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A Study on Inquiry Science Questions of Physical Domain for Korean Elementary Students (III)

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***Abstract*—The purpose of this study is to analyze students' responses for evaluating scientific inquiry abilities of 5th and 6th grade students in Korea elementary school using inquiry-based science assessment questions. In this study, we mainly report the result about a physics (Kinetics & Energy) content domain of science assessment. To purse the goal of research, we chosen the research subjects of 1,198 fifth and sixth graders from seven elementary schools in Korea. The assessment questions were devised by modifying and reinforcing the NAAA (National Assessment of Academic Ability) developed by NIER (National Institute for Educational Policy Research of Japan) to correspond to 2007' revised National Science Curriculum in Korea. The percentage of correct answer on the inquiry-based assessment was analyzed to evaluate scientific inquiry abilities of fifth and sixth graders in Korea.**

***Index terms –Inquiry based assessment, Elementary student, Inquiry abili, Korea, Physics content domain*.**

I. Introduction

Many nations in the world today believe that science and technology are the keys in leading the national competitiveness in the future. So, science and technology often act as an indicator of a nation's future ability, and many countries including Korea constantly thrive to bring up their educational process to the world-class level through comparison studies on education achievement across the world such as TIMSS (Trends in International Mathematics and Science Study) and PISA (The Programme for International Student Assessment) [1, 2, 3, 4].

There had been many studies on analyzing scientific education achievements using questions from TIMSS and PISA Test and applying the results to the educational curriculum in Korea, but there had rarely been a study based on the inquiry learning elements suggested by the current educational curriculum [5, 6, 7, 8, 9].

In science education, it is called that it is most ideal for students to understand scientific idea and develop knowledge from inquiry skills gained from inquiry activities. Therefore, performance assessment in science needs to transcend the conventional method of each question asking for an independent set of idea and concepts [10, 11]. It should develop students' inquiry skills during the assessment by fluidly linking questions with each other within the assessment through inquiry activities. For this purpose, a performance assessment emulating scientists' inquiry activities in set of several inquiry stages needs to be developed [12, 13, 14, 15, 16].

This study devises inquiry-based science assessment questions based on the NAAA (National Assessment of Academic Ability) developed by NIER (National Institute for Educational Policy Research of Japan) to test inquiry skills of fifth and sixth graders in Korea in order to find a method of assessment that can heighten students' inquiry abilities. Furthermore, the study analyzes percentage of correct answers and commonly chosen wrong answers to propose guidelines on building inquiry-based science questions. The study also provides different teaching approaches for building students' inquiry skills by gathering students' preconceptions and misconceptions on science from each question.

II. Related Work

A. Research subjects and period

The research subjects selected for this study were 1,198 students, of who are 421 fifth graders and 777 sixth graders from seven elementary schools in Changwon, Jinju, Sacheon, Tongyeong, Hamyang, and Woolsan in the Province of Gyeongsamnam-do [17,18, 19].

The assessment was carried out and collected over two weeks period starting in mid-April 2013. The aim of the assessment, the rules and guidelines on the assessment were delivered to teachers before the assessment. The assessment time was set to 40 minutes.

B. Assessment questionnaires

The assessment used for this research was made by modifying and reinforcing the NAAA (National Assessment of Academic Ability) developed by NIER (National Institute for Educational Policy Research of Japan) accordingly to the level of 2007 amendment of science education curriculum of Korea. The assessment is made of four to five questions in each of four subjects of kinetic/energy, matter, biology, and earth science/universe, totaling in nineteen questions. The assessment questions were first translated and modified, and then reviewed by teachers [17, 18].

Each question has elements of fundamental inquiry skills and comprehensive inquiry skills, and questions were developed considering the connections between different questions to measure students' inquiry skills through inquiry activities. Question types were multiple choices (4-answer), short answers, short essays, or combined answer (multiple choice + short answer or short essay). Inquiry types and functions of each question are as listed in table 1.

<Table 1> Framework for inquiry skill and inquiry function for 'matter subject'

Question No	Inquiry subject	Type	Inquiry function
Q 10	Battery configuration and solar cell batteries	Comprehensive	Use of control variables
Q 11	Rubber band powered vehicle	Fundamental	Prediction
Q 12	Connection of batteries	Fundamental Comprehensive	Inference Generalization
Q 13	Strength of electromagnets	Fundamental Comprehensive	Problem recognition Making a hypothesis Using control variables
Q 14	Changing states of water	Fundamental Comprehensive	Communication Inference Problem recognition

C. Response analysis

The answers were graded using a prepared rubric in order to minimize subjectivity of the grader. Partially correct answer, wrong answer, and no response were all handled accordingly and separately as necessary. Of the research subjects of fifth and sixth graders, sixth graders' percentage of correct answers and commonly chosen wrong answers on question materials covered in the fifth grade curriculum were used to analyze possible misconceptions. Both fifth and sixth graders' responses to questions not covered by the standard curriculum were used to analyze any preconception held by students. The overall percentage of correct answer as well as the percentage of correct answer by class year and gender was also compared in order to analyze amount of understanding and amount of achievement on the assessment in different groups [17, 18].

III. METHODS

A. Analysis of responses to the assessment questions

Overall percentage of correct answer

The percentages of correct answers to inquiry-based science assessment questions in a kinetic and energy domain were analyzed by question type and material as table 2.

<Table 2> Percentages of correct answers to inquiry-based assessment questions

Correction ratio (%)	Sexual correction (%)				Year correction (%)		
	Girl (N=559)		Boy (N=639)		5th grade	6th grade	Total (N=1198)
	5th grade	6th grade	5th grade	6th grade			
Kinetic and energy	32.55	38.30	33.60	38.36	33.08	38.33	35.71
	36.16		36.76				

Overall percentage of correct answers on the assessment was 35.71%. The percentage of correct answer of inquiry-based assessment questions in a kinetics and energy were lower than that of the general schools' assessment [19].

Percentage of correct answer by class year

Percentage of correct answer per class year was 5.25% higher for 38.33% in sixth grade than the 33.08% in fifth grade.

Percentage of correct answer by gender

Overall inquiry skills appeared a little superior in boys who scored 36.16% compared to girls who scored 36.76%.

Relevance to the educational curriculum

The percentages of correct answers to inquiry-based assessment questions in kinetics and energy domain by material coverage of currently enforced 2007 amendment of science education curriculum are organized as in table 6. Of the 6 assessment questions, 1 question was covered in fifth grade curriculum and 2 questions were covered in sixth grade curriculum. Rest of the questions came from materials not covered in the educational curriculum.

B. Analysis per question

Each assessment question was further examined for its percentage of correct answer and for its commonly chosen wrong answer based on the particular inquiry skill demanded by the question. First, the particular inquiry skill asked by each question is described, and then student responses are listed in tables. The percentage of correct answer and wrong answers on each question are then analyzed to quarry for possible preconceptions and misconceptions students have on each question.

Question 10. Battery configuration and solar cell batteries

The comprehensive inquiry skill asked by this question was "use of control variables", and it tests for a knowledge that the powers of each model vehicle are greater when there are more number of rubber band windings, when there is stronger intensity of light casted on solar cell panel, and when the batteries are connected in parallel instead of in series.

The question is composed of two problems on solar cell batteries and on battery configuration. The percentages of correct answer on this question were 33.8% and 26.5% for each part and they are quite lower than the overall percentage of correct answer. Most common wrong answers were terms "energy" and "size", provided by 53.8% of test-takers. For

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question 10B, 43.6% of test-takers failed to use the term "series" or "parallel", and gave wrong answers using different terms. The percentage of correct answer of question 10B was low because the topic on properties of solar cell batteries was not yet covered in the test-takers' educational curriculum.

<Table 3> Percentage of correct answers on question 10A by class year

Year	Responded type	Question 10-A (Solution: 1)			Total
		0	1	9	
5th	Probability	53	126	242	421
	%	12.6	29.9	57.5	100.0
6th	Probability	96	279	402	777
	%	12.4	35.9	51.7	100.0
Total	Probability	149	405	644	1198
	%	12.4	33.8	53.8	100.0

<Table 4> Percentage of correct answers on question 10A by gender

Year	Sex	Responded type	Question 10-A (Solution: 1)			Total
			0	1	9	
5th	Girl	Probability	23	61	123	207
		%	11.1	29.5	59.4	100.0
	Boy	Probability	30	65	119	214
		%	14.0	30.4	55.6	100.0
6th	Girl	Probability	47	118	187	352
		%	13.4	33.5	53.1	100.0
	Boy	Probability	49	161	215	425
		%	11.5	37.9	50.6	100.0

<Table 5> Percentage of correct answers on question 10B by class year

Year	Responded type	Question 10-B (Solution: 1)				Total
		0	1	2	9	
5th	Probability	50	130	68	173	421
	%	11.9	30.9	16.2	41.1	100.0
6th	Probability	106	188	134	349	777
	%	13.6	24.2	17.2	44.9	100.0
Total	Probability	156	318	202	522	1198
	%	13.0	26.5	16.9	43.6	100.0

<Table 6> Percentage of correct answers on question 10B by gender

Year	Sex	Responded type	Question 10-B (Solution: 1)				Total
			0	1	2	9	
5th	Girl	Probability	23	62	40	82	207
		%	11.1	30.0	19.3	39.6	100.0
	Boy	Probability	27	68	28	91	214
		%	12.6	31.8	13.1	42.5	100.0
6th	Girl	Probability	53	72	79	148	352
		%	15.1	20.5	22.4	42.0	100.0
	Boy	Probability	53	116	55	201	425
		%	12.5	27.3	12.9	47.3	100.0

Question 11. Rubber band-powered vehicle

The fundamental inquiry skill tested in this question was "prediction", and the question asks for number of rubber band windings that would bring the rubber-powered vehicle to a stop just near the finish zone. The question also requires some mathematical inquiry skills.

The percentage of correct answer on this question was 44.0%, which was slightly lower than the overall percentage of correct answer. The percentage of correct answer was 45.3% for sixth graders and 41.6% for fifth graders. The scores were similar regardless of the material coverage in the coursework. This is because although students learn about rubber-powered model vehicle in third chapter of first semester curriculum of fifth grade in course titled "velocity of an object", the covered course material is relatively distant to the material of this particular question and mainly focuses on teaching how to measure the velocity of the rubber cart and not how to predict the expected travel distance from the number of rubber band windings.

The percentage of correct answer of boys and girls were both similar. The most commonly chosen wrong answer choice selected by 29.6% of test-takers was answer choice ②. This is because this mathematical question may have caused the test-taker to intuitively come up with a numeric correlation between the distance 5 m and the number of windings, 100 times in answer choice ②.

<Table 7> Percentage of correct answers on question 11 by class year

Year	Responded type	Question 11 (Solution: 1)						Total
		0	1	2	3	4	9	
5th	Probability	6	175	126	76	29	9	421
	%	1.4	41.6	29.9	18.1	6.9	2.1	100.0
6th	Probability	13	352	229	144	33	6	777
	%	1.7	45.3	29.5	18.5	4.2	.8	100.0
Total	Probability	19	527	355	220	62	15	1198
	%	1.6	44.0	29.6	18.4	5.2	1.3	100.0

<Table 8> Percentage of correct answers on questions 11 by gender

Year	Sex	Responded type	Question 11 (Solution: 1)						Total
			0	1	2	3	4	9	
5th	Girl	Probability	4	85	60	36	18	4	207
		%	1.9	41.1	29.0	17.4	8.7	1.9	100.0
	Boy	Probability	2	90	66	40	11	5	214
		%	.9	42.1	30.8	18.7	5.1	2.3	100.0
6th	Girl	Probability	3	160	105	68	15	1	352

	%	.9	45.5	29.8	19.3	4.3	.3	100.0
Boy	Probability	10	192	124	76	18	5	425
	%	2.4	45.2	29.2	17.9	4.2	1.2	100.0

Question 12. Connection of batteries

The fundamental inquiry skills tested in this question were "inference" and "generalization". The problem can be solved only when the student understands that connecting batteries in series increases the intensity of electric current but does not influence the lifetime of the battery while connecting batteries in parallel does not influence the intensity of electric current but increases the lifetime of the batteries.

The percentage of correct answers on this question was 41.2%, which is slightly lower than the overall percentage of correct answer. The percentage of correct answer of sixth graders was slightly higher than that of fifth graders because sixth graders learned of this topic in their curriculum. For gender variation, boys scored little bit higher than the girls.

The most commonly chosen answers were answer choice ④ selected by 24.7% of test-takers and answer choice ② selected by 21.6% of test-takers. This is because students had to differentiate a series configuration from a parallel configuration while understanding the direction of motion of vehicle in the figure. Students who did not understand the difference between series configuration and parallel configuration chose answer choice ④, and students who did not consider the direction of motion of vehicle chose answer choice ②.

<Table 9> Percentage of correct answers on question 12 by class year

Year	Responded type	Question 12 (Solution: 3)						Total
		0	1	2	3	4	9	
5^{th}	Probability	11	45	94	158	109	4	421
	%	2.6	10.7	22.3	37.5	25.9	1.0	100.0
6^{th}	Probability	16	69	165	335	187	5	777
	%	2.1	8.9	21.2	43.1	24.1	.6	100.0
Total	Probability	27	114	259	493	296	9	1198
	%	2.3	9.5	21.6	41.2	24.7	.8	100.0

<Table 10> Percentage of correct answers on question 12 by gender

Year	Sex	Responded type	Question 12 (Solution: 3)						Total
			0	1	2	3	4	9	
5^{th}	Girl	Probability	8	23	46	75	52	3	207
		%	3.9	11.1	22.2	36.2	25.1	1.4	100.0
	Boy	Probability	3	22	48	83	57	1	214
		%	1.4	10.3	22.4	38.8	26.6	.5	100.0
6^{th}	Girl	Probability	6	30	81	142	89	4	352
		%	1.7	8.5	23.0	40.3	25.3	1.1	100.0
	Boy	Probability	10	39	84	193	98	1	425
		%	2.4	9.2	19.8	45.4	23.1	.2	100.0

Question 13. Strength of electromagnets

The comprehensive inquiry skills tested in this question were "problem recognition", "making a hypothesis", and "using control variables". The question asks for understandings on conditions of electromagnetic strength. The electromagnet strength is determined by the intensity of electric current and number of windings of a magnet wire, and the question asks if the electromagnetic strength increases with increased intensity of electric current and increased number of windings of a magnet wire.

The percentage of correct answer on this question was 35.3%, which was lower than the overall percentage of correct answer. The percentage of correct answer were 26.1% for fifth graders and 40.3% for sixth graders, higher in sixth graders, and it shows that sixth graders show stronger inquiry skills considering the fact that both grades did not learn of this topic in their course curriculum. For gender variation, girls scored 45.5%, which was higher than boys who scored 36.0%. It shows that girls demonstrate stronger skills in high level inquiry activities such as "making a hypothesis" and "using control variables".

27.4% of test-takers gave no response and 36.8% gave an answer using terms completely unrelated from the answer. This was probably due to the fact that the question was difficult as is and the material of this question is not covered until the fifth chapter of the first semester curriculum of sixth grade.

<Table 11> Percentage of correct answers on question 13 by class year

Year	Responded type	Question 13 (Solution: 1)				Total
		0	1	2	9	
5^{th}	Probability	135	110	1	175	421
	%	32.1	26.1	.2	41.6	100.0
6^{th}	Probability	193	313	5	266	777
	%	24.8	40.3	.6	34.2	100.0
Total	Probability	328	423	6	441	1198
	%	27.4	35.3	.5	36.8	100.0

<Table 12> Percentage of correct answers on question 13 by gender

Year	Sex	Responded type	Question 13 (Solution: 1)				Total
			0	1	2	9	
5^{th}	Girl	Probability	68	53	0	86	207
		%	32.9	25.6	.0	41.5	100.0
	Boy	Probability	67	57	1	89	214
		%	31.3	26.6	.5	41.6	100.0
6^{th}	Girl	Probability	84	160	0	108	352
		%	23.9	45.5	.0	30.7	100.0
	Boy	Probability	109	153	5	158	425
		%	25.6	36.0	1.2	37.2	100.0

Question 14. Changing states of water

The fundamental inquiry function tested in this question was “communication” and comprehensive inquiry functions tested in this question were “problem recognition” and “inference”.

The question tests for a knowledge that water can change its state to water, water vapor, or mist (steam) depending on its temperature. The question is composed of part E, F, and G, and the percentage of correct answer on each question were 51.1%, 22.0%, and 37.9% respectively. Sixth graders scored higher in all three questions than the fifth graders.

For question 14E, a lot of students chose answer choice ①, “air”, as the wrong answer, and this shows that many students have the misconception that when water boils water turns into “air” instead of “water vapor” which is invisible. Answer choice ①, “air”, was also commonly chosen wrong answer for question 14F, and this shows that students in general lack understandings on changing states of water.

Of three questions, the lowest percentage of correct answer was on question 14G which asked for knowledge that it is “vapor” when water heats up, and it is “mist” when the steam of water cools down in the air for condensation. The low percentage of correct answer shows that there were very few students who understood the difference between “water vapor” and “mist (sometimes steam, but steam is technically also invisible)”, and this is because of a preconception malformed in student’s daily life.

So, it is encouraged to correct these misconceptions and preconceptions students have on changing states of water.

<Table 13> Percentage of correct answer on question 14E by class year

Responded type / Year		Question 14-E (Solution: 5)										Total
		0	1	2	3	4	5	6	7	8	9	
5th	Probability	30	75	23	21	26	197	4	36	0	9	421
	%	7.1	17.8	5.5	5.0	6.2	46.8	1.0	8.6	.0	2.1	100.0
6th	Probability	40	123	29	46	34	415	10	65	3	12	777
	%	5.1	15.8	3.7	5.9	4.4	53.4	1.3	8.4	.4	1.5	100.0
Total	Probability	70	198	52	67	60	612	14	101	3	21	1198
	%	5.8	16.5	4.3	5.6	5.0	51.1	1.2	8.4	.3	1.8	100.0

<Table 14> Percentage of correct answer on question 14E by gender

Responded type Year Sex			Question 14-E (Solution: 5)										Total
			0	1	2	3	4	5	6	7	8	9	
5th	Girl	Probability	11	40	9	14	10	98	2	18	0	5	207
		%	5.3	19.3	4.3	6.8	4.8	47.3	1.0	8.7	.0	2.4	100.0
	Boy	Probability	19	35	14	7	16	99	2	18	0	4	214
		%	8.9	16.4	6.5	3.3	7.5	46.3	.9	8.4	.0	1.9	100.0
6th	Girl	Probability	17	56	8	18	13	196	5	35	2	2	352
		%	4.8	15.9	2.3	5.1	3.7	55.7	1.4	9.9	.6	.6	100.0
	Boy	Probability	23	67	21	28	21	219	5	30	1	10	425
		%	5.4	15.8	4.9	6.6	4.9	51.5	1.2	7.1	.2	2.4	100.0

<Table 15> Percentage of correct answer on question 14F by class year

Responded type / Year		Question 14-G (Solution: 7)										Total
		0	1	2	3	4	5	6	7	8	9	
5th	Probability	31	83	13	39	19	67	75	83	3	8	421
	%	7.4	19.7	3.1	9.3	4.5	15.9	17.8	19.7	.7	1.9	100.0
6th	Probability	42	179	30	39	17	133	131	181	6	19	777
	%	5.4	23.0	3.9	5.0	2.2	17.1	16.9	23.3	.8	2.4	100.0
Total	Probability	73	262	43	78	36	200	206	264	9	27	1198
	%	6.1	21.9	3.6	6.5	3.0	16.7	17.2	22.0	.8	2.3	100.0

<Table 16> Percentage of correct answer on question 14F by gender

Responded type Year Sex			Question 14-F (Solution: 7)										Total
			0	1	2	3	4	5	6	7	8	9	
5th	Girl	Probability	12	40	8	18	9	39	35	41	1	4	207
		%	5.8	19.3	3.9	8.7	4.3	18.8	16.9	19.8	.5	1.9	100.0
	Boy	Probability	19	43	5	21	10	28	40	42	2	4	214
		%	8.9	20.1	2.3	9.8	4.7	13.1	18.7	19.6	.9	1.9	100.0
6th	Girl	Probability	17	95	19	13	8	67	49	77	1	6	352
		%	4.8	27.0	5.4	3.7	2.3	19.0	13.9	21.9	.3	1.7	100.0
	Boy	Probability	25	84	11	26	9	66	82	104	5	13	425
		%	5.9	19.8	2.6	6.1	2.1	15.5	19.3	24.5	1.2	3.1	100.0

<Table 17> Percentage of correct answer on question 14G by class year

Responded type / Year		Question 14-G (Solution: 3)										Total
		0	1	2	3	4	5	6	7	8	9	
5th	Probability	34	53	9	135	48	41	28	33	29	11	421
	%	8.1	12.6	2.1	32.1	11.4	9.7	6.7	7.8	6.9	2.6	100.0
6th	Probability	52	85	16	319	85	69	60	35	45	11	777
	%	6.7	10.9	2.1	41.1	10.9	8.9	7.7	4.5	5.8	1.4	100.0
Total	Probability	86	138	25	454	133	110	88	68	74	22	1198
	%	7.2	11.5	2.1	37.9	11.1	9.2	7.3	5.7	6.2	1.8	100.0

<Table 18> Percentage of correct answer on question 14G by gender

Responded type Year Sex			Question 14-G (Solution: 3)										Total
			0	1	2	3	4	5	6	7	8.0	9	
5th	Girl	Probability	13	32	5	64	22	20	13	17	16	5	207
		%	6.3	15.5	2.4	30.9	10.6	9.7	6.3	8.2	7.7	2.4	100.0
	Boy	Probability	21	21	4	71	26	21	15	16	13	6	214
		%	9.8	9.8	1.9	33.2	12.1	9.8	7.0	7.5	6.1	2.8	100.0
6th	Girl	Probability	19	37	6	153	36	32	35	14	16	4	352
		%	5.4	10.5	1.7	43.5	10.2	9.1	9.9	4.0	4.5	1.1	100.0
	Boy	Probability	33	48	10	166	49	37	25	21	29	7	425
		%	7.8	11.3	2.4	39.1	11.5	8.7	5.9	4.9	6.8	1.6	100.0

VI. Conclusion

This study develops inquiry-based assessment questions by modifying and reinforcing the NAAA by NIER of Japan to match 2007 amendment of science education curriculum of Korea. The assessment was given to fifth and sixth grade students, and the responses were collected for analysis. The percentages of correct answers and commonly chosen wrong answers from the assessment were ascertained, and students' inquiry abilities were able to be determined.

The following conclusions were made from this study. First, students' inquiry abilities could be determined from analyzing percentage of correct answers according to the material coverage in the educational curriculum. Students familiar with a single question asking for a single concept were challenged by the assessment format asking for inquiry skills in a series of questions. The overall percentage of correct answer was 35.71%, which was lower than that of the school's general assessment. The percentage of correct answer for questions based on materials covered in class was 38.47%, which was higher than that of questions based on materials not covered in class at 30.90%. However, both were quite lower than the score of the school's general assessment.

Second, based on the result of this study, future assessment methods in the subject of science should all turn to assessments testing for students' inquiry abilities. For such transition to happen, further studies need to be carried out to develop inquiry-based questions in various subjects for challenging and testing inquiry skills in different subjects.

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