Analysis on Cognitive Strategies of Scientific Predicting according to 6th Graders' Predicting Skills Based on Eye Movement

Kim, Yeram · Shin, Donghoon

(Seoul National University of Education)

초등학교 6학년들의 예상 능력에 따른 과학적 예상의 인지전략 분석 - 안구운동을 중심으로 -

김예람 · 신동훈

(서울교육대학교)

국문초록

이 연구의 목적은 과학적 예상 과정에서 초등학생의 안구운동을 분석하여 과학적 예상의 인지전략을 발견하는 것이다. 예상은 관찰, 측정, 추론과 같은 기초 탐구 과정들을 통해 문제를 해결하는 중요한 탐구 능력이다. 6학년 초등학생 40명이 자발적으로 이 연구에 참여했으며, 과학적 예상 두 과제를 해결하였다. 예상 과제는 점진적으로 변화하는 모형의 다음 모양을 예상하는 것과 14일 간의 기온 그래프를 보고 다음 5일간의 기온을 예상하는 과제였다. 과학적 예상 과정에서 참가자들의 안구 운동을 기록하기 위해 SMI사의 안구운동 추적기를 사용하였다. 40명의 참가자들 중 15명(그룹 A)은 두 과제를 모두 해결하였으며, 17명(그룹 B)은 하나의 과제만 해결하였고, 8명(그룹 C)은 두 과제 모두 해결하지 못했다. 예상 능력이 높은 학생과 낮은 학생의 인지 전략의 차이를 규명하기 위해 그룹 A와 그룹 C의 안구운동을 비교 · 분석하였다. 연구 결과는 다음과 같다. 첫째, 그룹 A는 짧은 시간 동안 문제를 읽고 문제의 주요어에 집중했으며, 단서들을 비교하고 경향성을 찾고 답을 재확인하는 활발한 움직임을 보였다. 그룹 C는 문제 자체를 이해하는데 긴 시간이 걸렸으며, 주요어와 단서를 찾지 못하고, 무의미한 짧고 빠른 도약 안구 운동을 보였다. 둘째, 그룹 A와 C의 안구 운동의 고정, 도약, 시선 경로를 분석한 결과, 6가지의 안구 운동 패턴이 나타났다. 셋째, 안구운동 분석결과를 토대로 참가자들의 인지 전략을 유동전략과 고착전략의 두 가지로 구분하였다. 본 연구에서 규명한 과학적 예상의 인지전략은 교사들이 과학적 예상의 문제 해결 단계에서 학생들이 겪는 어려움을 이해하고, 예상 능력을 향상시키는 프로그램을 개발하는 것에 도움이 될 것이다.

키워드 : 예상 능력, 탐구 능력, 안구 운동, 안구 추적, 인지 전략

I. Introduction

The goal of science education is to teach students scientific methods like hypothesizing, manipulating the physical world, and reasoning from data (Padilla, 1990). SAPA defined them as “science process skills” and there are two groups involved in this: basic science process skills (BSPS) and integrated science process skills (ISPS). Observing, inferring, measuring, communicating, classifying, and predicting compose BSPS, which reflects the behaviors of scientists and provides a foundation for learning more complex skills (ISPS). SAPA defined predicting as stating the outcome of a future event based on a pattern of evidence. Predicting utilizes

2014.10.28(접수), 2014.11.11(1심통과), 2014.11.21(최종통과)
E-mail: dhshin@snue.ac.kr(Shin, Donghoon)

BSPS to state the future; it is a complex cognitive process. BSPS can be taught (Padilla *et al*., 1985; Thiel & George, 1976; Tomera, 1974) but it is hard to teach predicting skill since the cognitive strategies during predicting is uncertain. If the cognitive strategies and characteristic of predicting is known, it would be easier for students to obtain predicting skill during a science class.

There have been many researches on the relationship between eye movement and cognition using an eye tracker (Henderson *et al*., 2013; Liu & Chuang, 2011; Liversedge & Findlay, 2000; Richard *et al*., 2007; Susac *et al*., 2014). Eye movement during information processing and reading has been widely studied (Just & Carpenter, 1980; McConkie *et al*., 1988; Rayner, 1998; Tinker, 1958). Also there have been studies on the problem solving process (Hegarty *et al*., 1992; Susac *et al*., 2014; Verschaffel *et al*., 1992) and on science education (Slykhuis *et al*., 2005; Tai *et al*., 2006; Tsai *et al*., 2012). Eye tracking technique is based on eye-mind assumption which suggests that eye fixation location reflects attention, while eye fixation duration reflects processing difficulty and amount of attention (Just & Carpenter, 1980; Tsai *et al*., 2012). This was a technological development in the late 1990s prompting researchers to explore the cognitive process (Jacob & Karn, 2003). Tracing an individual's eye movements can be considered a blueprint that shows how encoded information is processed (Underwood & Radach, 1998). The common measures of eye movement are fixation, saccade, and scan path (Rayner, 1998; Tai *et al*., 2006). Rayner (1998) said that when people read something or see an object, rapid eye movements called saccades are made and eyes remain relatively still during fixations for about 200- 300 ms between saccades. Gandini *et al*. (2008) stated that scan path patterns show individuals' cognitive strategies used in goal-oriented tasks; scan path is a great measure to analyze the cognitive strategies. Eye tracker can discover the outcome of an individual's cognitive strategies as the duration of eye fixations, the number of fixations, and the amount of refixation reveal patterns describing how one's attention is directed to a certain region (Liu & Chuang, 2011). Cognitive strategies are defined as procedures that support individuals as they develop internal procedures that enable them to accomplish cognitive goals (Dole *et al*., 2008; Mazman & Altun, 2012; Rosenshine *et al*., 1996). There have been studies that analyze the cognitive strategies based on eye movement. Mazman and Altun (2012) categorized a complex task-performing process into three steps and found six cognitive strategies.

However, a study on elementary science education and the eye movements of elementary school students is rare (Liu & Shen, 2011). How elementary school students predict and how a cognitive process proceeds have not been explored. A common tool used to assess a student's learning result is test score, however, assessments based on test scores might be misleading and might give little to no information about problem-solving behavior and strategies used by the test-taker (Tai *et al*., 2006). An interview after the problem solving process is a common tool used in studies but the accuracy and objectivity of answer is uncertain and they are not a very reliable measure since people barely notice their cognitive process that takes place in a short period of time (Susac *et al*., 2014). Henderson *et al*. (2013) suggested that eye movements are directly influenced by cognitive processes and can be used as a non-invasive source of input to infer an individual's cognitive state. Eye tracker is an adequate tool that analyzes the predicting process instantaneously and subjectively because cognitive process is invisible and signs of cognitive process are shown through the eyes. Also its non-invasive characteristic doesn't interrupt the cognitive process (Tai *et al*., 2006), that is, the eye tracker is suitable for elementary school students whose concentration lasts for only a short period of time. The purpose of this study is to figure out the cognitive strategies of scientific predicting by using an eye tracker to gather eye movement data.

II. Methodology

1. Participants

Forty elementary school students from 6th grade voluntarily participated in this study. Before this study, participants took a program for national student assessment. Every student took three required subjects (Korean, mathematics, and English). Two optional subjects − social studies and science − were given only to sample students. Eight students among forty were used as samples and took optional subjects. Participants were grouped into three groups according to the assessment result. There were six achievers, seven underachievers, and twenty-seven participants who had average scores.

2. Materials

Two computer-based tasks that require scientific predicting were given to participants (Fig. 1). These two multiple choice problems were chosen from Test of Science Process Skill (Kwon & Kim, 1994) to assess a participant's predicting skill. Task 1 showed a circle that gradually changed its shape in three steps while the participants were asked to predict what that shape would be like at the 4th step. Task 2 showed a temperature graph that indicated a tendency of three-day-cold-four-day-hot. Participants were required to predict the temperature graph for the next five days. Both tasks had the same format shown in Fig. 1: (a) question, (b) clue (a graph or shapes), and (c) examples. To solve both tasks, the participants had to find a pattern or a rule from the clue − the graph and shapes. Area of Interest (AOI) was set according to format and on problem keywords needed to find the tendency.

3. Procedure

The experiment was planned in order of Calibration → Validation → Pre-task 1, 2 → Inform Task → Task 1 → Task 2 (Fig. 2). At calibration stage, a student's eye movement was calibrated with five targets on the computer screen. At validation stage,

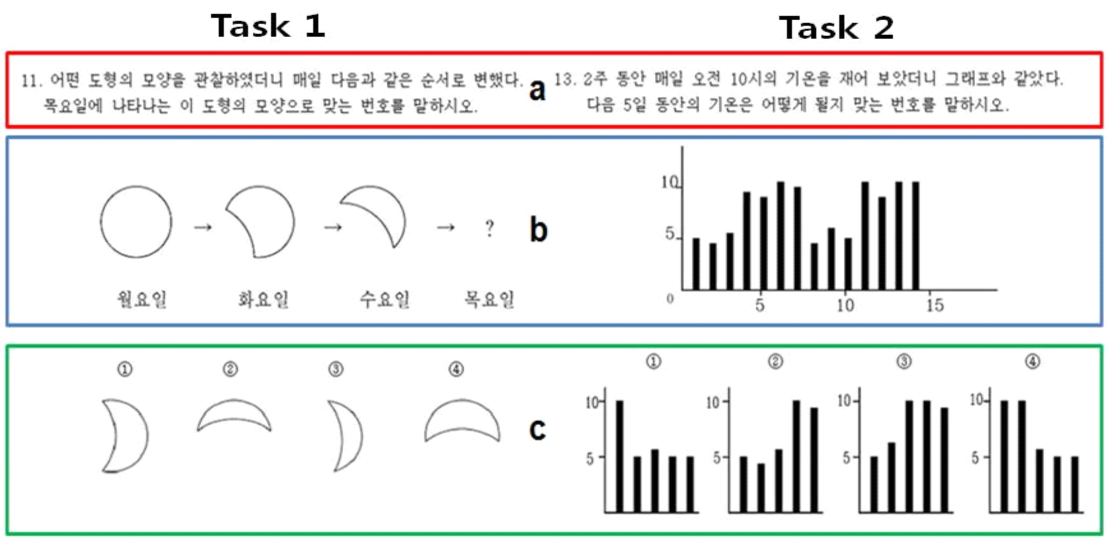


Fig. 1. Task 1 and 2 and components of tasks.

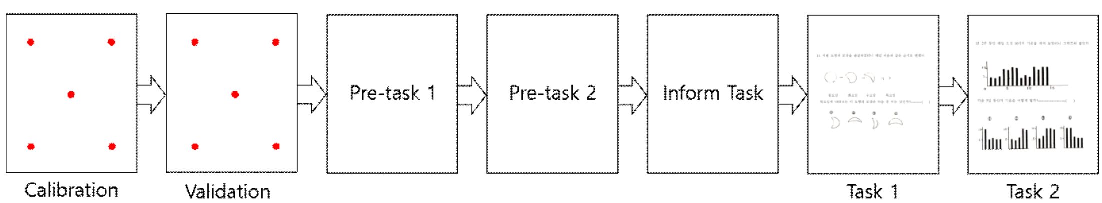


Fig. 2. Experiment procedure.

the experiment proceeded only if a participant's pupil deviation of x-axis and y-axis were both lower than 0.5°. Since eye movement tracking study requires pupil deviation to be lower than 0.5° (Holmqvist *et al.*, 2011; SMI, 2011a), validation was repeated until a participant's pupil deviations on the x-axis and y-axis were both lower than 0.5°. After calibration and validation, participants had 60 seconds to understand the experiment and materials with two pre-task. At inform task stage, the operator told the participants to say the answer they predicted and to press the space bar to move on to the next task. Task 1 was easier to predict than Task 2. Since no time limit was set, the participants had as much time as they needed.

4. Experimental Apparatus

SMI's Eye Tracker (iView X^{tm} RED 120 Hz) was used to collect eye movement data while Begaze software analyzed the task performing process and eye movements. The eye tracker used infrared rays and computer-based image processing to measure pupil movement and relative size of pupil. The eye tracker was attached to a personal computer, and a keyboard was used to operate the computer. Since an eye tracker is non-invasive and doesn't require any physical contact, it serves as an adequate tool for elementary school students to use.

5. Data Analysis

To analyze eye movement and discover the cognitive strategies of predicting, Area of Interest (AOI) was set. AOI was ascribed a question, clue, example, and keywords on the question (Fig. 3). Ten AOIs and seven AOIs were provided each task to figure out the eye movement patterns between problem elements and the fixation rate on problem keywords. Scan paths have been analyzed to discover cognition patterns in various studies (Greene *et al.*, 2012; Noton & Stark, 1971). Scan path is a series of fixation and saccades showing the order of eye movements. By segmenting and categorizing scan paths, eye movement patterns are found. The scan path, eye fixation, and saccades of each participant were collected for analysis. To discover the cognitive strategies of predicting, eye movement during the whole predicting process was observed and compared within a group and between groups. Eye fixation position and saccade direction showed a certain pattern. Every participant's eye movement was analyzed with these patterns to reveal the predicting strategies. Also, fixation time and ratio on the problem keywords of a question were compared between groups.

III. Results and Discussion

1. Eye Movement Analysis

Eye movements during the predicting process showed the characteristics of each group. Group A spent little time on reading questions but focused on the keywords

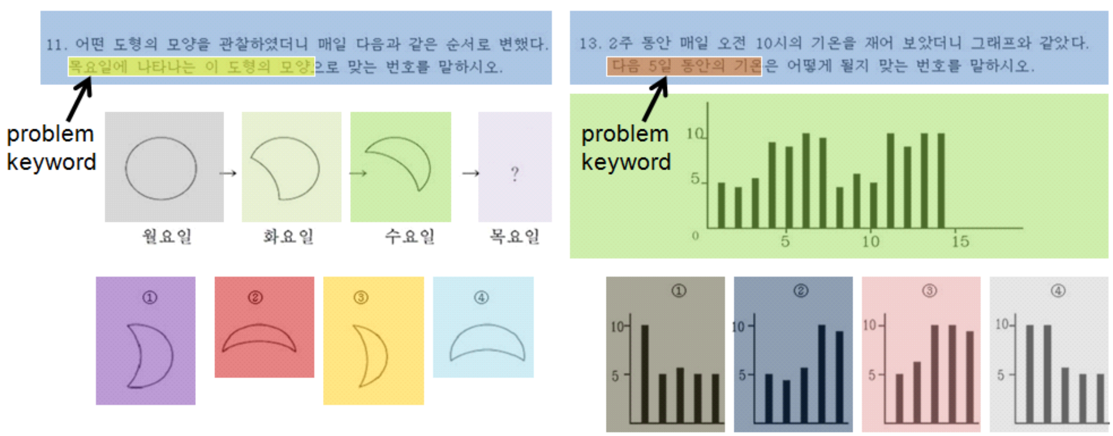


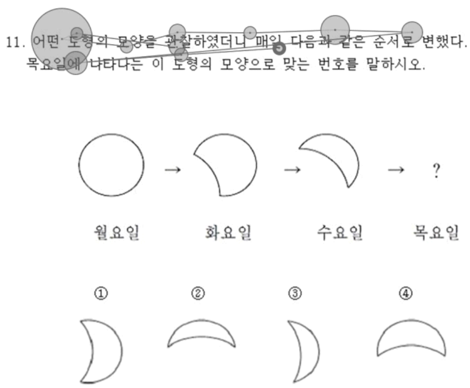
Fig. 3. Area of Interest (AOI) on each task.

of the question. They showed active eye movements within clues, discovered tendencies, and checked for accuracy. Group C spent a long time reading questions but missed keywords and clues. They showed a lot of meaningless and busy saccades, especially regressions to question. Regardless of which group they belonged to, participants showed a common tendency of eye movement: they read the question first, read clues, and found answers by comparing clues with examples.

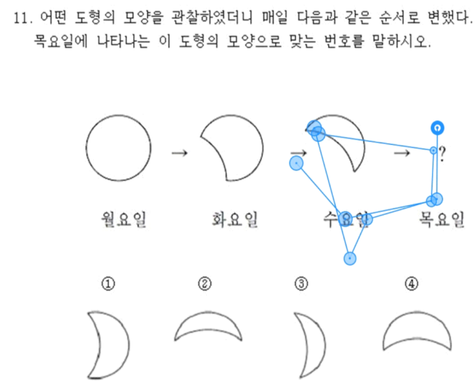
Every participant's eye movement was analyzed and six patterns of eye movement were found: reading a question, reading a clue, reading examples, comparing a question with a clue, comparing a clue with an example, and comparing all-around (Table 1). As par-

Table 1. Six patterns of eye movement during the scientific predicting process

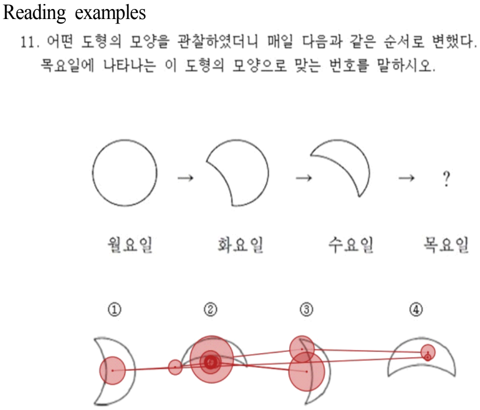
1. Reading question



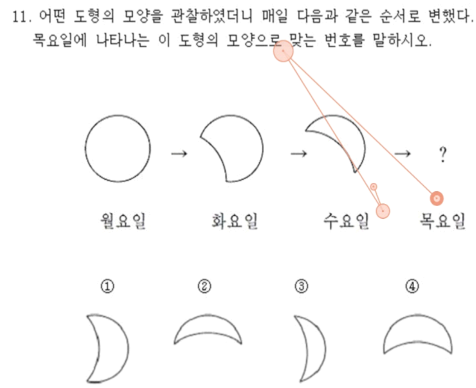
2. Reading clue



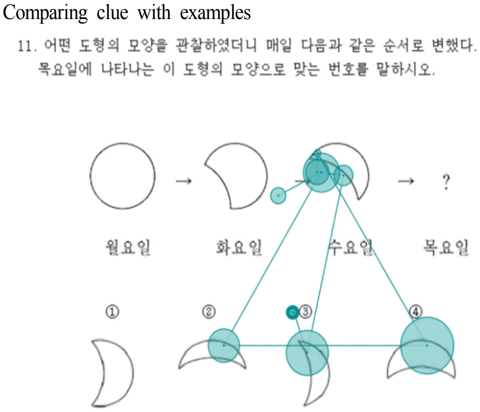
3. Reading examples



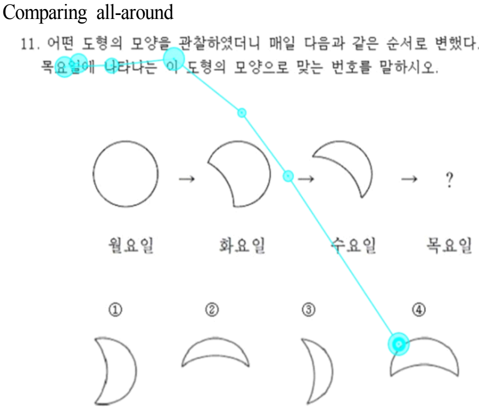
4. Comparing question with clue



5. Comparing clue with examples



6. Comparing all-around



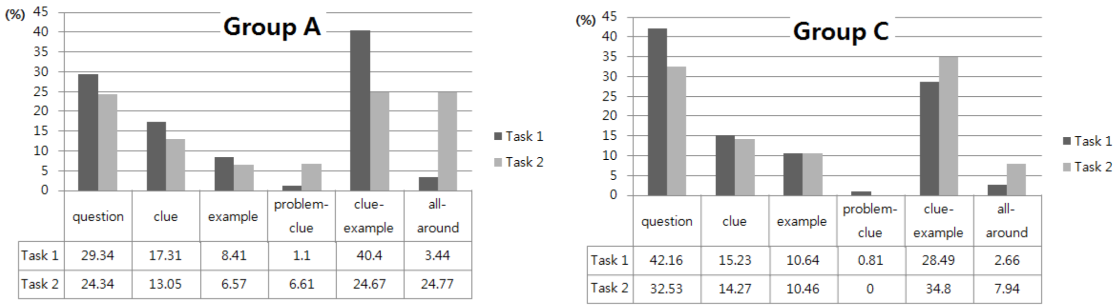


Fig. 4. Eye movement pattern ratio graph of Group A and Group C.

ticipants started to solve each problem, most participants read the question first. After reading the question, reading the clue and comparing the clue with examples followed. Few students read examples or compared a question with a clue. Also most participants read every element of the problem (question, clue, and example) quickly but in a different manner. Fig. 4 shows the average eye movement pattern ratio for the two tasks by group. Two major patterns shown from both groups are reading question and comparing clue with examples.

2. Cognitive Strategies Analysis

Hegarty *et al.* (1992) stated that a high-accuracy student group and low-accuracy student group showed different eye movement patterns. Group A's eye movement patterns were simpler than Group C's. Group A's participants had a strong tendency of eye movement flow. They read the question, read the clue, and predicted the answer as they compared a clue with examples. Group C's eye movement patterns were complicated and they found tendencies with difficulty. Both Group A and B showed similar eye movement flow as their major eye movement patterns shifted from reading a question to reading a clue and from reading a clue to comparing a clue with examples. However, Group C showed eye movement patterns that were rare in Group A; reading examples, comparing a question with a clue, and comparing all-around. This explains why some elementary school students couldn't understand the question after they read. Even though their eyes see the question, cognitive understanding doesn't take place.

The relationship among eye movement patterns indicated different cognitive processes for each group (Henderson *et al*., 2013). As cognitive strategies were invoked to make a cognitive progress (Flavell, 1979), it was assumed that they used different cognitive strategies to predict. There were two distinguishable differences of eye movement between Group A and Group C that indicated different cognitive strategies.

First, the scan path of eye movement showed a big difference between Group A and Group C from the beginning. When reading a question for the first time, Group C focused on every word and letter whereas Group A centered on keywords and made only few fixations. Group C showed regression to question later in the problem solving process (Table 2).

Brand-Gruwel *et al.* (2005) suggested that individuals generally started to solve a problem after defining the

Table 2. Total fixation count and fixation ratio on problem keywords of Group A and Group C

	Task 1		Task 2	
	Total fixation count	Fixation ratio on problem keywords	Total fixation count	Fixation ratio on problem keywords
Group A	534	11.7%	2,665	15.9%
Group C	1,057	8.8%	4,451	10.6%

problem. There was a proficiency gap between Group A and Group C in identifying a question. As shown in Table 2, Group C focused more on the question but less on the problem keywords which is consistent with study from Hegarty *et al*. (1995). Group A fixed their eyes longer on the problem keywords even though they had less fixation count and fixation duration on the question part (Fig. 5). This suggested that with fewer fixations, they understood the question and sensed what they had to do next. This finding is in line with results from studies from Susac *et al.* (2014) that experts have a successful strategy to "know where to look". Group C seemed to have unproductive eye movement, or more fixation count and lower fixation ratio. Fig. 5 showed that they fixed their eyes on the question for quite a long time and tended to look at meaningless parts. Rayner (1978) said that longer fixation durations indicated two things: an intensive cognitive processing or difficulties in information processing. Group C looked longer on question statement because it was hard for the group to extract the crucial information within a question statement (Lin & Lin, 2014). Group A analyzed and gathered information to identify the problem as they read the question for the first time but Group C just read the question without understanding it. The first difference was that Group A searched the keywords of the question (keywords searching strategy) and Group C scanned the question (scanning strategy). That is, low achievers or unsuccessful students fail solving problems of scientific predicting even though they spend more time and put more effort since their cognitive strategy is ineffective.

Second, eye movement patterns after the first question reading showed a different tendency for two groups. Group A read a clue after reading a question but Group C reread the question or compared the question with the clue (Fig. 6). Group A directly read a clue to figure out the tendency or rule after reading the question for the first time. Group A focused on searching relative factors to predict. They knew what to look for in the clue by reading a question and showed eye movement that searched the tendency for a clue (top-down process). As they found the tendency, they predicted a possible answer and looked for the one they had in mind from the examples. However, most participants of Group C went back to the question after the first question reading. This regression of Group C was consistent with the finding of Tai *et al.* (2006) that some students needed more fixations in order to process information on problem statements. There were two possible reasons for unsuccessful problem solvers going back to a question: (a) They

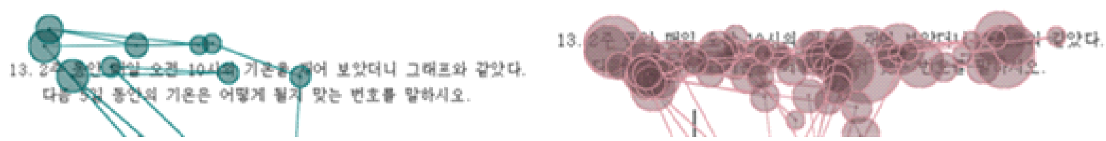


Fig. 5. The scan path on the question during the whole predicting process.

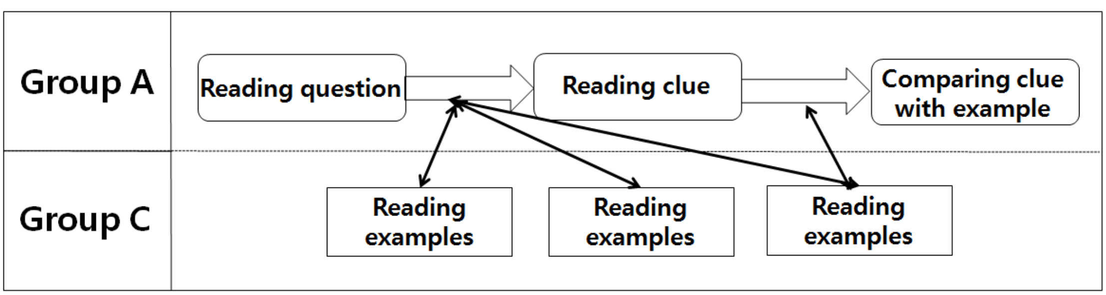


Fig. 6. Eye movement pattern tendency of two groups.

had a hard time understanding the question. They failed to find the relationship between a question and clues as they couldn't figure out the question. (b) They tried to find a tendency or hint from the question. As Group A solved Task 2, they compared a clue with an example less than they did for Task 1 with fixation ratio decreasing from 40.4% to 24.67%, but Group C compared even more, with fixation ratio increasing from 28.49% to 38.40% (Fig. 4). This was because group C didn't look for the answer that they predicted from the question and clue. Their eye movement wandered whereas group A searched an example that fit what they predicted. Fig. 7 showed a comparison of scan path between Groups A and C. For the same 3 seconds, Group C compared a clue with a question in order to find a relative factor. Group C showed rare eye movement that only appeared in Group C. Short and busy fixations and skipped saccades were caused because they didn't know what to look for next. It was more likely that unsuccessful problem solvers went back to a question because they didn't understand the question.

Group A didn't go back to the question part after their first reading of a question because they understood or acquired enough information they needed. They looked for the relative factors (searching relative factor strategy). Group C reread the question because they didn't know where to look, so they wander and reread the question (rereading question strategy).

These different strategies each group used compose superior cognitive strategies. Searching keywords strategy and searching releative factor strategy appeared when Group A adapted to different task situations by shifting to the most suitable cognitive strategy (shifting strategy). Scanning strategy and rereading question strategy appeared when Group C stuck to the same strategy regardless of changing tasks (sticking strategy).

Task 1 was easy to predict as shape change was shown in three steps. However, there was an increment in the degree of difficulty from Task 1 to Task 2. Task 2's clue was a graph and it was difficult to understand it because there was no unit on the x-axis and y-axis. To solve the second problem, participants had to infer the x-y axis from the question. By comparing a question with a clue, they could figure out x-axis as "temperature" and y-axis as "day." As the degree of difficulty of task increased, time increment was caused. Comparing average problem solving time between Task 1 and Task 2, Group A's average

Table 3. The cognitive strategies of Group A and Group C

	Superior-strategy	Sub-strategy
Group A	· Shifting strategy	· Searching keywords strategy · Searching relative factor strategy
Group C	· Sticking strategy	· Scanning strategy · Rereading question strategy

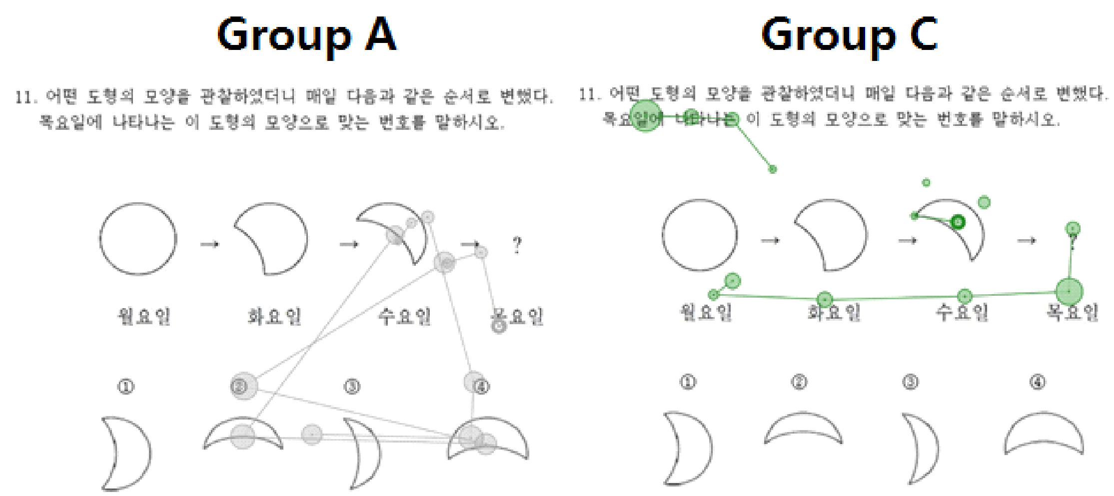


Fig. 7. The eye movement pattern of the participants of Group A and C exhibiting a "comparing clue with examples" in 3 seconds.

problem solving time increased from 24.30 seconds to 33.41 seconds, and Group C's from 24.33 seconds to 45.43 seconds. Also their eye movement patterns changed.

To predict the temperature in the next five days, the participants had to find the unit of x-axis and y-axis. Only by comparing a question with a clue could they find the core cue. Group A's eye movement pattern ratio on comparing a question with a clue increased from 1.10% to 6.61% (Fig. 4). It meant that they knew what they didn't know and looked for what they needed to know. Flavell (1979) stated that meta-cognition (thinking about thinking) is monitored by meta-cognitive strategy and individuals with high meta-cognitive knowledge can determine which strategy would be effective in achieving a goal. Group A's major eye movement patterns switched as their strategy changed in order to solve the problem effectively. They adapted to the task using shifting strategy.

However, Fig. 4 shows that Group C didn't make any eye movement of comparing a question with a clue (eye movement pattern ratio decrement from 0.81% to 0.00%). They read a question and a clue but didn't realize the relationship between them. They couldn't find the unit and failed to read the graph. The main eye movement pattern of Group C remained the same as reading a question, comparing a clue with an example, and reading a clue regardless of task (Fig. 4). They held on to the same strategies which suggests sticking strategy. This was consistent with the statement that unsuccessful problem solvers couldn't use strategies effectively and switched between ineffective strategies even when they knew they led to mistakes (Hill & Hannafin, 1997; Lazonder, 2000; Mazman & Altun, 2012).

Also, comparing all-around pattern became Group A's main eye movement pattern, with dramatic ratio increment from 3.44% to 24.77% (Fig. 4). In solving Task 1, Group A usually showed an all-around comparison pattern at the end of the problem solving process such as by checking their answers. But as problem difficulty rose and they failed to figure out the question and tendency of a clue, they showed an active, all-around comparison pattern. It suggested that comparing all-around patterns could be the indication of cognition difficulty. As cognitive difficulty increased, comparing all-around patterns appeared often because they looked for information needed to understand the question.

The change in eye movement pattern suggested that Group A adapted effectively to the task in order to predict. Shifting strategy included searching keywords strategy and searching relative factor strategy as these two gave direction to shift strategy. Group C just stuck to the same strategies (scanning and rereading question strategy) in different problem situations. Strategies show the cognitive difference of scientific predicting process between successful achievers and unsuccessful achievers.

Ⅳ. Conclusion

This study was designed to discover cognitive strategies used during the scientific predicting process for elementary school students. Why are some students good at scientific predicting and others are not? Their problem solving process might seem similar and it's hard for unsuccessful solvers to say what difficulty they face. That's because cognitive process is a very quick and natural process and hard for an individual to notice his own cognitive process. Especially elementary school students are not trained to explain their state. Based on eye-mind assumption, eye movement provides information about one's cognitive strategies. This study gave two scientific predicting tasks to forty elementary school students and analyzed their eye movements. As scan paths were analyzed in patterns, six eye movement patterns occurring in the predicting process were found. The relationship among eye movement patterns suggested cognitive strategies that each group used. Participants who are good at predicting used shifting strategy that utilizes searching keywords strategy and searching relative factor strategies to choose the most suitable strategy to different tasks. Participants who are not good at predicting used sticking strategy that utilizes scanning strategy and rereading question strategy because they couldn't find the crucial information.

These findings are meaningful in elementary science education field as they support teachers to understand student's cognitive process and help them effectively. The biggest problem that unsuccessful achievers face is not being able to understand the question. Since they couldn't understand the question, ineffective eye movements such as rereading question and wandering eye movements appear. Teachers need to lead students to notice what they don't understand from the question and understand what it asks for.

The cognitive difference between successful achievers and unsuccessful achievers is the cognitive strategy that they use. Successful achievers searched problem keywords and relative factors as they approach each tasks. Also as problem difficulty arose, their eye movement changed; they selected cognitive strategy that fits solving changed question. Whereas successful achievers shifted cognitive strategies, unsuccessful achievers stuck to the same strategies regardless of different characteristics of questions. Because they couldn't understand the question and couldn't extract the crucial information from clues, they scanned the question, even the meaningless parts, and reread the question repeatedly.

These cognitive strategies could be a blueprint for students to follow in predicting situation. Teachers can teach predicting easily by explaining each strategy and what strategies students should use. These strategies are not unique characteristics only found in scientific predicting and they can be applied to other science process situations.

By analyzing elementary school student's eye movement, different eye movement patterns between successful problem solvers and unsuccessful problem solvers are found and a training program that advance sticking strategy to shifting strategy should be developed. A training program for students to predict and select effective cognitive strategy is useful not only for those who are poor at scientific predicting but also for those who are good at it. Eye movement pattern can also be used to measure the cognitive difficulty that students face and to assess a student's predicting proficiency.

There is a main limitation of this study. Although eye movement does give information on cognitive strategies and the relationship between cognitive strategy and eye movement has been widely studied, the cognitive process is so complex that only one element isn't enough to explain the mechanism. To investigate cognitive strategies of elementary school students in science process situation, a connection research between an eye tracker and an fMRI will be needed in future research.

References

Brand-Gruwel, S., Wopereis, I. & Vermetten, Y. (2005). Information problem solving by experts and novices: Analysis of a complex cognitive skill. *Computers in Human Behavior*, 21(3), 487-508.

Carpenter, P. A. & Just, M. A. (1977). Reading comprehension as eyes see it. Cognitive processes in comprehension (pp. 109-139). New Jersey: Lawrence Erlbaum Associates, Inc.

Dole, J. A., Nokes, J. D. & Drits, D. (2008). Cognitive strategy instruction. In S. E. Israel & G. G. Duffy (Eds.), Handbook of research on reading comprehension (pp. 347-372). New York: Rutledge.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, 34(10), 906-911.

Gandini, D., Lemaire, P. & Dufau, S. (2008). Older and younger adults' strategies in approximate quantification. *Acta Psychologica*, 129(1), 175-189.

Greene, M. R., Liu, T. & Wolfe, J. M. (2012). Reconsidering Yarbus: A failure to predict observers' task from eye movement patterns. *Vision Research*, 62, 1-8.

Hegarty, M., Mayer, R. E. & Green, C. E. (1992). Comprehension of arithmetic word problems: Evidence from students' eye fixations. *Journal of Educational Psychology*, 84(1), 76.

Hegarty, M., Mayer, R. E. & Monk, C. A. (1995). Comprehension of arithmetic word problems: A comparison of successful and unsuccessful problem solvers. *Journal of Educational Psychology*, 87(1), 18.

Henderson, J. M., Shinkareva, S. V., Wang, J., Luke, S. G. & Olejarczyk, J. (2013). Predicting cognitive state from eye movements. *PloS One*, 8(5), e64937.

Hill, J. R. & Hannafin, M. J. (1997). Cognitive strategies and learning from the World Wide Web. *Educational Technology Research and Development*, 45(4), 37-64.

Holmqvist, K., Nystrom, M., Anderson, R., Dewhurst, R., Jarodzka, H. & Van de Weijer, J. (2011). Eye tracking: A comprehensive guide to methods and measures, pp. 9-144. Oxford University Press.

Jacob, R. J. & Karn, K. S. (2003). Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. *Mind*, 2(3), 4.

Jarodzka, H., Scheiter, K., Gerjets, P. & Van Gog, T. (2010). In the eyes of the beholder: How experts and novices interpret dynamic stimuli. *Learning and Instruction*, 20(2), 146-154.

Just, M. A. & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, 87, 329-354.

Kwon, J. & Kim, B. (1994). The development of an instrument for the measurement of science process skills of the Korean elementary and middle school students. *Journal of the Korean Association for Science Education*, 14(3), 251-264.

Lazonder, A. W. (2000). Exploring novice users' training needs in searching information on the WWW. *Journal of Computer Assisted Learning*, 16, 326-335.

Lin, J. J. & Lin, S. S. Tracking eye movements when solving geometry problems with handwriting devices. *Journal of Eye Movement Research*, 7(1):2, 1-15

Liu, C. J. & Shen, M. H. (2011). The influence of different representations on solving concentration problems at elementary school. *Journal of Science Education and Technology*, 20(5), 621-629.

Liu, H. C. & Chuang, H. H. (2011). An examination of cognitive processing of multimedia information based on viewers' eye movements. *Interactive Learning Environments*, 19(5), 503-517.

Liversedge, S. P. & Findlay, J. M. (2000). Saccadic eye movements and cognition. *Trends in Cognitive Sciences*, 4(1), 6-14.

Mazman, S. G. & Altun, A. (2012). Modeling cognitive strategies during complex task performing process. *Turkish Online Journal of Qualitative Inquiry*, 3(4), 1-27.

McConkie, G. W., Kerr, P. W., Reddix, M. D. & Zola, D. (1988). Eye movement control during reading: I. The location of initial eye fixations on words. *Vision Research*, 28(10), 1107-1118.

Noton, D. & Stark, L. (1971). Scanpaths in eye movements during pattern perception. *Science*, 171(3968), 308-311.

Padilla, M. J. (1990). The science process skills. Research matters-to the science teacher, No. 9004.

Padilla, M., Cronin, L. & Twiest, M. (1985). The development and validation of the test of basic process skills. paper presented at the annual meeting of the National Association for Research in Science Teaching, French Lick, IN.

Radach, R. (1998). Eye guidance and visual information processing: Reading, visual search, picture perception and driving. *Eye Guidance in Reading and Scene Perception*, 1, 1-27.

Raney, G. E., Campbell, S. J. & Bovee, J. C. (2014). Using eye movements to evaluate the cognitive processes involved in text comprehension. *JoVE (Journal of Visualized Experiments)*, (83), e50780-e50780.

Rayner, K. (1978). Eye movements in reading and information processing. *Psychological Bulletin*, 85(3), 618.

Richardson, D. C., Dale, R. & Spivey, M. J. (2007). Eye movements in language and cognition. Empirical methods in cognitive linguistics, 323-344.

Rosenshine, B., Meister, C. & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of Educational Research*, 66(2), 181-221.

Slykhuis, D. A., Wiebe, E. N. & Annetta, L. A. (2005). Eye-tracking students' attention to Power Point photographs in a science education setting. *Journal of Science Education and Technology*, 14(5-6), 509-520.

Susac, A., Bubic, A., Kaponja, J., Planinic, M. & Almovic, M. (2014). Eye movements reveal students' strategies in simple equation solving. *International Journal of Science and Mathematics Education*, 1-23.

Thiel, R. P. & George, K. D. (1976). Some factors affecting the use of the science process skill of prediction by elementary school children. *Journal of Research in Science Teaching*, 13(2), 155-166.

Tinker, M. A. (1958). Recent studies of eye movements in reading. *Psychological Bulletin*, 55(4), 215.

Tomera, A. N. (1974). Transfer and retention of transfer of the science process of observation and comparison in junior high school students. *Science Education*, 58(2), 195-203.

Tsai, M. J., Hou, H. T., Lai, M. L., Liu, W. Y. & Yang, F. Y. (2012). Visual attention for solving multiple-choice science problem: An eye-tracking analysis. *Computers & Education*, 58(1), 375-385.

Verschaffel, L., De Corte, E. & Pauwels, A. (1992). Solving compare problems: An eye movement test of Lewis and Mayer's consistency hypothesis. *Journal of Educational Psychology*, 84(1), 85.