stage	Example	Quantity relation: (a, b) vs. (c, d)
(I) Intuitive	(3, 4) vs. (2, 2)	$\{a<c, b<d \ \& \ a<b, c=d\}$
(II) Concrete operational	(1, 2) vs. (2, 4)	$\{\frac{m}{n}a=c, \frac{m}{n}b=d \ \& \ na\neq b, nc\neq d\}$
(III) Formal operational	(2, 7) vs. (3, 5)	$\{ma\neq c, mb\neq d \ \& \ na\neq b, nb\neq d\}$

could use different strategies to solve the "orange juice test" problem because of the numerical relationships. Hence, this study utilized a modified form of Noelting's (1980a) "orange juice test" to investigate the relationship between students' perception of the concentration problems and the problem-solving strategies they used. This test comprised three stages, and each stage consisted of comparing the taste of orange juice in two cups (see Table 1). In this study, the three stages were (I) the intuitive stage, (II) the concrete operational stage, and (III) the formal operational stage.

The aim of this study was to explore elementary school students' problem solving strategies on solving concentration problems with different representational types. To that end, the following problems were posed: First, how can the representational types affect elementary school students' problem solving? Second, what strategies used by elementary school students of different grades were helpful in solving concentration problems?

Methodology

Participants

The participants of this study were thirty-seven elementary school students: nineteen third-grade students (mean age ± SD = 9.0 ± .1) and eighteen fifth-grade students (mean age ± SD = 11.0 ± .1). All students had taken and passed a visual acuity test, and their eye movements were calibrated on a computer screen prior to the test. Participants were seated approximately 70 cm away from the computer monitor. After calibration, participants were presented randomly-generated stimuli and asked to verbally answer which one (A or B) had a higher concentration of orange juice.

Experimental Design and Material

The materials were adapted from Noelting's "orange juice test" experiment. It consisted of three stages of problems: intuitive, concrete operational, and formal operational stages. Each problem was displayed in the form of iconic and symbolic representations (see Table 2). For example, the problem at the intuitive stage is posed as "(A) There is a mixture of three cups of orange juice and four cups of water. (B) There are two cups of orange juice and two cups of water. Which one is more highly concentrated?" This question was also designed and presented in iconic and symbolic representations as were all other questions. Hence, there were 2 (types of representation) × 3 (stages of problem) experimental conditions. Each condition was presented in three stages in two types of representation and

Table 2 Display of the problems

<table>
<tr><th rowspan="2">Stage</th><th colspan="2">Representation types</th></tr>
<tr><th>Iconic</th><th>Symbolic</th></tr>
<tr><td>Intuitive stage</td><td>
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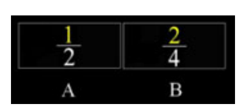
<tr><td>Concrete operational stage</td><td>
</td><td>
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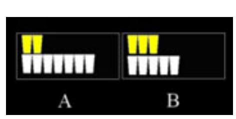
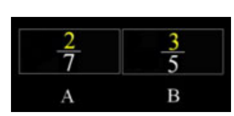
<tr><td>Formal operational stage</td><td>
</td><td>
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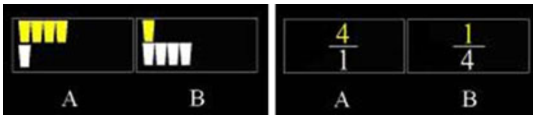


Fig. 1 Samples of stimuli: **a** iconic form, and **b** symbolic form

designed using varying quantity relations. Each condition, therefore, included 8 questions for a total of 48 problems.

The two pictures of the same problem (shown in Fig. 1) have different meanings for elementary school students. The left picture displays the ratio in iconic form: the yellow cup contains orange juice, and the white cup contains water. The ratio displayed in the picture on the right represents the symbolic form. On the right, the cups of orange juice and water were represented in numbers (symbolic representations). That is, in Fig. 1, the picture on the left is an iconic representation showing two choices (A and B). A shows four cups of orange juice and one cup of water; B shows one cup of orange juice and four cups of water. The picture on the right is a symbolic representation of the same problem. That is, $\frac{4}{1}$ indicates that there are four cups of orange juice and one cup of water, and $\frac{1}{4}$ indicates that there is one cup of orange juice and four cups of water. This study used these two types of representations to show the numerical relationship in problems of concentration. All participants were required to solve these 48 problems as they were randomly generated on a screen. They were asked to identify which one had a higher concentration; they pressed a response button and then answered aloud. Students' spoken answers were recorded, and the fixation durations of eye movements were detected by the eye-tracking system.

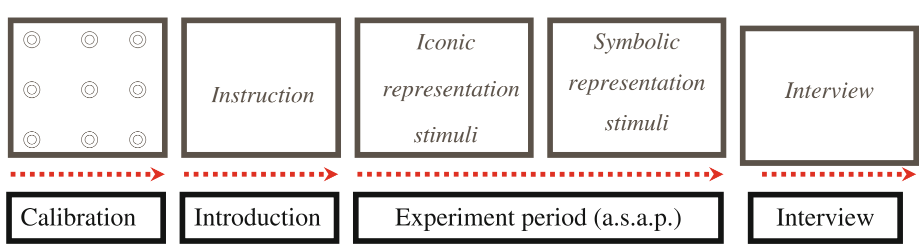
Instrument

The iView X RED eye-tracking system included two monitors and one infrared camera. One monitor (SAMSUNG 920N) was used for presenting stimuli to participants, and the other monitor (SAMSUNG 9438) was for researchers to control the experiment. The monitor resolution setting was 1,024 × 768 pixels, and the refresh rate was 75 Hz. The eye movement sample rate was 60 Hz. The data from the experiment were collected using the SMI Experiment Center program.

Experimental Procedure

In this research, an eye-tracking experiment was designed to explore the impact of types of representations and age differences on the concentration problem solving of the ratio concept at the elementary school level, specifically among third- and fifth-grade students. The problems in the "orange juice test" were displayed in two types of representations on the monitor and the eye movement of the participant was recorded by eye-tracking technology. To confirm the strategies the participants used in problem solving, post-test interviews were conducted. Hence, the procedure of this study involved four phases (see Fig. 2). The first phase was a calibration test to insure the reliability of the eye-movement data. At the beginning of the experiment, each participant had to undergo a visual acuity test to calibrate the position of the eye. Each participant had to pass the calibration test before their eye-tracking data were collected. In the second phase, we explained the purpose of this study to participants and demonstrated how to respond to the problems on the screen. Each participant practiced how to press the button until he/she felt comfortable with the procedure. In the third phase, each participant solved 48 problems that were randomly generated on the monitor. They answered the problems displayed on the monitor while their eye-movements were being recorded. All participants solved problems of three stages and two types of representations. In the fourth phase, at the end of the experiment, an interview was conducted to ascertain the thinking processes of the participants. During the interview, the participant explained why he/she made a particular move and what he/she was thinking at that time. The data of the participants' eye movements were used in the interview to help the students recall what they were thinking, what they did, and what they felt as they were watching a particular part of the screen. Participants were also requested to complete a short questionnaire about the strategies they used in solving the problems. For example, "What types of strategy was more useful for solving the problem?"

Fig. 2 The procedure in this study (four phases)



Analysis Method

Eye-movement data included eye fixation paths, a video of gaze overlay, and the data of the gaze location with statistical calculations. During the experiment, when the participant's eyes stayed in one location for 200 ms or more, we defined it as "a fixation". Fixation is considered as an indicator of perceived points of interest, and the duration of fixation indicates the cognitive complexity of information being acquired (Henderson and Hollingsworth 1998). Slykhuis et al. (2005) suggested that the total numbers and the duration of fixation within a region can be considered an indicator of perceived importance accompanied by a high probability for long-term memory encoding. Chang et al. (1985) indicated that when an individual fixates at some area, that area is salient, surprising, interesting, or important. It has also been determined that fixation counts are related to the number of components that the individual had to process (Goldberg and Kotval 1999). Therefore, the duration or counts of fixation may actually be a better indicator of the student's focus areas. This study proposed that students take a strategic approach when solving concentration problems according to their acquired visual information. They gazed at the regions of the problem where they could extract the most relevant information for solving the problem.

Repositioning the fovea from the current object to a new direction is called saccade (Duchowski 2003). Data analysis of eye movement in this study focused on these Areas of Interest (AOI). The AOI was defined as the cups of orange juice in the left (L-up), the cups of orange juice in the right (R-up), the cups of water in the left (L-down), and the cups of water in the right (R-down) (see Fig. 3). This study analyzed the indicators of eye movement, for example, fixation, saccade, and blink in defined AOIs. Eye-tracking data collected the counts and duration of indicators of eye movement in AOI. Moreover, this study defined that the total fixation duration (TFD) is the average time of all fixation duration. The average fixation duration (AFD) is the quotient of fixation duration divided by fixation count in each problem. These defined indicators in data analysis are useful for interpreting the results.

In addition, an interview was conducted immediately after completing the experiment. Many studies confirmed the effectiveness of combining eye movement data with verbal protocols (Mackworth and Morandi 1967; Von Keitz 1988). Whereas eye tracking provided one possible insight on problem solving, interviews were found to be a more interpretive source of information on the usefulness and quality of the problem solving. All participants were asked to explain how they compared the two ratios and what strategies they used to solve the problems in iconic or symbolic representations.

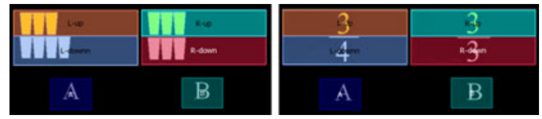


Fig. 3 Sample pictures of AOI in iconic and symbolic representations

Results

The Correct Rates Reflect the Performance of Problem-Solving

To answer the research questions, this study analyzed the correct rate of problem solving over three stages of the problems and two representational types. This study employed a 2 (representational types) by 3 (stages of problem) by 2 (age groups in the third and the fifth grades in elementary schools) experiment design. The first two factors were within-subjects variations. The analysis of variance showed a significant effect on stages of problems $F(2, 34) = 31.69$, $p < .05$, $\eta^2 = .651$ but no significant effect on the representational types $F(1, 35) = 2.33$, $p = .135$, $\eta^2 = .063$ or school year $F(1, 35) = 4.089$, $p = .05$, $\eta^2 = .105$. None of the interactions were significant except the interaction between the representational types $\times$ the stages of problems $F(2, 34) = 8.54$, $p < .05$, $\eta^2 = .334$. Thus, it can be concluded that students had different performance levels for solving problems because of the different stages of the problems. Stages of problems, especially the concrete operational stage, impacted students' problem solving. Figure 4 illustrates students' correct rates of problem solving in different representational types and stages of problems.

As illustrated in Fig. 4, fifth-grade students had higher correct rates of solving the problem at the intuitive and the concrete operational stages than did third-grade students, but students of both grades had similar correct rates at the formal operational stage with iconic representations. Most of the students' correct rate of solving problems with

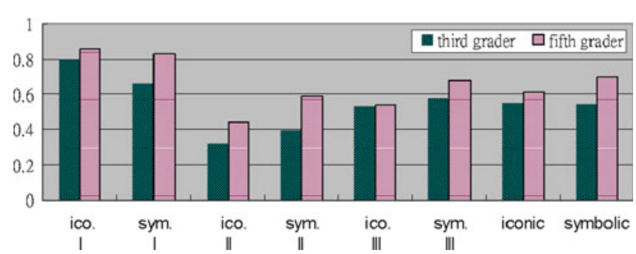


Fig. 4 Differences of correct rate between third graders and fifth graders. *Note* ico. stands for iconic representation; sym. stands for symbolic representation; I stands for the intuitive stage; II stands for the concrete operational stage; III stands for the formal operational stage

symbolic representations was higher at the concrete operational and formal operational stages. At the intuitive stage, however, the results were opposite. This result suggests that students were extremely influenced by the representational types when they were solving problems at the intuitive stage. Overall, both groups of students had the highest correct rate at the intuitive stage; a moderately high correct rate at the formal operational stage; and the lowest correct rate at the concrete operational stage. This result did not correspond to Noelting's conclusion that states problems at the concrete operational stage are easier for children than those at the formal operational stage. In this study, the correct rate of concrete operational items was lower than that of formal operational items, particularly for third-grade students. Therefore, this study further analyzed the eye-tracking data to investigate the differences between students of different grades.

The Eye-Tracking Data Reflect the Strategies of Problem-Solving

To further distinguish the differences between the students of the two grades, this study analyzed three eye-tracking indicators: Fixation duration (FD), Saccade duration (SD), and Blink Duration (BD). This part of the study analyzed the differences in concentration problem-solving between third- and fifth-graders by the sum of FD, SD and BD.

First, there were certain differences in the eye-tracking indicators between students of the two grades. These results are presented in Table 3. Table 3 shows that Total Fixation Duration (TFD) and Total Blink Duration (TBD) were significantly different between the two grades with TFD: $t\ (35) = 7.285$, $p < .001$; and TBD: $t\ (35) = -4.594$, $p < .001$ by t test. The TFD of third-grade students was significantly longer than that of fifth-grade students, but the TBD of fifth-grade students was significantly longer than that of third-grade students. The time of the TFD further indicated that third-grade students spent more time gazing at AOI as they solved the concentration problems. However, third-grade students had shorter blink duration than did fifth-grade students. A comparison of the Total Time (TT) was also employed. TT is the duration of time from the beginning of the student's gaze at AOI to their signal to continue to the next question, that is, the average time of solving 48 problems. Total time for problem solving also indicated a significant difference with TT: $t\,(35) = 4.209$, $p < .001$. This finding suggests that the third-grade students spent more time solving problems than did the fifth-grade students. According to the post-test interview data, most fifth-grade students used numerical computation to solve problems while the third-grade students were more inclined to compare the quantities in fractions to solve the problems. Hence, we concluded that the average time third-grade students spent solving all problems was longer than the average time for the fifth-grade students. This result corresponds to the developmental stages of the children.

Second, an analysis of the eye-tracking indicators was performed using a 2 (grades) $\times$ 2 (representational types) repeated-measurement ANOVA. These indicators included AFD, ASD, and ABD. The results are shown in Table 4. The main effect of fixation duration between iconic and symbolic representations was significant ($F = 6.16$, $p < .05$, $\eta^2 = .146$). The main effect of blink duration was found to be $F = 9.713$, $p < .01$, $\eta^2 = .212$, revealing that the duration of blink in fifth-grade students was longer than that for third-grade students. None of the interactions was significant. In Table 4, the results show that the time to solve problems displayed in symbolic representations was longer than the time spent solving problems in iconic representations. Representational types impacted students' thinking processes on how to solve problems. It was thus inferred that AFD and ABD are related to students' problem solving.

To investigate which strategy or rule students used to solve problems, the numbers of fixation were analyzed with correlation statistics. As shown in Fig. 5, the analysis of AOI was defined as six directions of fixating the picture. In other words, students were comparing the cups of orange juice as they were fixating on the AOI between L-up and R-up. In Table 5, results show that third-grade students tended to compare the difference between the orange juice (D1) and the water (D3). Third-grade students used the same rule to solve concentration problems in iconic and

Table 3 The difference in indicators between third graders and fifth graders

	Third-grade students Mean (SD)	Fifth-grade students Mean (SD)	t	p
Total fixation duration [ms]	4,788 (4,262)	3,770 (3,030)	7.285*	.000
Total saccade duration [ms]	431 (465)	450 (589)	−1.025	.306
Total blink duration [ms]	450 (895)	631 (1,261)	−4.594*	.000
Total time [ms]	6,050 (5,081)	5,060 (3,919)	4.209*	.000

* $p < .001$

Table 4 Two-way ANOVA of different dependent variables (Average Fixation Duration: AFD; Average Saccade Duration: ASD; Average Blink Duration: ABD) between third graders and fifth graders

Indicators		Rep. types		Grades F	Rep. types F	Grades × rep. types
		Iconic	Symbolic			
AFD	G3	2,604(1380)	2,717(1488)	.039	6.16*	3.15
	G5	2,256(896)	2,922(1028)			
ASD	G3	204(90)	220(136)	1.069	5.052	.917
	G5	228(128)	272(127)			
ABD	G3	191(154)	247(192)	4.847*	9.713**	2.894
	G5	320(277)	512(474)			

* $p < .05$; ** $p < .01$

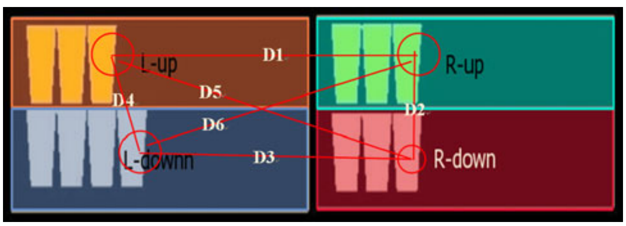


Fig. 5 There were six directions of attention when students used different strategies to solve problems. *Note* D1 means the direction of attention between L-Up and R-Up, D2 means the direction of attention between R-up and R-down, and D5 means the direction of attention between L-up and R-down

Table 5 Different directions of attention during the process of problem solving

Stages	Rep. types	Third graders	Fifth graders
I	Iconic	D1–D3	D1–D3
I	Symbolic	D1–D3	D1–D3
II	Iconic	D2–D4	D2–D4
II	Symbolic	D1–D3,	D5–D6
III	Iconic	D1–D3, D2–D4	D1–D3, D5–D6
III	Symbolic	D1–D3	D5–D6

symbolic representations whereas fifth-grade students did not. Fifth-grade students used the same rule of comparison (D1–D3 or D2–D4) to solve problems in iconic representations but used a different rule (D5–D6) to solve problems in symbolic representations. Results also indicated that fifth-grade students used different rules to solve problems displayed in iconic representations at different stages of the problems. Thus, why iconic representations influenced students' use of strategies in problem solving was further investigated.

The analysis of scan path helped us further understand the students' processes when problem solving. Through the scan path of eye tracking, the problem solving process was displayed. This study analyzed the scan path during students' problem solving with iconic or symbolic representations. For example, Fig. 6 illustrates two pictures with

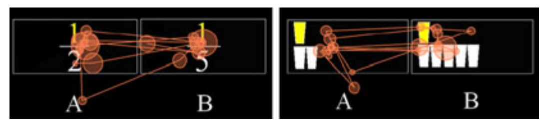


Fig. 6 Samples of scan path during the solving of concentration problems

similar scan paths and displays students' direction of gaze clearly. Scan path displays large and small circles in these two pictures. It indicated a student's duration of thinking when he or she was looking at the numbers or cups. These data indicated a longer duration of thinking while students solved problems displayed in symbolic representations than problems in iconic representations. The reason for the difference in duration of thinking was that students had to calculate the ratio when the problem was displayed in symbolic representations, but they could use intuitive rules to judge the numbers in iconic representations.

Discussion and Conclusions

This study revealed many differences between third graders and fifth graders. Results from behavioral data revealed that the performances of problem solving are similar between third-grade students and fifth-grade students. Representational types appear to impact students' problem solving at different stages of the problems. This study further analyzed the eye-tracking data to investigate the impact of the representational types and found that fifth graders tended to use numerical computation when the problems were displayed in symbolic representations. The results will be further discussed in the following paragraphs.

First, there was a significant difference on student's correct rate as third-grade and fifth-grade students solved problems among the three stages of the problems. In problem solving at the intuitive and formal operational stages, fifth-grade students solved problems more successfully than third-grade students. However, the correct rate was lower for students of both grades at the concrete operational stage. It was inferred that the problem itself in the formal operational stage was difficult for students of both grades, but it did not correspond to Noelting's work. The results further indicate that both third graders and fifth graders were influenced by different representational types and unconsciously changed their strategies to solve problems (Schnotz et al. 2002; Seufert 2003; van Sommeren et al. 1998). The types of representation could possibly affect the performance of problem solving at the concrete operational stage. Thus, these findings implicate that the representational types in textbooks are a key factor in learning science concepts.

Second, results showed that students of two different grade levels solved problems in iconic and symbolic representations differently. The correct rate of concentration problem solving for fifth-grade students was higher than that of third-grade students, except for solving problems at the formal operational stage with iconic representations where students in both grades had similar results. To understand the reason behind this difference, the interview data were examined. The interview data indicated some reasons for the similar correct results. Students, regardless of grade level, used the same strategy to solve problems in iconic representations at the concrete operational stage. That is, most fifth-grade students observed the numbers of cups rather than applying the intuitive rule in their problem-solving process. However, they applied the intuitive rule 'more A, more B' to solve problems in iconic representations (Stavy and Tirosh 2000). The results revealed that the representational types influenced students' selection of problem solving strategies (Ametller and Pintó 2002; Linn 2003; Mathewson 1999). These findings suggest that the representational types should be chosen as carefully as new approaches and rules are selected in teaching.

Finally, this study explored the data of fixation and saccade, two indicators of eye-tracking movements, to understand students' thinking processes and to determine which strategies they used in problem solving. In this study, results showed that AFD in AOI of third-grade students and fifth-grade students was similar. That is, it took approximately the same time for students of both grades to fixate on the concentration problems. However, AFD found there was a strong relationship between different representational types and the grade levels of the students. That is, it took fifth-grade students longer to solve problems in symbolic representations than problems in ionic representations. The longer fixation duration showed that fifth-grade students used numerical computation, the strategy taught in schools, to solve the problems. They did not ponder the concept of concentration, but directly resorted to numerical computation to quickly obtain the answer. These findings corresponded to the conclusions of Kozma and Russell (1997), Kozma (2003), and Seufert (2003). Although fifth-grade students could solve the problems quickly, they lost opportunities for critical thinking and reasoning. According to these results, it was inferred that fifth-grade students were more inclined to use numerical computation, while third-grade students employed intuitive rules to solve concentration problems.

Concentration in science learning is a measurement of the relative proportions of two or more quantities in a mixture. The concept of concentration is important in acquiring basic proportional relationships in elementary school and for comprehending chemical reactions in junior high school. The relative concepts of concentration are the basis for higher level science concepts, but concentration has been thought to be a difficult concept for elementary school students. In this study, third-grade students had not learned the concept of concentration, but they knew the sweetness of orange juice. Thus, they used intuitive rules to judge the sweetness (concentration) of two cups of orange juice. Fifth-grade students, however, had acquired the concept of concentration, and they had been taught another method, numerical computation, to solve problems of concentration. According to behavioral data, this study suggests that third-grade and fifth-grade students all had fully developed the formal operational skills for the learning of science. Piaget's Cognitive Development Theory suggests that children between seven and eleven years of age should reach the same cognitive stage (Piaget 1974), therefore, the results of this study can be explained by Piaget's theory. In this study, students of both grades had similar performances among three stages of problems in two representational types.

The data from the eye-tracking study, however, revealed interesting differences. The Total Fixation Duration for concentration problem solving showed a significant difference between third-grade students and fifth-grade students. That is, the Total Fixation Duration of problem solving was significantly longer for third-grade students than for fifth-grade students. This finding suggests that third-grade and fifth-grade students used different strategies to solve these problems. Third-grade students did not comprehend the concept of concentration, but they knew what sweetness was. With lower levels of prior knowledge, these students used intuitive rules to solve a variety of concentration problems. The strategies they used did not change according to the representational types. Fifth-grade students, however, possessed higher levels of prior knowledge and related knowledge of concentration. They had also been taught to use approaches other than intuition, such as numerical computation, to solve these problems. With these advantages, fifth-grade students spent less time on problem solving, but their prior knowledge and their ability to use numerical computation also restrained their ability to think about the numerical relation of concentration problems. Therefore, students taught using numerical computation may have misconceptions about concentration.

To conclude, this study found that different representational types impact students' science conceptual learning. We propose that other factors, such as teaching, prior knowledge, and problem-solving strategies, also be investigated for their impact on science conceptual learning. Because the impact of representational types has been confirmed in this study, future studies could investigate the impact of representational types in multimedia environments or representational types displayed in different media. We suggest that eye-tracking technology, which was found in this study to effectively reflect children's thinking, be adopted in future studies on children's problem-solving strategies. With these results, we believe that this study has contributed to the understanding of elementary school students' problem-solving strategies and the usability of eye- tracking technology in related researches.

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References

Ametller J, Pintó R (2002) Students' reading of innovative images of energy at secondary school level. Int J Sci Educ 24(3):285–312

Anderson JR, Bothell D, Douglass S (2004) Eye movements do not reflect retrieval processes: limits of the eye-mind hypothesis. Psychol Sci 15(4):225–231

Chang KT, Antes J, Lenzen T (1985) The effect of experience on reading topographic relief information: analyses of performance and eye movements. Cartogr J 22:88–94

Duchowski AT (2003) Eye tracking methodology: theory and practice, 1st edn. Springer, London

Goldberg JH, Kotval XP (1999) Computer interface evaluation using eye movements: methods and constructs. Int J Ind Ergon 24:631–645

Hegarty M, Carpenter PA, Just MA (1991) Diagrams in the comprehension of scientific text. In: Barr R, Kamil ML, Mosenthal P, Pearson PD (eds) Handbook of reading research, vol 2. Longman, New York, pp 641–668

Henderson JM, Hollingsworth A (1998) Eye movements during scene viewing: an overview. In: Underwood G (ed) Eye guidance in reading and scene perception. Elsevier, Oxford, pp 269–294

Inhelder B, Piaget J (1958) The growth of logical thinking: from childhood to adolescence. Basic, New York

Just MA, Carpenter PA (1984) Using eye fixations to study reading comprehension. In: Kieras DE, Just MA (eds) New methods in reading comprehension research. Erlbaum, Hillsdale, NJ, pp 152–182

Kozma R (2003) The material features of multiple representations and their cognitive and social affordances for science understanding. Learn Instr 13(2):205–226

Kozma R, Russell J (1997) Multimedia and understanding: expert and novice responses to different representation of chemical phenomena. J Res Sci Teach 34(9):949–968

Linn M (2003) Technology and science education: starting points, research programs, and trends. Int J Sci Educ 25(6):727–758

Mackworth NH, Morandi AJ (1967) The gaze selects informative details with pictures. Percept Psychophys 7:173–178

Mathewson JH (1999) Visual-spatial thinking: an aspect of science overlooked by educators. Sci Educ 83(1):33–54

Noelting G (1980a) The development of proportion reasoning and the ratio concept: part i—differentiation of stages. Educ Stud Math 11:217–253

Noelting G (1980b) The development of proportion reasoning and the ratio concept: part ii—problem structure at successive stages; problem solving strategies and the mechanism of adaptive restructuring. Educ Stud Math 11:331–363

Patrick MD, Carter G, Wiebe EN (2005) Visual representations of DNA replication: middle grades students' perceptions and interpretations. J Sci Educ Technol 14(3):353–365

Piaget J (1952) The child's conception of number. Routledge & Kegan Paul, London

Piaget J (1974) The child's conception of quantities (A. J. Pomerans, Trans.). Routledge & Kegan Paul, London

Rayner K, Rotello CM, Stewart AJ, Keir J, Duffy SA (2001) Integrating text and pictorial information: eye movements when looking at print advertisements. J Exp Psychol 7:219–226

Schnotz W, Kulhavy RW (eds) (1994) Comprehension of graphics. Elsevier, Amsterdam

Schnotz W, Bannert W, Seufert T (2002) Towards a integrative view of text and picture comprehension: visualization effects on the construction of mental models. In: Graessser A, Otero J, Leon JA (eds) The psychology of science text comprehension. Erlbaum, Hillsdale, NJ, pp 385–416

Seufert T (2003) Supporting coherence formation in learning from multiple representations. Learn Instr 13(2):227–237

Slykhuis DA, Wiebe EN, Annetta LA (2005) Eye-tracking students' attention to PowerPoint photographs in a science education setting. J Sci Educ Technol 14(5–6):509–520

Stavy R, Tirosh D (2000) How students (Mis-)understand science and mathematics: intuitive rules. Teachers College, New York

Stavy R, Strauss S, Orpaz N, Carmi G (1982) U-shaped behavioral growth in ration comparisons, or that's funny I would not have thought you were U-ish. In: Strauss S, Stavy R (eds) U-shaped behavioral growth. Academic, New York, pp 11–36

Steffe LP, Parr RB (1968) The development of the concepts of ratio and fraction in the fourth, fifth and sixth year of elementary school. Department of Health, Education and Welfare, Washington D. C.

Tai RH, Loeher JF, Brigham FJ (2004) Introduction to the use of eye-gaze tracking to study participant behavior during problem-solving. In NARST (ed) Annual meeting of the national association for research in science teaching, Vancouver, 2004. NARST

van Sommeren M, Reimann P, Boshuizen H, de Jong TD (eds) (1998) Learning with multiple representations. Permagon, Amsterdam

Von Keitz B (1988) Eye-movement research: do consumers use the information they are offered? Market Res Today 16:217–224