Exploring Reasoning Patterns of Students' Scientific Thinking, Inquiry Activities in Textbook, and Examination Items

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ABSTRACT

Scientific reasoning is one of the main concerns in current science education. This study have tried to answer on the question whether Korean science education has the potential to help improve of students' ability to think scientifically. Therefore, the present study investigated the relationship between reasoning patterns evident in science textbook and science examination items, and students' scientific reasoning skills across grades in Korea. 1975 subjects (1022 females and 953 males) were administered in the Lawson's Test of Scientific Reasoning skills. Forty seven science textbooks and 240 assessment instrument were analyzed by several scientific reasoning keys. Scientific reasoning patterns were adopted from Lawson's classification which characterized the patterns as the empirical-inductive and the hypothetical-deductive. This study found that reasoning patterns evident in textbook analyses and assessment instrumental items do not evidentce the potential to stimulate the development of students' reasoning skill. In order to improve the students' abilities to think and achieve, higher levels of reasoning must be included in the science textbook and examination. Further, some of scientific reasoning processes, such as generating hypotheses, designing experiments, and logical prediction, were not found in science textbooks and test items in Korean secondary schools. This study also discussed the educational implication of these results and further studies about to develop student's reasoning ability.

Key words: reasoning pattern, scientific thinking, examination items

I. Introduction

Korea was the top-performing country at both the third and fourth grades in the IEA's Third International Mathematics and Science Study (TIMSS, Martin *et al.*, 1997). Korea also was the top performing country at the seventh and eighth grades in the TIMSS (Beaton *et al.*, 1996). According to the TIMSS results, Korean students' scientific ability might be among the top performers in the world.

However, several studies have reported Korean high school students' science achievement ranks as one of the lower-performing countries in the world and the research competitiveness and the creative research productivity of Korean universities ranks thirtieth in the world (Han, 1994). In addition, there is a decline in Korean students' academic achievement as their grades become higher. According to longitudinal studies on Korean students' science achievements and attitudes toward science have shown a decline as they become upper-grade (Kim *et al.*, 1999; Kwon *et al.*, 1999). Furthermore, researches on Korean students' logical

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thinking have shown that about 30% were not reached conservational stage and 90% were not reached correlational stage in elementary school students (Kang & Woo, 1995). Also, 30% of students were not reached conservational stage and 70% were not reached correlational stage in secondary school students (Choi & Hur, 1987; Im, 1992).

Recent study on Korean students' scientific reasoning ability have also shown that around 40% of secondary school students were categorized as empirical-inductive thinker, while around 30% of the students were categorized as hypothetical-deductive thinker (Chung *et al.*, 1999). Analyses of longitudinal study show that logical thinking abilities decline as become upper-grades in secondary school (Kim *et al.*, 2000). About 5% of students have reached formal operational stage in 5th and 6th grade students (Kim & Kim, 1988). Also, 2.2% of 7th grade, 3.4% of 8th grades students, 7.4 % of 9 grade have reached formal operational stage (Choi & Hur, 1987). The result of comparison with Korea and Japan secondary school of cognitive levels and science process skills show that Korean students were lower than Japanese students (Kim, 1989; Soh & Woo, 1994; Takemura, 1989; Yoo, 1988),

What causes this decline of Korean students' scientific skills as they become upper-grades? In other words, what causes the decline of Korean adolescents' low-performing in scientific reasoning? An possible answer may be the gap between reasoning patterns of program activities and students' reasoning abilities, which may fail to stimulate students' reasoning development. Research data have shown the case of unbalenced reasoning pattern between textbook inquiries and students' thinking skills in Korea. For example, Chung *et al.*(1999) reported that only 38.9 and 29.1 % of junior high school students were categorized as empirical-inductive reasoners and hypothetical-deductive reasoners, respectively, whereas 86.4% and 13.6% of textbook inquiries were categorized as empirical-inductive and hypothetical-deductive reasoning patterns, respectively. Therefore, the present study investigated reasoning patterns of science textbooks and science examination items, and students' scientific thinking skills across grades in Korea.

Ⅱ. Methodology

This study consists mainly of two parts: test of students' scientific reasoning skills; analyzing thinking patterns of textbook inquiries, and examination items.

1. Test of students' scientific reasoning skills

Subjects. One thousand and nine hundred seventy-five subjects (1022 females and 953 males) ranging in age from 8.4 to 16.2 years from a big city, a small town and a rural area participated in the test of students' scientific reasoning skills. Each student was enrolled 1 of 48 male or female 3^{rd}-through 10^{th}-grade classes.

Scientific Reasoning Test. A 14-item written test was adapted from Kwon (1997) to assess students' scientific reasoning ability. The test was originally modified from the version of Lawson's Classroom Test of Scientific Reasoning (Lawson, 1987). The modified test contains 8 of the original 12 items. The original items were based on Piagetian tasks and involve the identification and control of variables, and proportional, probabilistic, correlational and combinatorial reasoning (Suarez & Rhonheimer, 1974). Two of the additional items on the modified test involve proportional and combinatorial reasoning and came from

Lawson *et al.* (1976). The four remaining items came from Lawson *et al.* (2000). Two of these involve water rise in an inverted cylinder after the cylinder had been placed over a burning candle sitting in water. The other two involve changes in the appearance of red onion cells when bathed in salt water. These four items require students to use hypothetical-deductive reasoning to reject hypotheses involving theoretical entities.

All items required students to respond to a question or make a prediction in writing and to either explain how they obtained their answer, or in the case of quantitative problems, to show their calculations. Items were judged correct (a score of 1) if the correct answer plus an adequate explanation or set of calculations were present. Incorrect answers were scored 0. A Cronbach's alpha reliability coefficient of 0.75 was obtained in Kwon (1997). Validity of the test has been established through numerous studies (e.g., Kwon, 1997; Lawson, 1978; 1987; Lawson & Weser, 1990; Lawson *et al.*, 2000).

2. Reasoning patterns of textbook inquiries and examination items

Reasoning Patterns. Reasoning patterns of scientific inquiries in textbooks and science items in formal examination were identified from Lawson (1995) which characterized students' reasoning patterns as the empirical-inductive and the hypothetical-deductive reasoning patterns. The empirical-inductive students could not recognize their own patterns of reasoning, and their remarks were contradictory or inconsistent with the general facts. The hypothetical-deductive students could recognize their own patterns of thinking, and were critical of them, and, on the basis of general information, they actively investigated their valid results. This provides the concrete frame for the analysis of reasoning levels (Lawson, 1995).

Textbook Inquiries. Reasoning patterns of all scientific inquiries in the section of biological science from sixteen elementary school textbooks (8 books about nature and 8 books about experimental observation), twenty-four 7^{th} to 9^{th} grade science textbooks and seven 10^{th} grade common science textbooks were analyzed. Chapters of the section of biological science in textbooks were followed: 'Frogs and cabbage butterfly', 'Growth of plants', and 'The creatures in the pond' in the third grade of primary school; 'Small creatures' and 'Life and environment' in the fourth grade; 'The structures and functions of plants' and 'The metabolism of the body and its growth' in the fifth grade; 'Nutrition and health' and 'Environmental pollution and protection of nature'; 'The neighboring creatures' in the 7^{th} grade; 'The structures and functions of living things' in the 8^{th} grade; 'Heredity and evolution' and 'Natural environment and our life' in the 9^{th} grade; and 'Life' in the 10^{th} grade common science textbooks.

The analysis of exploring activities was directed at the contents requisite for student activities. The items in every textbook for the students' activities differed in respectively. For example, the students' activities involved inquiries, questions, examinations and summary. In secondary schools, most of the final experimental activities presented the examinations and the sums as the students' own activities.

Examination Items. The objects of the analysis of the tested items in Korean primary, secondary schools were the midterm and final exams taken in 45 schools. There were 240 types of test papers analyzed. In the case of the third grade during the first term, the number of test items in the subject, 'Nature' was 14-30; the fourth grade 10-31; the fifth grade 10-33; and the sixth grade 11-23. Each of the schools had many of their different test items. In the secondary schools, 20 or 30 questions were made.

Rating Validity. Two professors in science education, one doctoral student in science education and two science teachers rated reasoning patterns of textbook inquiries and examination items. Before rating, they took a workshop session about Lawson' theory of scientific reasoning. Their interrater reliability was 0.91 for a sample of student response. After four weeks, they showed 0.94 interrater reliability.

Ⅲ. Results and Discussion

1. Student scientific reasoning skills by grade

Table 1 shows students' performance on scientific reasoning test across grade. As shown in the Table 1, the higher the grades, the higher the scientific reasoning skills. But, development of scientific reasoning skills not show linear pattern.

The proportion of students in the empirical-inductive stage became decreased in the higher grades. The percentage, however, increased only in the eighth grade, while those in the hypothetical-deductive stage increased from the fifth to the seventh grades, decreased in the eighth grade, increased again in the ninth grade, and then decreased in the tenth grade. In short, the proportional change of students in the hypothetical-deductive stage indicated that the development of their thinking power was not linear.

Table 1. Scientific reasoning scores by grade ( ) : SE

Grade	3rd	4th	5th	6th	7th	8th	9th	10th
Scientific reasoning	1.2 (.04)	1.3 (.07)	.8 (.09)	2.7 (.14)	5.0 (.17)	3.6 (.16)	5.5 (.19)	5.8 (.17)

The change in each student's scores showed that the girls in the third grade got higher scores than the boys. The boys in the fourth grade, however, got higher scores than the girls. At the same time, there was no great change in the scores of the third from the fifth grade. There was, however, a sudden increase in scores from the fifth to the seventh grade, and again a decrease in the eighth grade. In addition, the thinking power scores of the eighth to ninth graders increased. These results confirm prior researches (Kwon & Lawson, 1998). According to the results, scientific reasoning skills were improved as they are higher grader. But, development trend to plateau and spurt (Kwon & Lawson, 1998; Kim *et al*., 2000).

2. Reasoning patterns of textbook inquiries

The analyzed subjects were the textbook contents related to third grade biology in elementary school to the 10th grade in high school. These included three units from third grade in elementary school, and two units from the fourth to the sixth grade respectively; also one unit each from the seven and eight grade, and two units from the 9th grade in secondary school. In the 10th grade of high school, 'Life', one unit of common science, was analyzed.

A lot of content classification (EI 1) was required in the thinking levels of the third and fourth grade primary school textbooks. The fifth and sixth grade textbooks had many level applications of descriptive concepts (EI 4). There were no contents that needed classification (EI 2) and (HD 2) in the third, fourth and sixth grades in elementary school.

In general, empirical-inductive thinking levels were required for much of the textbook contents. More than 80% of the primary school science textbooks required empirical-inductive thinking. In the case of hypothetical-deductive processes, the third to fifth grade texts had a lot of related content, while in the sixth grade this proportions decreased.

Table 2. Scientific thinking level of inquiry activities in elementary science textbook ( ) : %

Grade	Empirical-inductive (EI)					Hypothetical-deductive (HD)				
	EI1	EI2	EI3	EI4	EI5	HD1	HD2	HD3	HD4	HD5
3rd	94 (48.7)	0 (0.0)	48 (24.9)	27 (13.9)	3 (1.6)	10 (5.2)	0 (0.0)	0 (0.0)	9 (4.7)	2 (1.0)
4th	90 (30.8)	0 (0.0)	71 (24.3)	77 (26.4)	0 (0.0)	32 (11.0)	0 (0.0)	0 (0.0)	12 (4.1)	10 (3.4)
5th	39 (16.1)	0 (0.0)	68 (28.0)	82 (33.7)	9 (3.7)	23 (9.5)	2 (0.8)	1 (0.4)	11 (4.5)	8 (3.3)
6th	33 (12.5)	0 (0.0)	61 (23.1)	124 (47.0)	10 (3.8)	28 (10.6)	1 (0.4)	0 (0.0)	3 (1.1)	4 (1.5)

Of the primary school textbooks, there was a strong focus on the development of thinking powers. Most of the empirical-inductive processes were EI 1, EI 3 and EI 4, while most of the hypothetical-deductive ones were HD 1 and HD 4. At the same time, not all grades demanded EI 2, and some grades did not require HD 2 and HD 3.

This results were corresponded to prior research (Choi *et al.* 1993) in elementary school. Concepts in elementary school science textbook were demanded more cognitive level than theirs cognitive level in Korea.

Among the empirical-inductive processes, the seventh and eighth grade science textbooks in secondary school demanded a great number of EI 1 levels, and the ninth and tenth grade in secondary school required a large number of EI 4. None of the secondary school grades dealt with EI 2 levels.

Table 3. Scientific thinking level of inquiry activities in secondary science textbook ( ) : %

Grade	Empirical-inductive(EI)					Hypothetical-deductive(HD)				
	EI1	EI2	EI3	EI4	EI5	HD1	HD2	HD3	HD4	HD5
7th	391 (53.1)	0 (0.0)	146 (19.8)	187 (25.4)	1 (0.1)	7 (1.0)	1 (0.1)	0 (0.0)	2 (0.2)	1 (0.1)
8th	169 (32.8)	0 (0.0)	111 (21.5)	140 (27.1)	3 (0.6)	38 (7.4)	9 (1.7)	4 (0.8)	28 (5.4)	14 (2.7)
9th	89 (19.2)	0 (0.0)	80 (17.3)	148 (32.0)	18 (3.9)	98 (21.1)	5 (1.1)	3 (0.6)	11 (2.4)	11 (2.4)
10th	29 (4.5)	0 (0.0)	123 (19.1)	242 (37.6)	47 (7.3)	151 (23.4)	11 (1.7)	3 (0.5)	14 (2.2)	24 (3.7)

As the grades of secondary school grow higher, there were decreasing the contents pertinent to the empirical-inductive thinking. 86.5% of the contents of all the secondary schools demanded the EI thinking and 13.5% of the contents HD one. Many parts of HD thinking were comprised of the applications of the theoretical concepts (HD 1). In particular, 1.4% of the contents in seven grade science textbooks were demanded hypothetical- deductive reasoning skills.

Although seventh grade student represents their first formal exposure to science (Miller & Prewitt, 1979), scientific motivation get low because those textbook did not stimulate students' thinking skills. Hypothetical-deductive thinking levels much more higher than elementary students, but second science textbook did not consist of hypothetical-deductive processes as their development level of thinking skills. In particular, HD 1 was much more include than elementary, but other of hypothetical-deductive thinking levels not changed in textbook. Based on these analyses, we were suggested that secondary science textbooks did not stimulate the students' reasoning skills.

3. Reasoning patterns of examination items

In the elementary school, evaluations are now performance assessment, and in secondary school, the students' achievement are evaluated by midterm and final exams during each semester. The tests are made directly by the teachers in charge of the subjects, and this research analyzed their test items.

The elementary school examinations tested many EI 3 level processes in the fourth and sixth grade, while EI 4 level processes were tested in the third and fifth grades. The third to the fifth tests grade did not have the test items that asked EI 2, HD 2 and HD 3 processes. About 60% of the items asked the empirical-inductive questions. Among the hypothetical-deductive thinking levels, the highest proportion of items related to HD 1.

Table 4. Scientific thinking level of assessment in school ( ) : %

Thinking level Grade	Empirical-inductive					Hypothetical-deductive				
	EI1	EI2	EI3	EI4	EI5	HD1	HD2	HD3	HD4	HD5
3rd	18 (16.01)	0 (0.00)	29 (25.89)	34 (30.36)	1 (0.89)	15 (13.39)	0 (0.00)	0 (0.00)	9 (8.04)	6 (5.36)
4th	18 (18.0)	0 (0.00)	32 (32.0)	11 (11.0)	0 (0.00)	19 (19.0)	0 (0.00)	0 (0.00)	12 (12.0)	8 (8.0)
5th	19 (19.59)	0 (0.00)	23 (23.71)	24 (24.74)	0 (0.00)	18 (18.56)	0 (0.00)	0 (0.00)	7 (7.22)	6 (6.19)
6th	12 (14.29)	1 (1.19)	19 (22.62)	17 (20.24)	1 (1.19)	16 (19.05)	2 (2.38)	3 (3.57)	5 (5.95)	8 (9.52)
7th	118 (41.26)	3 (1.06)	16 (5.59)	95 (33.22)	11 (3.85)	32 (11.19)	3 (1.05)	1 (0.35)	4 (1.40)	3 (1.05)
8th	38 (13.82)	1 (0.36)	11 (4.00)	101 (36.73)	28 (10.18)	67 (24.36)	4 (1.45)	20 (7.27)	5 (1.82)	0 (0.0)
9th	32 (11.39)	5 (1.78)	5 (1.78)	90 (21.03)	89 (31.67)	32 (11.39)	6 (2.14)	18 (6.41)	3 (1.07)	1 (0.36)
10th	48 (19.05)	1 (0.40)	26 (10.32)	66 (26.19)	37 (14.68)	48 (19.05)	0 (0.0)	11 (4.37)	2 (0.79)	13 (5.16)

Around 80% of the primary school science textbooks demanded empirical-inductive thinking levels (Table 2), and about 20% required hypothetical-deductive thinking levels. At the same time, about 60% of the tests done in school were empirical-inductive, and 40% were hypothetical-deductive.

In the seventh grade of secondary school, over 70% of the items were made up EI 1 and EI 4, while in the eighth grade one over 60% were EI 4 and HD 1, and in the ninth grade about 50% were EI 5 and HD 1. In the tenth grade, half of the test items required EI 4 and HD 1 processes. The test items, then, focused on specific levels of thinking.

There was no major difference between primary and secondary schools in the proportion of items which asked HD 5 levels from HD 2 related to experimental designs and the control of variables. In elementary school, however, about 15% of the items required the thinking power, while in secondary schools about 10% did. The assessment was very important for learning direction to students (Linn & Gronlund, 1995). But, the assessment did not performance on basic role in Korea.

Ⅳ. Conclusions and suggestions

1. Conclusions

It is possible to develop the students' scientific thinking ability through the inclusion of concrete content. This research discussed the question of whether science education was suitable for the improvement of the students' ability to think. As it turned out, it was improper for its education to develop the ability to think. The reasons are:

First, science education did not stimulate the students' thinking power. In order to improve the students' abilities to think and achieve, higher levels contents must be included in the textbook. In secondary school, however, the levels of the curricula and the evaluations were similar to the students' thinking levels, or lower (Fig. 1). Therefore, science education in secondary schools was not adequate to improve their abilities to think.

In an international comparison, this is possibly why the Korean secondary students attainments are lower than that of the primary students. Currently, the thinking levels of the inquisitive activities and examinations of secondary schools are the same or lower than the students' levels, their achievements, as a results, are lower than the primary students'.

Second, since the textbook contents and test evaluate only parts of the students' thinking processes, they do not help develop their abilities to think. As the result, the students are not able to use proportional, combined, or correlative logic. Most texts and exams contain only descriptive or theoretical concepts. In particular, preserved logic was not dealt with in any if the science books, at any grade.

Third, secondary schools did not study such contents as experimental designs, the control of variables, or/and complicated inquiries of any sort. In the examinations, the research results showed that more high school students did not respond to the items ranging from the eleventh to the fourteenth questions than the primary students. The elementary students tried to express themselves even by incorrect answers, while a number of the high students in the hypothetical-deductive stage did not respond. In addition, about 55% of seventh to ninth grades students, and 66% of the tenth graders in high school, did not respond. This suggests that the science classes failed to develop the students' complex abilities to think.

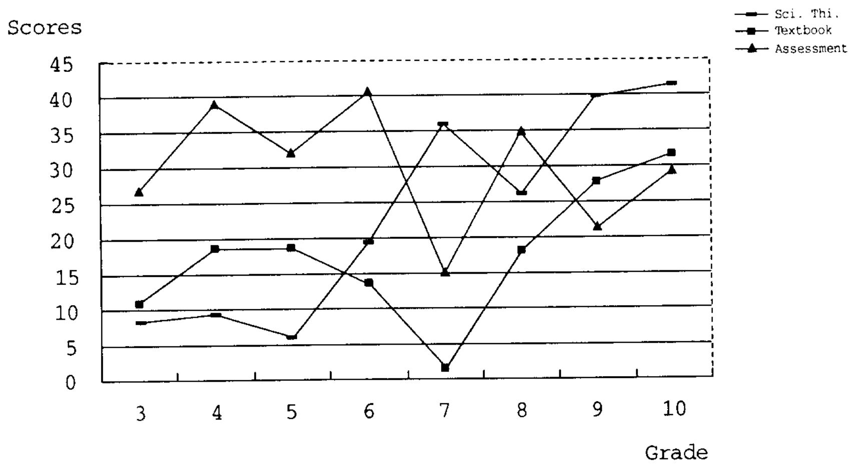

Fig. 1. Reasoning patterns among students' reasoning, textbook inquiries, and examination items across grade

2. Suggestions

So far, we have analyzed the thinking levels, as well as the scientific abilities to think, of third graders in primary school and first graders in high school. As a result, we concluded that science education in secondary school was not adequate for developing scientific thinking. We would now like to suggest some ideas about science education for increasing students' scientific thinking powers.

There must first be items requiring higher inquisitiveness in the textbooks and examinations. The current levels are the same, or lower than the students'. For developing hypothetical-deductive processes, proper exploring activities and examinations need to be done. We should include more use of combined logics, experimental designs through the control of variables, result predictions, and logical probability of data analyses.

Second, textbooks and evaluations should include various students' thinking processes. Currently they focus on a few areas, but not on others. Furthermore, some high school students were not able to form sub-logics, like preserved logics, proportional logics, etc. Throughout all grades, logic should be targeted and reinforced to varying degrees.

Third, students should be exposed to various inquisitive activities. The existing textbooks and test items, are limited to teaching and examining only partial thinking levels. They should include more use of combined logics, experimental designs, result predictions, and probability logics of the data analyses. Diversified activities can improve students' comprehensive abilities.

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