JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

DEVELOPMENT OF AN INQUIRY ACTIVITY MODEL EMPHASIZING THE REPRESENTATION OF PRIMARY SCIENCE TEXTBOOKS

Soyeon Kim,
Jung Bog Kim

Abstract. *Despite increased research interest in improving students' scientific inquiry abilities, how to conduct scientific inquiry using science textbooks that are easily accessible to primary school students remains understudied. This study developed and verified an inquiry activity model (IAM) to improve the performance of primary school students in science textbook inquiry activities. Data were collected from sixth-grade primary students (n = 167) to analyze the difficulty level of textbook inquiry activities. An analysis tool was developed, focusing on inquiry skills and process flow. Expert analysis increased the tool's validity. The analysis revealed that students possessed low integrated inquiry skills, were partially aware of the inquiry process flow, and could not design experiments. Hence, the IAM was developed to enhance students' ability to perform textbook inquiry activities and understand the activity phases. It emphasized the flow and representation of the inquiry process for students to easily recall the contents as they learn the interconnectivity between phases. The post-test of the experimental group and the inquiry process flow chart showed significant improvement in all areas of inquiry ability. The scores for "connections" and "interconnectivity" in the inquiry process flow were high, reflecting the model's effectiveness in showing the interconnectedness of all stages.*

Keywords: *primary science textbook, inquiry activity model, representation in inquiry activity, inquiry phase*

Soyeon Kim
Kumnam Elementary School, Korea
Jung Bog Kim
Korea National University of Education, Korea

Introduction

Scientific inquiry holds an important position in science education as students experience and appreciate the essence of science. Students can develop scientific knowledge and concepts through scientific inquiry (Kirschner et al., 2006; Kruit et al., 2018; van Uum et al., 2017). Their experiences help them understand what scientists do and how scientific knowledge forms and expands (Concannon et al., 2020). Previous studies have proven that inquiry classes are effective in improving science learning (Geier et al., 2008; Lederman & Lederman, 2019; Liu et al., 2022; Minner et al., 2010; Schroeder et al., 2007). Small-group scientific inquiry helps students interact with their peers (Wilmes & Siry, 2018), increasing their interest in and enjoyment of the subject. Engaging in scientific inquiry has been shown to positively influence future-oriented science motivation, the promotion of science self-concept, and the development of high self-efficacy (Cairns & Areepattamannil, 2019).

Inquiry has been consistently emphasized as a key subject in science education since the 20th century (Bybee & DeBoer, 1994; National Research Council, 2000). Inquiry-oriented curricula and textbooks have been developed in numerous countries (Ministry of Education Singapore, 2007; Qualifications and Curriculum Authority, 2004; Song, 2006). Furthermore, despite several curriculum revisions, the ability to conduct scientific inquiry remains an important goal in science education. Moreover, each country reflects a variety of inquiry activities in its science curriculum (Edelson et al., 1999; Singer et al., 2000; Zion et al., 2004; Wang & Zhao, 2016). Efforts have been made to implement inquiry activities in textbooks so that teachers and students may easily access them (Dogan, 2021, Aldahmash et al., 2016; Andersen, 2020). However, there are also limitations. For example, textbooks in China do not help students develop scientific inquiry or reasoning skills (Li et al., 2024). Korea's science curriculum also fails to include detailed information on inquiry, and the nature of inquiry that takes place in schools is sometimes presented differently in each textbook (Lee, 2005).

Primary science textbooks in Korea are activity-oriented, rather than concept-oriented; hence, students acquire knowledge of science concepts through various inquiry activities (Lim, 2020). These inquiry activities are important to understand students' grasp of science concepts. To compensate

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

for the shortcomings of the national textbook system, as of 2022, primary science textbooks have been changed to an authorized textbook system in Korea. The content and methods of inquiry activities in primary science textbooks vary among authors, resulting in a diversity of inquiry activities. This diversity explains the varied approaches to inquiry found in primary science education. However, in primary schools, teachers with majors in various subjects teach science. Consequently, they may struggle to understand scientific inquiry and inquiry skills (Lee et al., 2004; McDonald & Songer, 2008; van Zee et al., 2005). Therefore, teachers must be provided with specific guidance to conduct scientific inquiry activities. A primary student inquiry activity model (IAM) must be developed to allow teachers to enhance students' abilities to engage in textbook inquiry activities.

To enhance the scientific inquiry abilities of primary school students, it is crucial to consider the characteristics of their cognitive development. Primary school students in Korea, aged 6-12, typically fall within Piaget's concrete operational and formal operational stages (Gabel & Sherwood, 1980). Science textbook exploration activities can positively impact students by engaging their cognitive thinking abilities, thus facilitating cognitive development. These activities are most effective when presented slightly above the students' current cognitive level (Martin, 2012).

Recent studies have described how to represent scientific knowledge or concepts in various forms, such as texts, pictures, and models, to understand and acquire them for enhancing scientific inquiry skills (Balgopal et al., 2017; Lämsä et al., 2018; Ryoo & Bedell, 2019). Studies focusing on information transfer and effective understanding of scientific concepts through visual representation have been conducted in science education using the concept of "representational competence" (Kozma & Russell, 1997, 2005; Nitz et al., 2014). The findings show that student participation in the visualization process through representation (Tippett, 2016) and the use of visual representation enhance students' scientific reasoning and participatory and communication skills (Ainsworth et al., 2011). Knowledge is derived from representation, and its use requires representation (Newell, 1994). In other words, to conduct inquiry activities, students need knowledge, which must be represented in some form. Research has been conducted on various representations but not on representations in textbook inquiry activities or representations actively created by students.

Therefore, this research aimed to develop an IAM that improves students' ability to perform inquiry activities by allowing them to use their representations in each phase of activities. The research questions are as follows:

1. What difficulties do primary students face when conducting textbook inquiry activities?
2. What should be the composition and content of a science IAM that emphasizes representation and enhances students' ability to perform an inquiry activity in a primary science textbook?
3. What is the effect of applying a scientific IAM that emphasizes representation?

Research Methodology

Design

In this study, the research problem was specified based on the difficulties the researchers had experienced as a teacher while guiding students' textbook-based science exploration activities. Based on previous research, we adopted a quantitative research design and collected data using questionnaires and flowcharts.

The study was conducted from March to December 2022. The participants were students from four schools located in cities and rural areas in the Republic of Korea, who were 6th-grade primary school students and not enrolled in gifted or special classes.

Participants were informed about the study by teachers in their primary school science classes, and those who wanted to participate voluntarily did so with the consent of their parents.

Procedure

Student inquiry performance difficulties were analyzed, designing an inquiry model and verifying its effectiveness. In the inquiry performance difficulty analysis, various scientific inquiry definitions were selected through a literature review of the science inquiry function and flow in primary science textbooks. A test of science process skills (TSPS) and modified scientific process flowchart assessment (Mo-SPFA) were developed to measure primary students' science inquiry ability and process flow. Three science education experts and three primary school teachers analyzed each questionnaire for validity and reliability. This process was followed by a preliminary test; wherein primary students' science inquiry skills and process flow were examined to analyze their inquiry performance.

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

In the IAM development stage, an IAM was developed based on the results of the student inquiry ability and process flow tests. The model was modified and supplemented by performing a content validity test and pilot test on experts. The students were divided into two groups: the experimental group, wherein classes were conducted using the developed IAM and worksheet; and the comparison group, wherein classes were conducted using traditional textbooks and observations. Although different teachers implemented the model in each participating school, the instructors for both experimental and control groups were consistent within each school. The instructors conducted the class as per their teaching method. To validate the effectiveness of the IAM after its application, a post-inquiry ability test and an inquiry process flow test were conducted to analyze the changes in students' science inquiry ability and the inquiry process flow.

Participants

The study participants were 6th-grade students from four schools in two urban and two rural areas in the Republic of Korea. One of the city schools has more than 1,000 students, while the other school has fewer than 700 students. One of the rural schools has 200 students, and the other has fewer than 60 students. In Korean primary school textbook inquiry activities, the basic inquiry skills and the integrated inquiry skills are both used in the 6th grade. Therefore, in this study, 6th-grade students were selected to elucidate the difficulties students had in the inquiry process. Two classes were selected from each school, resulting in a total sample of 167 students. Participants were chosen based on their agreement with the study's purpose and methods, with consideration for variations in students' science achievement levels. To examine the effect of implementing the model, 84 students from four schools were introduced to the model, forming the experimental group, while 83 students formed the control group. The sample size was large enough for quantitative verification ($n > 30$) and, if sampled independently and randomly, shows a normal distribution regardless of distribution (Kwak & Kim, 2017).

Data Analysis

SPSS (version 28) was employed for conducting a quantitative analysis on the pre- and post-test results for each analysis element. Additionally, before introducing the IAM, a scientific inquiry ability test was performed to verify the homogeneity of the groups, and the group identity was confirmed through *t*-tests. The difficulties faced by students in inquiry activities were analyzed using an independent samples t-test and a paired-samples *t*-test.

Instrumentation

The TSPS

The TSPS, developed by Kwon and Kim (1994), was modified and supplemented to examine the science inquiry ability of primary students. The TSPS was developed to apply to fifth graders in primary school and third graders in middle school. Inquiry ability is divided into basic and integrated inquiry skills. As the inquiry model developed here is based on government textbooks that reflect the Korean national curriculum, a variety of text and picture materials at the primary school level are presented to make it easy for students to understand. It was evaluated to be appropriate to examine students' scientific inquiry abilities, using the TSPS, which has been successfully used by previous research targeting Korean primary school students (Kang & Noh, 2017; Hong & Hong, 2019; Park et al., 2017). The TSPS originally consisted of 30 questions (with four choices each), with three questions for each sub-element. However, for the present study, only 28 questions were chosen by deleting the concepts of observation and measurement, which are unfamiliar to primary students. The content validity index (CVI) was obtained and analyzed by applying a two-step rating method of appropriate (1) and inappropriate (0), based on the responses of six experts. On finalizing the questions, the reliability (Cronbach's α) was found to be 0.74. A total of 28 points were scored, with 1 point for a correct answer and 0 for an incorrect answer. The examination time was about 40 minutes.

Mo-SPFA

The Next Generation Science Standards (National Research Council, 2013) categorizes "inquiry-based science" as one of the "dimensions" of science learning that students should participate in and emphasizes "scientific practice." Examining the processes and phases of scientific inquiry is necessary for scientists to understand the processes

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

and procedures of studying the natural world. To conduct effective scientific inquiry, experiment classes, including various elements of the inquiry process, must be conducted. Students' understanding of the inquiry process can be enhanced by learning the elements of the inquiry process and the interrelationships between these elements (Kim, 2007). Even in the case of gifted middle school students, who believe that they know the inquiry process, the connections they draw between the inquiry elements are inaccurate (Park et al., 2015). Therefore, it is important to recognize the inquiry process' phases and flow to enhance students' ability to perform inquiry activities. Wilson and Rigakos (2016) determined that the existing tools to evaluate the scientific inquiry process are unsuitable because they identify only the segmented steps of students' scientific inquiry. Therefore, to understand the overall observable flow chart of the scientific inquiry process, five items were presented as a rubric – connection, experiment design, reason for doing science, nature of science, and interconnectivity. In this study, the SPFA chart evaluation tool, developed by Wilson and Rigakos (2016), was modified and supplemented to suit primary students and used as a tool to intuitively evaluate students' understanding of the inquiry process' steps and flow. The TSPS and Mo-SPFA, to analyze the difficulties of student inquiry activities, were introduced in March at the beginning of the semester.

To analyze textbook inquiry activities, the researchers used the analysis framework developed by Millar (2010) to analyze textbook inquiry activities. This framework can aid in the analysis of various areas, such as inquiry goals, activities, and content of thinking in inquiry activities. Based on the analysis of the types of inquiry activities in the textbooks, the contents of the Mo-SPFA were produced, with activity goals, contents, and thinking contents that are most frequently presented in the textbooks. The Mo-SPFA was created using the inquiry activities of the third- and fourth-grade science achievement standards that the students learned the previous year. Based on the analysis of the types of inquiry activities in the textbooks, the contents of the Mo-SPFA were produced, with activity goals, contents, and thinking contents that are most frequently presented in the textbooks. The post-Mo-SPFA content was similar to the pre-test, based on the inquiry activities at the fifth- and sixth-grade science textbook levels. The SPFA suggested five analysis factors, however, on consultation with experts and considering the science level and ability of the primary students, as required by the national level curriculum, connection, interconnectivity, and experimental design were set as the three analysis factors.

The interconnectivity element analyzes the overall flow chart structure of the inquiry activity process. The experimental design element evaluates the overall terms of the inquiry activity process, such as research problems, hypothesis, and variable control. In this research, the analysis method adopted was based on the notion that writing down the direct search terms or the contents of each process was the same among primary students. The Dreyfus Model, developed by Dreyfus and Dreyfus in 1980, was used to assign a grade score for each item. "Naïve" had 1 point, "novice" had 2 points, and "intermediate" had 3 points. However, primary students had difficulty in setting research questions during both open and guided inquiry (Byun et al., 2011; Krajcik et al., 1998). Hence, more naïve scores than novice scores appeared in the Dreyfus Model. It was modified (Tables 1 and 2) by giving scores for each item as per expert consultation.

Table 1
Connection Evaluation Criteria

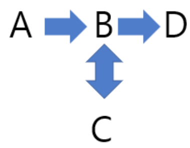
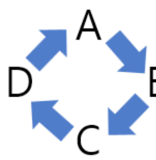
Item	Dimension	Score (in points)			
		0	1	2	3
Connections	Lines that connect ideas	None	Some	Some	Some
	Arrows going in one direction	None	None	Some	Some
	Double-sided arrows	None	None	None	Some

https://doi.org/10.33225/jbse/24.23.315

Journal of Baltic Science Education, Vol. 23, No. 2, 2024

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 2
Rubric Used to Analyze Interconnectivity Rating

“	Dimension	Form	Score
Interconnectivity rating	Directionless link		0
	One-way link		1
	Circular link		2
	Link in all directions		3

As the evaluation criteria for experimental design elements, the five phases of inquiry-based learning, developed by Pedaste et al., (2015), were orientation-conceptualization-investigation-conclusion-discussion. Based on this, the number of evaluation criteria for the experimental design elements of the pre-and post-test was matched and analyzed. The revised Mo-SPFA was analyzed by obtaining a CVI by applying a two-step rating method of "appropriate" (1) and "inappropriate" (0) by six experts. The CVI of the "connection" and "experimental design" elements of questions 1, 2, and 3 was 1.0, and the CVI of the "interconnectivity" element was 0.83. A quantitative analysis was performed on the pre-and post-test results for each analysis element.

Research Results

Difficulties in Student Inquiry Activities in the Textbook

In schools, science inquiry is conducted in various ways, however, mostly, students perform inquiry activities by reading the instructions in the textbooks. Students face difficulties in reading textbooks and performing inquiry activities. Therefore, by analyzing the types of inquiry activities in textbooks, this study examined the students' lack of inquiry skills and understanding of the inquiry process flow. In this manner, the ways to improve students' ability to perform inquiry activities were explored. Two analysis tools, TSPS and Mo-SPFA, were created. The results are as follows.

TSPS

TSPS was performed to analyze the difficulties faced by students in conducting inquiry activities. In Table 3, the results show the achievement of 50 points or more in basic science inquiry skills, such as observation, classification, and prediction, with a minimum score of 51.5 points (measuring) and a maximum score of 70.8 points (predicting).

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 3
Results of the Pre-TSPS

Inquiry skills	Total #	Total scores	Correct answer rate
Observation	2	1.36	68.0
Classification	3	2.10	69.8
Measuring	2	1.03	51.5
Inferring	3	1.70	56.7
Predicting	3	2.12	70.8
Transforming data	3	1.47	49.1
Interpreting data	3	1.57	52.4
Formulating hypotheses	3	1.36	45.2
Controlling variables	3	1.81	60.4
Generalization	3	1.29	42.3

The scores for integrated inquiry skills were lower than basic scientific inquiry skills, ranging from 42.3 (generalization) to 60.4 (controlling variables). Among the integrated inquiry skills, low scores were observed for "transforming data,""interpreting data,""formulating hypothesis," and "generalization." This is because of the limited number of inquiry activities that primary students can plan and perform and because they learn integrated inquiry skills in the fifth or sixth grade. Therefore, students do not have enough opportunities to acquire inquiry skills, such as transforming and interpreting data, leading to low scores.

Mo-SPFA

As a result of analyzing textbook inquiry activities, three types of inquiry in primary school science textbooks were identified: inquiry activity goals, activities, and thought contents. The Mo-SPFA consists of 3 questions. Table 4 shows the pre–Mo-SPFA content elements, and Figure 1 is the questionnaire to measure Mo-SPFA.

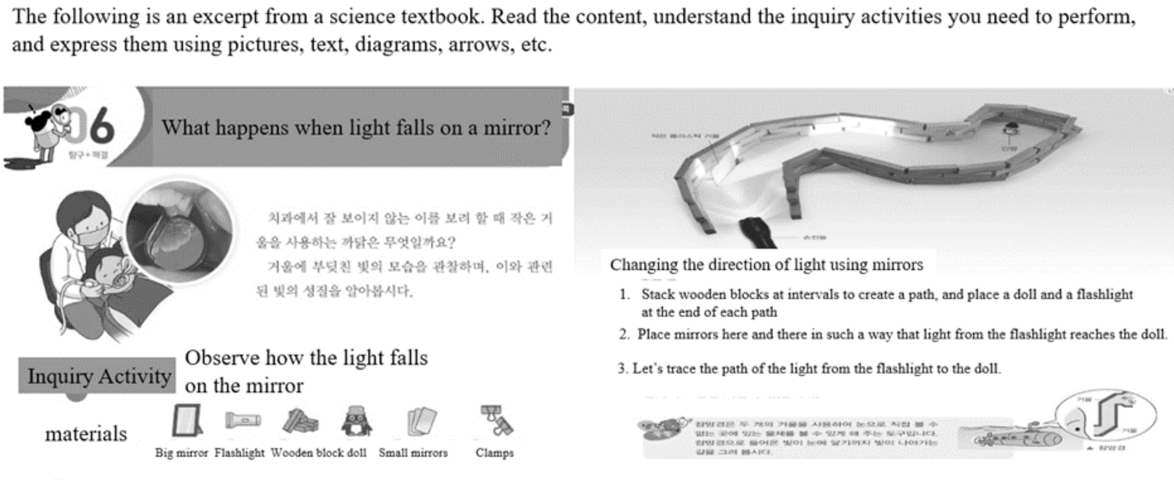
Table 4
Composition Pre–Mo-SPFA Content Elements

Inquiry activity analysis element	Contents		
	Item 1. Shadow and mirror	Item 2. Separation of mixtures	Item 3. Life cycle of a plant
Learning objective	Students recall an observable feature of an object, material, or event	Students gain a better understanding of a scientific idea, concept, explanation, model, or theory	Students recall a pattern in observations (e.g., a similarity, difference, trend, relationship)
What students have to do with objects and materials	Present or display an object or material	Observe an aspect or property of the object, material, or event	Use an observing or measuring instrument
What students must "do" with ideas	Report observations using scientific terminology	Make and/or test a prediction	Identify a similarity or difference (between objects, materials, or events)

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 1
A Part of the Mo-SPFA Questionnaire



In Tables 5 and 6, for the elements of each question, connection and interconnectivity account for 3 points, with the experimental design score being based on the item – question 1 for 4 points, question 2 for 7 points, and question 3 for 5 points.

Table 5
Pre Mo-SPFA Scores

Question #	Connections	Experimental Design	Interconnectivity
#1	0.35	0.63	0.06
#2	0.72	0.09	0.18
#3	0.40	0.99	0.10

Table 6
Percentage of Correct Answers for Each Experimental Design (Acquisition Score Ratio Value)

	#1	#2	#3
Scores	15.30	14.10	19.80

As reported in Table 6, the scores obtained for connection and interconnectivity are extremely low, implying that the students did not realize the connection between each phase of the inquiry process. They scored low on experimental design as well, scoring less than 20 out of 100 points, although the school science classes covered this aspect. This indicates a low awareness level of experimental design regarding the question, hypothesis, and experiment, in addition to the elements connected to the inquiry process. Thus, it may be inferred that the current scientific inquiry methods outlined in Korean science textbooks make it difficult for students to obtain scientific inquiry skills and understand the inquiry process flow.

Development of the IAM Emphasizing Representation and Phases

The IAM developed in this research was expected to improve primary students' ability to perform science inquiry activities prescribed in their textbooks. Furthermore, it was expected to be easily used and modified by teachers based on the curriculum flow. Therefore, it was necessary to develop the model based on the 2022 authorized textbooks. The developed IAM was to be used within the existing science classes so that the students would not be burdened with the content. The IAM content was given the highest priority among the inquiry activity types.

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The composition of the inquiry activities was based on orientation-conceptualization-investigation-conclusion-discussion by integrating the inquiry process model developed by Pedaste et al. (2015) and the scientific practice presented by the Next Generation Science Standards. During the activities, when an inquiry question was not explicitly revealed, it was clarified in the inquiry process. Inquiry activities are shown in the order of inquiry design and execution. In addition, textbook inquiry activities included both linear and non-linear activities. When developing the IAM, using representations, the researchers tried to change the textbook contents into easy-to-understand information that the students could easily remember. Thus, the inquiry activities presented in the textbook were expressed in simple sentences and organized systematically so that the students could read the sentences necessary for carrying out the inquiry activity and undertake the representation process by expressing the activity in pictures. For example, during an inquiry activity, students read the sentence, "I am making an electric circuit by connecting batteries, wires, and switches" and drew a simple picture. The student could either draw a picture of a battery, wire, or switch, or represent a picture connecting a battery, wire, and switch.

To verify the model validity, a validity test was conducted, and six experts were interviewed to review the IAM's relevance, effectiveness, and applicability. An overall positive scale of 0.83 or higher was obtained, indicating that each IAM question is consistent with expert evaluation to a considerable extent. In addition, to examine the model validity and its effectiveness for students' inquiry activities, a pilot test was conducted based on the contents of other grades with different achievement standards to derive improvement points. The results showed that some students took a long time to express each stage of the inquiry activity through drawing. In fact, a tendency to focus on the drawing was noted. The second program was modified to express the process of the inquiry activities in various ways, using both pictures and text. The IAM is presented in Figure 1. From August to December 2022, the model was introduced in four primary schools in different regions. Classes were conducted for the experimental group with the IAM, while the control group took classes with the existing national textbooks, using the same units and contents as the experimental group. All the conditions, such as the learning target level, content, and achievement standard of both groups were similar. When applying the IAM, the participants were not informed about their respective groups. To minimize the influence of teacher variables in the IAM, both groups were assisted by the same teachers.

Effects of IAM Development

To verify the IAM's impact on exploration ability, an independent sample t-test between the groups was conducted. In addition, to determine the degree of improvement in exploration ability, a pre- and post-paired t-test was conducted for each of the groups.

Analysis of Science Inquiry Ability

The independent samples t-test was performed on post-scores between the two groups. Table 7 presents the results of the independent sample t-test to identify the statistically significant difference between the IAM and each sub-factor. The significant changes are indicated in bold.

Table 7
Comparison of Post-TSPS Results between the Experimental Group and Control Group

Inquiry skills	Group	*N*	*M*	*SD*	*t*	*p*
Observation	Experimental	83	1.65	0.50	2.646	<.001
	Control	84	1.44	0.52		
Classification	Experimental	83	2.58	0.54	3.858	<.001
	Control	84	2.20	0.70		
Measuring	Experimental	83	1.51	0.67	4.137	<.001
	Control	84	1.09	0.62		
Inferring	Experimental	83	2.11	0.75	1.993	<.001
	Control	84	1.85	0.90		

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Inquiry skills	Group	*N*	*M*	*SD*	*t*	*p*
Predicting	Experimental	83	2.36	0.64	1.543	.125
	Control	84	2.19	0.80		
Transforming data	Experimental	83	1.83	0.78	2.021	<.05
	Control	84	1.58	0.84		
Interpreting data	Experimental	83	2.08	0.72	3.375	<.001
	Control	84	1.65	0.92		
Formulating hypotheses	Experimental	83	1.81	0.79	3.508	<.001
	Control	84	1.36	0.83		
Controlling variables	Experimental	83	2.02	0.78	1.435	.153
	Control	84	1.84	0.88		
Generalization	Experimental	83	1.84	0.83	3.600	<.001
	Control	84	1.35	0.92		

In the areas of observation, classification, measurement, and prediction, the average scores of the experimental group were 1.65, 2.58, 1.51, and 2.11, respectively, and of the control group were 1.44, 2.20, 1.09, and 1.85, respectively, revealing that the average scores of the former to be higher than the latter. These differences are statistically significant. Hence, the IAM proved to be effective in enhancing the inquiry ability of observation, classification, measurement, and inferring. In the predicting area of inquiry ability, the average of the experimental group was 2.36, higher than the average of 2.19 of the control group. However, it is not statistically significant at $t = 1.543$ ($p = .125$).

Among the integrated inquiry abilities, the averages of the experimental group in transforming data, interpreting data, formulating hypotheses, and generalization were 1.83, 2.08, 1.81, and 1.84, respectively, relatively higher than the averages of the control group, which were 1.58, 1.65, 1.36, and 1.35, respectively. These differences are statistically significant. Thus, the IAM was found to be effective in enhancing the integrated scientific inquiry ability, excluding controlling variables. The average of the experimental group in "controlling variables" was 2.02, higher than the average of 1.84 of the control group. However, the two groups showed no significant differences ($t = 1.435$; $p = .153$). In the IAM, the number of inquiry activities dealing with variable control was small and the effect was insignificant.

Table 8 shows that a paired samples t-test was performed on the pre- and post-scores of the inquiry skill of both groups. The significant changes are indicated in bold.

Table 8
Results of the TSPS in the Group

Inquiry skills	Experimental group					Control group				
	Pre	Post	*t*	*p*	Normalized Gain	Pre	Post	*t*	*p*	Normalized Gain
Observation	1.27	1.65	5.482	<.001	0.52	1.35	1.44	0.844	.402	0.09
Classification	2.05	2.58	4.869	<.001	0.56	2.12	2.20	0.522	.603	0.07
Measuring	1.12	1.51	4.979	<.001	0.47	0.99	1.09	1.111	.270	0.10
Inferring	1.67	2.11	3.895	<.001	0.33	1.67	1.85	1.461	.148	0.14
Predicting	2.02	2.36	3.140	<.01	0.35	2.15	2.19	0.091	.928	0.02
Transforming data	1.35	1.83	4.060	<.001	0.31	1.36	1.58	1.651	.103	0.12
Interpreting data	1.46	2.08	4.853	<.001	0.40	1.51	1.65	1.069	.288	0.08
Formulating hypotheses	1.23	1.81	4.814	<.001	0.33	1.35	1.35	0.000	1.000	0.00
Controlling variables	1.71	2.02	3.359	<.01	0.31	1.76	1.84	0.490	.625	0.05
Generalization	1.12	1.84	5.625	<.001	0.39	1.18	1.35	1.781	.079	0.13

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

In the experimental group, the average score improved from 1.27 to 1.65 in the observation aspect, from 1.12 to 1.51 in the measuring aspect, and from 2.02 to 2.36 in the predicting aspect. Hake Gain was found to be effective in improving inquiry ability as it was distributed between $0.3 < g < 0.7$, which is the middle-g area, in the case of teaching with the IAM.

In the control group, the average score improved from 1.35 to 1.44 in the observation aspect, from 2.12 to 2.20 in the classification aspect, and from 1.67 to 1.85 in the inferring aspect. By comparing the post-test averages of both the groups in the basic inquiry skills it could be shown that the average score of the experimental group was higher than the control group. Among the basic inquiry skills, the Hake Gain value of the classification aspect was 0.56 and the observation aspect was 0.52. Therefore, the IAM can be considered appropriate for acquiring the inquiry skills of observation and classification.

Among the integrated inquiry skills, the experimental group's transforming data factor increased from 1.35 to 1.83, interpreting data from 1.46 to 2.08, and formulating hypotheses from 1.23 to 1.81. The IAM developed with Hake Gain values of 0.40 and 0.39 in the areas of interpreting data and generalization, respectively, can be interpreted as appropriate for acquiring the above-mentioned skills. In the control group, the average scores improved for the transforming data factor from 1.36 to 1.58, interpreting data from 1.51 to 1.65, and controlling variables from 1.76 to 1.82. However, these were not statistically significant. Comparing the mean scores of both the groups for the integrated inquiry skills, the average score of the experimental group was found to be higher than the control group in all areas.

Analysis of Mo-SPFA

To verify the effect of the IAM on students' inquiry process flow, a post-test was conducted between the groups, followed by a pre- and post-test analysis within both groups.

Further, an independent samples t-test for the post-scores was performed. Table 9 presents the results to identify the statistically significant difference for each sub-factor. The significant changes are indicated in bold.

Table 9
Post-SPFA Score Results Between Groups Based on Questions

		Experimental	Control	*t*	*p*
		M	***M***		
#1	Connection	1.25	0.29	8.559	<.001
	Experimental design	1.89	1.01	4.748	<.001
	Interconnectivity	0.74	0.07	10.480	<.001
#2	Connection	1.25	0.52	6.390	<.001
	Experimental design	2.95	1.42	4.918	<.001
	Interconnectivity	0.71	0.14	7.731	<.001
#3	Connection	1.51	0.61	7.911	<.001
	Experimental design	3.40	1.22	10.320	<.001
	Interconnectivity	0.94	0.17	12.045	<.001

The average score for the SPFA Question 1 (Connection) was 1.25 for the experimental group and 0.29 for the control one. This difference is statistically significant at $t = 8.559$ ($p < .001$). The average score for experimental design was 1.89 for the experimental group and 1.01 for the control one. This difference is statistically significant at $t = 4.748$ ($p < .001$). The average score in interconnectivity was 0.74 for the experimental group and 0.07 for the control one. This difference is statistically significant at $t = 10.480$ ($p < .001$).

The average for SPFA Question 2 (Connection) was 1.25 for the experimental group and 0.52 for the control one. This difference is statistically significant at $t = 6.390$ ($p < .001$). The experimental design score averaged 2.95 in the experimental group and 1.42 in the control group. This difference is statistically significant at $t = 4.918$ ($p < .001$).

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

The mean of interconnectivity was 0.71 in the experimental group and 0.14 in the control one. This difference is statistically significant at $t = 7.731$ ($p < .001$).

The average score for SPFA Question 3 (Connection) was 1.25 for the experimental group and 0.52 for the control one. This difference is statistically significant at $t = 6.390$ ($p < .001$). For the experimental design factor, the average score was 2.95 for the experimental group and 1.42 for the control one. This difference is statistically significant at $t = 4.918$ ($p < .001$). The mean of interconnectivity was 0.71 in the experimental group and 0.14 in the control one. This difference is statistically significant at $t = 7.731$ ($p < .001$). These results indicate that the IAM is highly effective for the inquiry skills corresponding to the goal, content, and idea of inquiry activity.

As a result of the IAM, the average of the experimental group was higher than that of the control group for all the SPFA sections. Furthermore, the differences were statistically significant, particularly between the average scores of the groups in the connection and interconnectivity sections. When analyzing students' responses to the SPFA, several presented inquiry problems during the experimental design phase. All the contents were connected using numbers, lines, and arrows, hence, there was a flow. Thus, it can be discerned that after applying the IAM, the students explicitly saw how each inquiry flow was organically connected to the other.

A paired samples *t*-test for pre- and post-scores in the group was performed. To verify the IAM's effectiveness, pre- and post-analysis of the SPFA was conducted, using questions 1, 2, and 3. The significant changes are indicated in bold in Table 10.

Table 10
Score Results of the Pre-Post SPFA #1

	Experimental group				Control group			
	pre	post	*t*	*p*	pre	post	*t*	*p*
Connection	0.46	1.27	8.676	<.001	0.22	0.29	0.973	.333
Experimental design	0.79	1.91	7.303	<.001	0.78	1.01	1.882	.063
Interconnectivity	0.06	0.76	11.9	<.001	0.05	0.07	0.705	.483

Table 10 shows the pre-and post-average scores for the connection factor of Question 1 in the experimental group, which were 0.46 and 1.27, respectively, indicating an improvement in the score after applying the IAM. This was similar to the experimental design factor, where the experimental group showed a pre-average and post-average of 0.79 and 1.91, respectively. Further, for interconnectivity, the experimental group recorded a pre-average and post-average score of 0.06 and 0.76, respectively. These differences were statistically significant at $t = 8.676$ ($p < .001$), $t = 7.303$ ($p < .001$), and $t = 11.9$ ($p < .001$), respectively. The significant changes are indicated in bold in Table 11.

Table 11
Score Results of the Pre-Post SPFA #2

	Experimental Group				Control Group			
	pre	post	*t*	*p*	pre	post	*t*	*p*
Connection	0.63	1.13	4.535	<.001	0.61	0.49	1.235	.220
Experimental design	1.20	2.98	6.035	<.001	1.11	1.42	1.896	.062
Interconnectivity	0.10	0.75	9.756	<.001	0.18	0.14	0.726	.470

Table 11 shows the pre- and post-average scores in the experimental group for the connection factor in question 2, which were 0.63 and 1.13, respectively. For the experimental design factor, the experimental group showed a pre-average of 1.20 and a post-average of 2.98. For the interconnectivity factor, the experimental group had a pre-average of 0.10 and a post-average of 0.75, indicating an improvement after applying the IAM. These differences are statistically significant at $t = 4.535$ ($p<.001$), $t = 6.035$ ($p<.001$), and $t = 9.756$ ($p<.001$), respectively.

The pre- and post-average scores for the connection factor in question 3 in the experimental group were 0.49 and 1.55, respectively. For the experimental design factor, the scores were 1.33 and 3.46, respectively. For the

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

interconnectivity factor, the experimental group had a pre- and post-average score of 0.08 and 0.96, respectively, indicating an improvement after applying the IAM. These differences were statistically significant at t = 11.417 (p<.001), t = 10.517 (p<.001), and t = 15.911 (p<.001), respectively. In the experimental design factor, different perfect scores were used for each item. The score ratios were calculated and converted (Table 11). For question 1, the experimental group's before and after mean scores were 19.8 and 47.8, respectively. The score after the IAM was higher than the average score before the model. For question 2, the score for the experimental group ranged from 17.1 to 42.6, while for question 3, it varied from 26.6 to 69.2. The score after the IAM was higher than the average score before the IAM. The experimental group obtained more than 40 points in all post-test scores, regardless of the questions, resulting in intermediate gain values of 0.35, 0.31, and 0.58, respectively, according to Hake Gain. Thus, the IAM developed through this was statistically significant, with the experimental design factor of questions 1, 2, and 3 being t = 7.303 (p<.001), t = 6.035 (p<.001), t = 10.577 (p<.001), respectively. In other words, the IAM affected the experimental design factor.

In contrast, in the control group, the experimental design score was around 20 points, and no significant difference was found from the pre-test. The analysis of the connection and interconnectivity elements indicated that the students were aware of the interconnectivity of the inquiry process. However, they believed the inquiry to be linear and non-circular. These results are consistent with the findings of previous research on gifted high school students (Oh et al., 2021).

Discussion

When conducting scientific inquiry, students have difficulty performing integrated inquiry skills rather than basic science inquiry skills. Additionally, they struggle to understand the flow of research as a whole. Therefore, in this study, IAM was developed to reduce students' difficulties in inquiry textbook science. When providing guidance on inquiry activities to students or setting up scaffolding in inquiry-based classes, teachers should offer specific and explicit guidance (Balgopal et al., 2017; van Uum et al., 2017). In fact, an appropriate level of guidance can reduce the uncertainty faced by students (Zhang, 2018). Therefore, the IAM sought to guide the inquiry activity phase with explicit instructions regarding the necessary procedures or methods that help students perform difficult tasks (Kruit et al., 2018; Moon et al., 2017). The IAM developed in this research integrates the inquiry process model developed by Pedaste et al., (2015) and scientific practice elements to clarify student awareness of the connection and flow of the inquiry process when performing scientific inquiry activities. Moreover, the phases of inquiry activities were explicitly revealed.

The IAM provided students with an opportunity to reconstruct their thoughts by using representations when conducting inquiry activities. Students were instructed to go through the process of representing inquiry activities in various forms, such as texts and pictures, to understand them and acquire knowledge. Since strategies using representations have been proven to be effective in inquiry-based classes, students should be provided with opportunities to reconstruct their thoughts using data, self-correct, and verify results (Fuhrmann et al., 2018; Ryoo & Bedell, 2019; Samarapungavan et al., 2017). In addition, when using various representations, learners' problem-solving ability increases, leading to ambiguous problems being solved (Kohl et al., 2007). Therefore, students can clearly see what they need to do during the inquiry process, it is helpful to perform inquiry activities if various representations are used for ambiguous activities.

Germann, Haskins, and Auls (1996) and Chinn and Malhotra (2002) argued that science textbooks based on inquiry activities do not help develop students' scientific inquiry skills. However, in this study, the overall ability to perform inquiry skills increased when using the primary school textbook IAM. However simple predicting and conducting inquiry activities do not improve the inquiry ability of prediction, similar to previous studies (Lee et al., 2005), which showed a lower degree of understanding than other basic inquiry abilities. When learners observe and experiment after anticipation, they have an opportunity to reinforce their answers by diagnosing and correcting their misconceptions (Lee & Lee, 2010). Therefore, in this IAM, step-by-step guidance is needed to enhance the inquiry skill of "predicting. Furthermore, the analysis of the Mo-SPFA indicated that some students understood that the experiment was cyclical or non-linear and the IAM results varied depending on the learners' inquiry abilities. The "experiment design" element received consistent high scores across all questions. Our analysis indicates this experiment played a crucial role in enhancing students' understanding of experimental design aspects, including problem recognition, hypothesis formulation, inquiry design, and inquiry performance throughout the inquiry process.

In the "interconnectivity and connections" element, it was more difficult for students to understand the flow

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

of the inquiry process even if they understood that each phase was connected. Therefore, inquiry activities in textbooks must be presented as non-linear and cyclical activities to allow students to understand the inquiry process flow. The IAM showed a greater effect on students with intermediate or lower-than-average achievements than on students with extremely low or high levels of inquiry skills and inquiry process flow awareness. This is consistent with the finding that students with low to moderate prior knowledge acquire more concepts than students with low prior knowledge (van Riesen et al., 2018). Therefore, providing detailed and extensive guidance does not guarantee effective learning. However, it can be effective to guide students who have a certain level of prior knowledge to understand and apply content.

Conclusion and Implications

This study developed a primary science textbook IAM using representations to improve students' inquiry skills and verified its effectiveness. First, students show difficulties with their inquiry skills while carrying out textbook research activities. In particular, they struggled to perform integrated inquiry skills compared to basic ones. This means that Korean primary school science textbooks have dealt with a lot of basic scientific inquiry skills, but that there are almost no integrated activities in which students can directly plan and carry out scientific inquiry. In addition, because integrated inquiry skills concern more factors compared to basic inquiry skills, primary school science textbooks should be strengthened so that the integrated inquiry skill can be acquired through different types of inquiry activities.

Second, students have difficulty understanding the flow of textbook inquiry activities. Students had low awareness of the "connections" and "interconnectivity" of the inquiry activity process and did not clearly know what "experiment design" elements were. Therefore, for primary school students who are still in the concrete and formal operational stages, explicit phases must be provided to the students.

Third, students' inquiry skills improved as a result of applying an IAM that explicitly revealed the phases of the inquiry process by emphasizing students' own representations. In addition, understanding of the flow of textbook research activities was improved. Overall, students' inquiry skills improved and their understanding of the flow of the inquiry process increased, but it was especially effective for students with intermediate or lower-than-average achievements. Based on this, the effect may be better if the IAM is applied to students with intermediate levels of achievement who have difficulty performing textbook inquiry activities.

Based on these results, an IAM that can explicitly reveal the phases of the inquiry process by emphasizing students' own representations is needed to improve student performance of science textbook inquiry activities. If students have difficulties when teachers conduct inquiry using science textbooks in primary schools, the developed IAM can be used to better apply inquiry activities. When each phase of inquiry is explicitly presented and students are aided in performing inquiry activities using their own representations, students' inquiry performance ability and understanding of the inquiry process flow can be improved.

Declaration of Interest

The authors declare no competing interest.

References

Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science*, *333*(6046), 1096–1097. https://doi.org/10.1126/science.1204153

Aldahmash, A. H., Mansour, N. S., Alshamrani, S. M., & Almohi. S. (2016). An analysis of activities in Saudi Arabian middle school science textbooks and workbooks for the inclusion of essential features of inquiry. *Research in Science Education*, *46*, 879–900. https://doi.org/10.1007/s11165-015-9485-7

Andersen, K. N. (2020). Assessing task-orientation potential in primary science textbooks: Toward a new approach. *Journal of Research in Science Teaching. 57*(4), 481–509. https://doi.org/10.1002/tea.21599

Balgopal, M. M., Casper, A. M. A., Atadero, R. A., & Rambo-Hernandez, K. E. (2017). Responses to different types of inquiry prompts: College students' discourse, performance, and perceptions of group work in an engineering class. *International Journal of Science Education*, *39*(12), 1625–1647. https://doi.org/10.1080/09500693.2017.1346847

Bybee, R. W., & DeBoer, G. E. (1994). *Research on goals for the science curriculum. Handbook of research on science teaching and learning*. Maxwell Macmillan International.

Byun, K. T., Kim, H. S., & Yoon, M. B. (2011). A case analysis of the process of finding inquiry problems in self-inquiry activities in elementary school science. *The Korean Society for School Science*, *5*(2), 117–128. https://doi.org/10.15737/ssj.5.2.201108.117

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Cairns, D., & Areepattamannil, S. (2019). Exploring the relations of inquiry-based teaching to science achievement and dispositions in 54 countries. *Research in Science Education*, *49*(1), 1–23. https://doi.org/10.1007/s11165-017-9639-x

Concannon, J. P., Brown, P. L., Lederman, N. G., & Lederman, J. S. (2020). Investigating the development of secondary students' views about scientific inquiry. *International Journal of Science Education*, *42*(6), 906–933. http://doi.org/10.1080/09500693.2020.1742399

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science education*, *86*(2), 175-218.

Dogan, O. K. (2021). Methodological? or dialectical? reflections of scientific inquiry in biology textbooks. *International Journal of Science and Mathematics Education*, *19*(8), 1563–1585. https://doi.org/10.1007/s10763-020-10120-7

Dreyfus, S. E., & Dreyfus, H. L. (1980). *A five-stage model of the mental activities involved in directed skill acquisition*. Operations Research Center, University of California. https://vorakl.com/files/dreyfus/skill-acquisition-1980.pdf

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the learning sciences*, *8*(3-4), 391-450.

Fuhrmann, T., Schneider, B., & Blikstein, P. (2018). Should students design or interact with models? Using the bifocal modelling framework to investigate model construction in high school science. *International Journal of Science Education*, *40*(8), 867–893. https://doi.org/10.1080/09500693.2018.1453175

Gabel, D., & Sherwood, R. (1980). The effect of student manipulation of molecular models on chemistry achievement according to Piagetian level. *Journal of Research in Science Teaching*, *17*(1), 75-81.

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *45*(8), 922–939. http://dx.doi.org/10.1002/tea.20248

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *33*(5), 475-499.

Hong, J., & Hong, S. (2019). Effects of fractal STEAM lesson for plant structure on scientific process skills, creative problem-solving ability and scientific interest using 3D printer. *Biology Education*, *47*(1), 50–58. https://doi.org/10.15717/bioedu.2019.47.1.50

Kang, H. T., & Noh, S. G. (2017). The effect on elementary science education based on student's pre-inquiry. *Universal Journal of Educational Research*, *5*(9), 1510–1518. https://doi.org/10.13189/ujer.2017.050908

Kim, Y. (2007). An analysis of science process skills of school laboratory class in elementary and middle school. *Secondary Education Research*, *55*(1), 47–67.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physical Review Special Topics-Physics Education Research*, *3*(1), 010108. https://doi.org/10.1103/PhysRevSTPER.3.010108

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *34*(9), 949–968. http://doi.org/10.1002/(SICI)1098-2736(199711)34:93.3.CO;2-F

Kozma, R., & Russell, J. (2005). Students becoming chemists: Developing representational competence. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 121–145). Springer. http://doi.org/10.1007/1-4020-3613-2_8

Krajcik, J., Blumenfeld, P., Marx, R., Bass, K., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *Journal of the Learning Sciences*, *7*(3), 313–350. https://doi.org/10.1080/10508406.1998.9672057

Kruit, P. M., Oostdam, R. J., Van den Berg, E., & Schuitema, J. A. (2018). Effects of explicit instruction on the acquisition of students' science inquiry skills in grades 5 and 6 of primary education. *International Journal of Science Education*, *40*(4), 421–441. https://doi.org/10.1080/09500693.2018.1428777

Kwak, S., & Kim, J. (2017). Central limit theorem: The cornerstone of modern statistics. Korean Journal of Anesthesiology, *70*(2), 144-156. https://doi.org/10.4097/kjae.2017.70.2.144

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.

Lämsä, J., Hämäläinen, R., Koskinen, P., & Viiri, J. (2018). Visualising the temporal aspects of collaborative inquiry-based learning processes in technology-enhanced physics learning. *International Journal of Science Education*, *40*(14), 1697–1717. https://doi.org/10.1080/09500693.2018.1506594

Lederman, N. G., & Lederman, J. S. (2019). Teaching and learning of nature of scientific knowledge and scientific inquiry: Building capacity through systematic research-based professional development. *Journal of Science Teacher Education, 30*(7), 737–762. https://doi.org/10.1080/1046560X.2019.1625572

Lee, O., Hart, J. E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching*, *41*(10), 1021–1043. https://doi.org/10.1002/tea.20037

Lee, B. W. (2005). Analysis of inquiry standards in foreign national science curricula. *Journal of the Korean Association for Science Education*, *25*(7), 873–884.

Lee, H,. Yang, I., & Cho, H. (2005). Elementary and Middle School Students' Understanding of Observation, Prediction, and Hypothesis. *Journal of Korean Elementary Science Education*, *24*(3), 236-241.

Lee, O., Hart, J. E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching*, *41*(10), 1021–1043. https://doi.org/10.1002/tea.20037

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Lee, S. B., & Lee, Y. S. (2010). The Effects of POE Model on Science Process Skills and Academic Achievement in Domain'Earth and Space'of Elementary School Science. *Journal of the Korean Society of Earth Science Education*, *3*(2), 132-140.

Lim, S. (2020). Analysis of teaching strategies, types of inquiry activities and the relationship between inquiry activities and concepts presented in elementary school science textbooks focusing on earth science. *Journal of Korean Elementary Science Education*, *39*(3), 449–463. https://doi.org/10.15267/keses.2020.39.3.449

Liu, Y., He, W., & Zhao, L. (2022). Effects of inquiry learning with different task orders on fifth graders' individual and situational interest and concept achievement in science education. *Journal of Baltic Science Education*, *21*(5), 849–861. https://doi.org/10.33225/jbse/22.21.663

Li, X., Zhang, Y., Yu, F., Zhang, X., Zhao, X., & Pi, Z. (2024). Do science teachers' beliefs related to inquiry-based teaching affect students' science process skills? Evidence from a multilevel model analysis. *Disciplinary and Interdisciplinary Science Education Research*, *6*(1), 1. https://doi.org/10.1186/s43031-023-00089-y

Martin, D. J. (2012). *Elementary science methods: A constructivist approach*. Cengage Learning.

McDonald, S., & Songer, N. B. (2008). Enacting classroom inquiry: Theorizing teachers' conceptions of science teaching. *Science Education*, *92*(6), 973–993. https://doi.org/10.1002/sce.20293

Millar, R. (2010). *Analysing practical science activities to assess and improve their effectiveness*. Centre for Innovation and Research in Science Education, Department of Educational Studies, University of York.

Ministry of Education Singapore. (2007). *2008 Science syllabus*. Ministry of Education Singapore.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis from years 1984 to 2002. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *47*(4), 474–496. https://doi.org/10.1002/tea.20347

Moon, A., Stanford, C., Cole, R., & Towns, M. (2017). Analysis of inquiry materials to explain complexity of chemical reasoning in physical chemistry students' argumentation. *Journal of Research in Science Teaching*, *54*(10), 1322–1346. http://doi.org/10.1002/tea.21407

Newell, A. (1994). *Unified theories of cognition*. Harvard University Press.

Nitz, S., Ainsworth, S. E., Nerdel, C., & Prechtl, H. (2014). Do student perceptions of teaching predict the development of representational competence and biological knowledge? *Learning and Instruction*, *31*, 13–22. https://doi.org/10.1016/j.learninstruc.2013.12.003

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. National Academies Press.

National Research Council. (2013). *Next generation science standards: For states, by states*. The National Academies Press.
Newell, A. (1994). *Unified theories of cognition*. Harvard University Press.

Nitz, S., Ainsworth, S. E., Nerdel, C., & Prechtl, H. (2014). Do student perceptions of teaching predict the development of representational competence and biological knowledge? *Learning and Instruction*, *31*, 13–22. https://doi.org/10.1016/j.learninstruc.2013.12.003
Oh, H., Yang, S. H., & Lee, J. (2021). Analysis of science-gifted students' understanding on scientific inquiry process using a flowchart. *The Korean Society for School Science*, *15*(5), 384–396.

Park, H., Choi, S., & Kim, Y. (2015). Scientifically gifted middle school students' cognitive structures about scientific inquiry process. *Biology Education*, *43*(1), 37–49. https://doi.org/10.15717/bioedu.2015.43.1.37

Park, K., Choi, H., & Yeon, E. M. (2017). An analysis of structural relationship among positive parenting attitudes, attitudes toward science, science inquiry skills, and science achievements perceived by middle school students. *Journal of the Korean Association for Science Education*, *37*(4), 669–677. https://doi.org/10.14697/jkase.2017.37.4.669

Pedaste, M., Mäeots, M., Siiman, L. A., Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*(1), 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Qualifications and Curriculum Authority. (2004). *National Occupational Standards*. http://www.qca.org.uk/adultlearning/workforce/2677.html

Ryoo, K., & Bedell, K. (2019). Supporting linguistically diverse students' science learning with dynamic visualizations through discourse-rich practices. *Journal of Research in Science Teaching*, *56*(3), 270–301. https://doi.org/10.1002/tea.21519

Samarapungavan, A., Bryan, L., & Wills, J. (2017). Second graders' emerging particle models of matter in the context of learning through model-based inquiry. *Journal of Research in Science Teaching*, *54*(8), 988–1023. https://doi.org/10.1002/tea.21394

Schroeder, C. M., Scott, T. P., Tolson, H., Huang, T. Y., & Lee, Y. H. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *44*(10), 1436–1460. http://doi.org/10.1002/tea.20212

Singer, J., Marx, R. W., Krajcik, J., & Clay Chambers, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist*, *35*(3), 165-178.

Song, J. W. (2006). JJ Schwab's life and his ideas of science education. *Journal of the Korean Association for Science Education*, *26*(7), 856–869.

Tippett, C. D. (2016). What recent research on diagrams suggests about learning with rather than learning from visual representations in science. *International Journal of Science Education*, *38*(5), 725–746. https://doi.org/10.1080/09500693.2016.1158435

van Riesen, S. A., Gijlers, H., Anjewierden, A., & de Jong, T. (2018). The influence of prior knowledge on experiment design guidance in a science inquiry context. *International Journal of Science Education*, *40*(11), 1327–1344. http://doi.org/10.1080/09500693.2018.1477263

van Uum, M. S., Verhoeff, R. P., & Peeters, M. (2017). Inquiry-based science education: Scaffolding pupils' self-directed learning in open inquiry. *International Journal of Science Education*, *39*(18), 2461–2481. https://doi.org/10.1080/09500693.2017.1388940

https://doi.org/10.33225/jbse/24.23.315

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

van Zee, E. H., Hammer, D., Bell, M., Roy, P., & Peter, J. (2005). Learning and teaching science as inquiry: A case study of elementary school teachers' investigations of light. *Science Education*, *89*(6), 1007–1042. https://doi.org/10.1002/sce.20084

Wang, J. Y., & Zhao, Y. (2016). Comparative research on the understanding of nature of science and scientific inquiry between science teachers from Shanghai and Chicago. *Journal of Baltic Science Education*, *15*(1), 97–108. https://doi.org/10.33225/jbse/16.15.97

Wilson, K., & Rigakos, B. (2016). Scientific Process Flowchart Assessment (SPFA): A method for evaluating changes in understanding and visualization of the scientific process in a multidisciplinary student population. *Life Sciences Education*, *15*(4), 1–14. https://doi.org/10.1187/cbe.15-10-0212

Wilmes, S. E. D., & Siry, C. (2018). Interaction rituals and inquiry-based science instruction: Analysis of student participation in small-group investigations in a multilingual classroom. *Science Education*, *102*(5), 1107–1128. https://doi.org/10.1002/sce.21462

Zion, M., Shapira D., Slezak, M., Link, E., Bashan, N., Brumer, M., Orian, T., Nussinovitch, R., Agrest, B., & Mendelovici, R. (2004). Biomind - A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education*, *38*(2), 59–67.

Zhang, L. (2018). Withholding answers during hands-on scientific investigations? Comparing effects on developing students' scientific knowledge, reasoning, and application. *International Journal of Science Education*, *40*(4), 459–469. http://doi.org/10.1080/09500693.2018.1429692

Received: *January 06, 2024* Revised: *February 14, 2024* Accepted: *April 03, 2024*

Cite as: Kim, S., & Kim, J. B. (2024). Development of an inquiry activity model emphasizing the representation of primary science textbooks. *Journal of Baltic Science Education*, *23*(2), 315–330. https://doi.org/10.33225/jbse/24.23.315

Soyeon Kim PhD in Physics Education, Elementary School Teacher, Kumnam Elementary School, Sejong, Republic of Korea.
E-mail: yeon.y083@gmail.com
ORCID: https://orcid.org/0009-0009-5676-3393

Jung Bog Kim *(Corresponding author)* PhD, Professor, Physics Education Department, Korea National University of Education, Cheongju, Republic of Korea.
E-mail: jbkim@knue.ac.kr
ORCID: https://orcid.org/0000-0002-6498-2483