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RESEARCH ARTICLE

Analysis of Model Development and Usage Patterns in Geological, Astronomical, and Atmospheric Domains in Korean Elementary School Science Textbooks

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ABSTRACT

In science education, models are used as key teaching tools to teach scientific phenomena and concepts to students. Although South Korea recognizes the value of model use in science education, it is necessary to analyze how model use is reflected in science textbooks and in classrooms. This study examined the development and usage patterns of models in experimental activities in the geological, astronomical, and atmospheric domains in three Korean elementary school science textbooks. A coding framework was developed and analyzed based on previous studies and science curricula in other countries. The study found that, first, the model development and usage patterns in experimental activities in the geological, astronomical, and atmospheric domains in science textbooks were largely similar, although some differences existed across domains. Second, the resources required for model development and development methods; evidence-based model development, evaluation, and modification; and the cyclic features of modeling were similar across the three domains, but the geological domain was characterized by model limitations and the astronomical domain was characterized by the process of investigating a phenomenon. Based on these findings, the study discussed model development activities in textbooks can be improved.

Key words: Model development, geology, astronomy, atmosphere science, south korea, elementary school, science textbook

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Introduction

Scientists use models as tools for explaining and predicting natural phenomena (Crawford & Cullin, 2004; Nicolaou et al., 2009; Schwarz et al., 2019). A model is a simple representation of a phenomenon or special features of a phenomenon (Gilnert, 2004). Scientists often use various models as tools to concretize or validate hypotheses (Boettcher & Meisert, 2011). In science education, model usage is a key teaching method for learning scientific phenomena and concepts.

In the past, science education has used models to explain difficult concepts to students or to show the interaction of different elements (Treagust et al., 2002). Examples range from billiard ball models and prune pudding models for atoms to particle models of light and plate tectonics models in geophysics (Matthews, 2007). More recently, compared with this type of approach, there has been a greater emphasis on integrating models into authentic scientific practice learning environments (Boschl et al., 2023; Malone & Yılmaz, 2023). In science education, this means that model usage has been expanded from visual conceptual learning tools to hands-on activities that students can engage in and explore (Zhai, He & Krajcik, 2022) As shown in Table 1, the United States and South Korea explicitly address modeling abilities in their curriculum documents. This shows that science education recognizes the educational value of model development.

Table 1. Modeling skills as described in the US and Korean curriculum documents.

Curriculum documents	Description of modeling abilities
A framework for K-12 science education: Practices, crosscutting concepts, and core ideas, p. 56	Building an understanding of models and their role in science helps students construct and revise mental models of phenomena. Better mental models, in turn, engender a deeper understanding of science and enhanced scientific reasoning.
Scientific Literacy for All Koreans Korean Science Education Standards for the Next Generation, p. 39	Modeling ability is the ability to simplify representations of objects in the natural world to represent important characteristics of these objects. This includes understanding models presented, representing objects as models, and helping students build their own models to predict future events.
Korea 2022 Revised Science Curriculum p. 6–12	Utilizing models, creating models to explain or predict phenomena, and explaining with models.

Gogolin & Kruger (2018) and Treagust et al. (2002) found that model education enhances students' science learning and promotes achievement in various content areas. Additionally, Lin & Yu (2022) attributed Singapore's high science performance in TIMSS 2011 compared with other countries to the integration of models into the curriculum and emphasis on model education. These studies also highlight that model education is effective for learning scientific concepts and allows students to engage in scientific problem-solving.

There are two competing perspectives on the effectiveness of model education in the classroom (Gouvea & Passmore, 2017). One school of thought believes that having students build a physical model of DNA to learn its structure and function can help them learn the necessary concepts, whereas another believes that the activity of developing a physical model does not lead to the goal of helping students learn how DNA models replicate and transmit genetic information. The former view of models is disadvantageous as it limits the generation of knowledge and its transition into practical science engagement to model usage. However, Gouvea & Passmore (2017) emphasize that even with disadvantages such as those described above, model education, such as activities that involve building physical models of DNA, can be a powerful way to engage students in scientific practice. In other words, the experience of creating a physical model encourages students to recognize models as tools that play a crucial role in the process of generating new knowledge and solving scientific problems.

If we want students to recognize models as a means of generating scientific knowledge and engaging in scientific practice, it is essential that they experience direct involvement in the model development process. Crawford & Cullin (2004) found that students' experience of developing models using software programs changed their perceptions of models, allowing for more complex and in-depth understanding. Similarly, Park et al. (2017) reported that the more frequently students practice digital model development, the greater is their awareness and understanding of models.

Such studies support the argument that model development experiences can increase students' awareness of models, extending their understanding of models as tools for generating scientific knowledge (Windschitl et al., 2008).

Meanwhile, textbooks are widely used as basic teaching and learning materials in formal education systems (McDonald, 2016). Because textbooks provide comprehensive coverage of basic concepts and knowledge in science education (Roseman et al., 2001; Schwarz et al., 2008) most teachers utilize textbooks as the primary source of instruction (Banilower et al., 2018). Particularly in textbooks covering earth science content, instructional analogy models are useful because they can provide an intuitive understanding of phenomena (Harrison & Treagust, 2000). Models are important in earth science because there are limitations in the direct observation or experimental exploration of the subject being explored (e.g., volcanoes, earth's internal structure, atmospheric phenomena) due to their scale or accessibility (Kastens & Rivet, 2010), and it is often difficult to conduct experiments on these under controlled conditions in a laboratory setting (Gobert & Clement, 1999).

In South Korea's science curriculum, the domain of earth science incorporates the sub-disciplines of geology, astronomy, and atmospheric sciences to cover a wide range of knowledge and concepts. These earth science sub-disciplines have different academic backgrounds and contexts, which are reflected in the textbooks and will influence the types of models used in the textbooks. For example, geology often utilizes physical models to directly show strata or geologic structures, whereas atmosphere science often utilizes simulation models to explain weather events or climate change with fluids that are invisible to students. Therefore, the development and usage patterns of models in the geological, astronomical, and atmospheric domains covered in South Korean textbooks may also vary by domain.

This study aims to investigate the development and usage patterns of models presented in the geological, astronomical, and atmospheric domains in elementary school science textbooks in South Korea. The results of this study will help us understand how students are being taught to develop and use the models presented in the textbook and what influences their perceptions and practices in relation to models.

Research Methods

Research Scope

To analyze the development and usage patterns of models in the geological, astronomical, and atmospheric domains covered in South Korean textbooks, first, the unit systems of nine types of elementary science textbooks used in South Korea were analyzed. The analysis results indicated that the unit systems of the nine elementary science textbooks were mostly similar. Instead of setting all nine textbooks as the subject of research, the researchers limited the study to the top three most popular textbooks in 2023 (Textbooks A, B, and C). Fig. 1 shows the structure of synthesizing the unit systems of nine elementary science textbooks. The unit systems commonly consist of the "Guide and open unit" section, "Science lab (including science lab activities)" section, "Creative Convergence activities" section, and "Wrap up the unit" section. In particular, the "Science lab" section is divided into 7–8 lessons (40 minutes per lesson) depending on the theme of each unit, and each lesson was found to have activities such as experimentation, observation, classification, survey, discussion, and explanation. These activities are collectively referred to as "science lab activities."

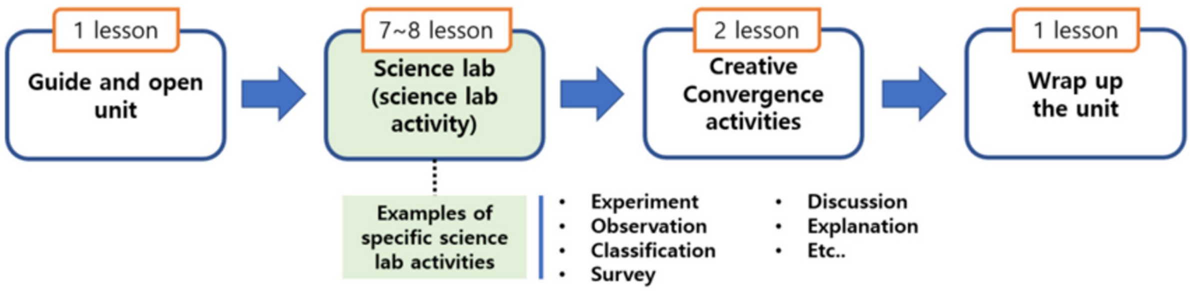

Fig. 1. Examples of unit system, number of lessons within a unit, and specific science lab activities for science lab.

Lastly, the researchers limited the scope of the study to lab activities related to models among activities in the "Science lab" section (science lab activities) (the shaded part of Fig. 1). To extract the target of analysis among these, we derived the experimental activities that are common to all three earth science textbooks, and a total of 69 activities (23 themes) were extracted.

Coding Framework Development

The development of coding framework for analyzing the model development and usage patterns in the geological, astronomical, and atmospheric domains covered in South Korean textbooks was based on Louca and Zacharia's (2019; 2015) studies on elementary school students' model development process, a study by Beak et al. (2011), and research on science curricula and literature in four countries (US, Singapore, Germany, and Australia) (Table 2). Louca & Zacharia (2019; 2015) described the modeling process for elementary school students as investigating a physical phenomenon, constructing a model, evaluating the model, and planning to modify the model. Beak et al. (2011) organized a modeling program for elementary school students into the following sequence: anchoring a phenomenon and central problem, constructing an initial model, conducing an empirical investigation, generating scientific ideas and computer simulations, evaluating and modifying the model, having peers evaluate this work, constructing a consensus model, and predicting or explaining the phenomenon involved. A synthesis of science curricula from the US, Singapore, Germany, and Australia was analyzed to identify model limitations, develop evidence-based models, and evaluate and modify these models. We also added the coding theme of "cyclic features of modeling" because the modeling process is chiefly characterized by a recurring cycle of processes such as constructing a model, evaluating it, modifying it, and reconstructing it (Campbell et al., 2013; Lee et al., 2015).

Table 2. Final coding framework.

Coding theme	Category & subcategory	Code
Investigating a phenomenon	● There is a phenomenon investigation activity	I
Resources and development methods required for model development	● Resources needed to develop the model	R
	·Presenting model development materials and scientific concepts, etc.	Rt
	·Model development materials presentation & students' recall of their experience and ideas	Rs
	● How to develop the model	M
	·Present development methods	Mt
	·Students explore development methods	Ms
Developing, evaluating, and modifying evidence-based models	● Evidence-based model development	D
	● Evaluate and modify evidence-based model	E
Purpose of model use	● Purpose of model use	U
	·Description	Ud
	·Prediction	Up
Limitations of models	● Limitations of models	L
Cyclic features of modeling	● Cyclic features of the model in the process of model development	C

To ensure the validity of the coding framework, we participated in three seminars attended by three science education experts with experience in modeling research to review the appropriateness and consistency of the coding framework and obtained confirmation that it was appropriate for the purpose of the study.

Analysis Method

Each lesson in Korean elementary school science textbooks has one science lab activity. Each activity consists of "Activity title," "Materials," and "Activity process" (Fig. 2).

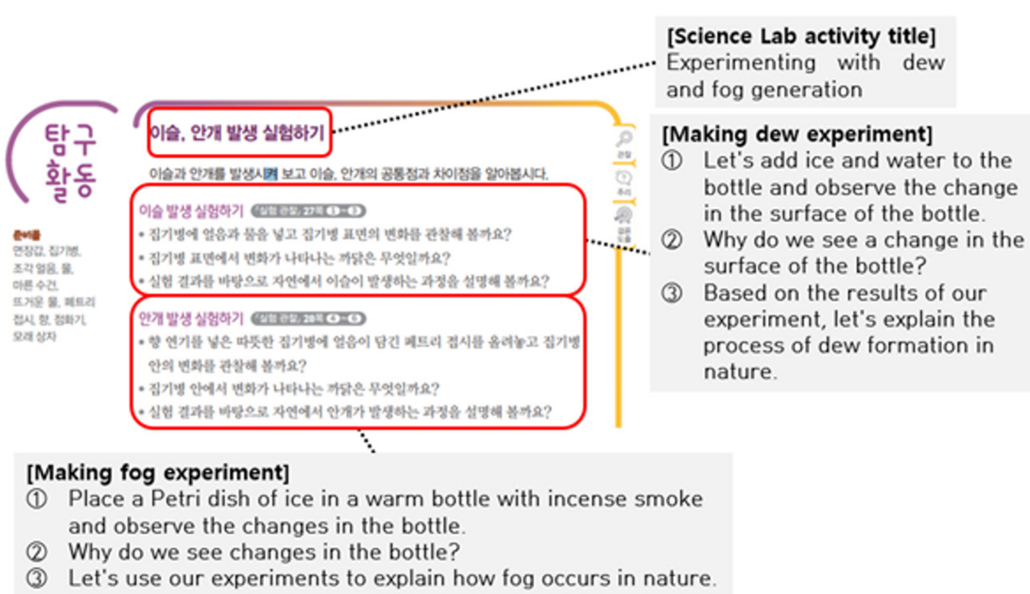

Fig. 2. Composition of science lab activities (Textbook A).

The 69 activities were analyzed based on the coding framework's categories. Here is an example of analyzing the "Making dew, fog experiment" (Fig. 2) among activities in the atmospheric domain. For the activity in Fig. 2, all materials are provided in the textbook, so it was classified into the subcategory "Presenting model development materials & scientific concepts, etc." (code: Rt) in Table 2 under the coding theme "Resources and development methods required for model development." In addition, the model development method detailed the materials and methods of development; hence, it was classified into the subcategory "Present development methods" (code: Mt) under the coding theme "Resources and development methods required for model development" in Table 2. As the developed model describes the process of making dew and fog, the purpose of model use was classified into "Description" (code: Ud), a subcategory of the coding theme "Purpose of model use" in Table 2. Finally, there was no content corresponding to the coding themes of "Evidence-based model development, evaluation, and modification," "Limitations of models," and "Cyclic features of modeling." The results of classifying and coding the science lab activity in Fig. 2 are shown in Table 3.

Table 3. Sample coding of data presented in Figure 2.

Inquiry activity Grade	Textbook	Code										
		I	R		M		D	E	U		L	C
			Rt	Rs	Mt	Ms			Ud	Up		
Making dew, fog experiment(5th)	A	-	○	-	○	-	-	-	○	-	-	-

Note: I = Investigating a phenomenon; R = Resources needed to develop the model; Rt = Presenting model development materials and scientific concepts, etc.; Rs = Model development materials presentation and student experience and ideas recall; M = How to develop the model; Mt=Present development methods; Ms = Students explore development methods; D = Evidence-based model development; E = Evaluate and modify evidence-based model; U = Purpose of model use; Ud = Description; Up = Prediction; L = Limitations of model; C = Cyclic features of the model in the process of model development.

Research Results and Discussion

Table 4 shows the analysis results of the 69 lab activities (23 themes) that were common to the three textbooks based on the coding framework.

Table 4. Analysis results of the 69 lab activities (23 themes)(continued)

Domain	Science lab activity (Grade)	Textbook	Code										
			I	R		M		D	E	U		L	C
				Rt	Rs	Mt	Ms			Ud	Up		
Geological	Investigating the shape of the earth (3rd)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	-	-	-	-	-	-	○	-	-	-
		C	-	-	-	-	-	-	-	○	-	-	-
	Comparing land and sea area (3rd)	A	○	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Learning how soil is made (3rd)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	○	-
	Observing how ground surface changes with running water (3rd)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Understanding the order in which strata are stacked (4th)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	○	-
		C	-	○	-	○	-	-	-	○	-	○	-
	Creating a sedimentary rock model (4th)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	○	-
		C	-	○	-	○	-	-	-	○	-	○	-
	Creating a fossil model (4th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	○	-
	Experimenting with volcanic activity models (4th)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	○	-
		C	-	○	-	○	-	-	-	○	-	○	-
	Experimenting with earthquake generation models (4th)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	○	-
		C	-	○	-	○	-	-	-	○	-	○	-
Astronomical	Comparing the relative sizes of the planets in the solar system (5th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	-	-	-	-	-	-	○	-	-	-
	Comparing the relative distances of the planets in the solar system (5th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Investigating the northern sky's signature constellations (5th)	A	-	-	-	-	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	-	-	-	-	-	-	○	-	-	-
	Changes in the sun's position due to the earth's motion (6th)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	-	-	-	-	-	-	○	-	-	-
	Learning why there are days and nights (6th)	A	-	○	-	○	-	-	-	○	-	○	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Experimenting with modeling phenomena caused by the earth's rotation (6th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Finding out why visible constellations change with the seasons (6th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	-	-	-	-	-	-	○	-	-	-
	Measuring solar elevation, shadow length, and temperature over the course of a day (6th)	A	○	-	-	-	-	-	-	-	-	-	-
		B	○	-	-	-	-	-	-	-	-	-	-
		C	○	-	-	-	-	-	-	-	-	-	-

Table 4. Analysis results of the 69 lab activities (23 themes)

Domain	Science lab activity (Grade)	Textbook	Code										
			I	R		M		D	E	U		L	C
				Rt	Rs	Mt	Ms			Ud	Up		
Astronomical	Exploring the relationships among solar elevation, shadow length, and temperature over the course of a day (6th)	A	○	○	-	○	-	○	-	○	-	-	-
		B	○	○	-	○	-	○	-	○	-	-	-
		C	○	○	-	○	-	○	-	○	-	-	-
	Interpreting seasonal meridian elevation, day and night length, and temperature data of the sun (6th)	A	○	○	-	○	-	-	-	○	-	-	-
		B	○	○	-	○	-	-	-	○	-	-	-
		C	○	○	-	○	-	-	-	○	-	-	-
	Experimenting with modeling temperature (energy) variation with solar meridian elevation (6th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Comparing the seasonal solar meridian elevation as a function of the earth's rotation axis tilt (6th)	A	○	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
Atmospheric	Experimenting with dew and fog formation (5th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-
	Experimenting with wind-making model (5th)	A	-	○	-	○	-	-	-	○	-	-	-
		B	-	○	-	○	-	-	-	○	-	-	-
		C	-	○	-	○	-	-	-	○	-	-	-

See Table 3 in the study results for notes.

We describe the results of analysis in the following order: "Investigating a phenomenon," "Resources required for model development and development methods," "Evidence-based model development, evaluation, modification, and cyclic features of modeling," and "Purpose of model use and limitations."

Investigating a Phenomenon(I)

Investigating a phenomenon only appeared in 10 of 69 experimental activities. This indicates that geological, astronomical, and atmospheric domain experimental activities do not investigate phenomena. Of the 10 experimental activities under the investigating a phenomenon category, 1 was in the geological domain, 9 were in the astronomical domain, and none appeared in the atmosphere domain. In the geological domain, this category involved observing the globe before developing a model for the difference in the extent of land and ocean. These activities were only identified in one textbook, so it is not reasonable to conclude that they are salient features of the geological domain. The astronomical domain, in contrast, had features distinct from those of the geological and atmospheric domains. Investigating phenomena in the astronomical domain was characterized by two aspects. First, it had activities that comprised solely investigating phenomena. The geological and atmospheric domains, in contrast, consisted mainly of the following activities: investigating a phenomenon, model development, and limitations of models. In other words, in the geological and atmospheric domains, students developed one model through one activity. However, in the astronomical domain, an activity of a single lesson consisted only of a single category, so the sequential process of investigating a phenomenon, model development, and explanation of learning using a model was organized into activities over multiple lessons. For example, to develop a model of the relationship between meridian elevation and temperature according to season, the first activity involved measuring solar elevation and temperature over the course of a day, and the second activity involved understanding the relationship between solar elevation and temperature. The third activity in the next lesson explained the relationship between solar elevation and temperature with a model. This was likely due to the fact that models in the astronomical domain are extensive and consist of many sub-elements.

The second feature of investigating a phenomenon in the astronomical domain involves data collection while investigating real-world phenomena. The objects of inquiry in earth science are vast in terms of space and time, so phenomena are often explored indirectly, e.g., through already developed pedagogical analogy models. However, in the astronomical domain, students directly observe and measure solar elevation, temperature, etc. as in the lab activity in Fig. 3. In other words, students collect data to develop models through investigating real-world natural phenomena.

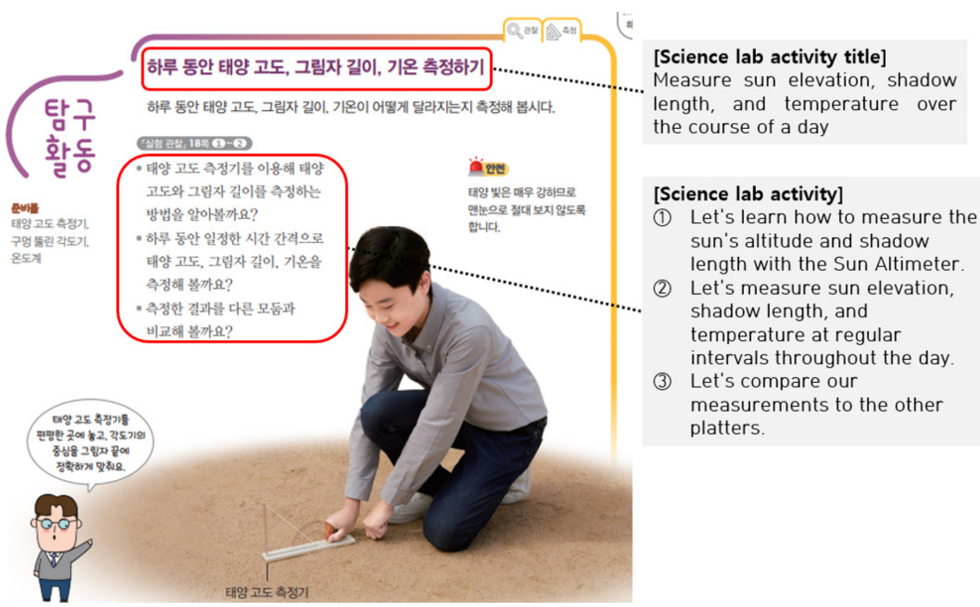

Fig. 3. "Measuring solar elevation, shadow length, and air temperature over the course of a day" inquiry activity (Textbook A).

The prominence of the investigating a phenomenon category in the astronomical domain compared with other domains could be related to students' cognitive development level. The astronomical domain is considered challenging because it is difficult for students to observe real-world phenomena; moreover, students are required to think spatially and use models such ast tables and graphs (Lee et al., 2015). As such, the astronomical domain is often included in the 5th–6th grade curriculum with a higher cognitive level, while the geological domain is often taught in the 3rd–4th grades and the atmospheric domain in the 5th grade. The authors of the textbook seem to have organized the activities with an emphasis on investigating a phenomenon, assuming that students in the 5th–6th grades would be able to explore real-world phenomena and develop models based on the data they collected.

The analysis also showed that there was no process to explicitly make students aware of the purpose of model development prior to investigating a phenomenon. As Schwarz et al. (2019) have argued, investigating a phenomenon right away without establishing the purpose of model development is highly likely to result in passive engagement in model development. In addition, assigning activities of phenomenon investigation without teaching students the purpose of model development should be avoided as students cannot engage in active model development or experience authentic and meaningful scientific practice (Boschl et al., 2023).

Investigating relevant materials for model development, namely, investigating a phenomenon, is fundamental to the modeling process (Bamberger & Davis, 2015; Kenyon et al., 2011). In particular, early observations are important because they can serve as a resource for model development. To facilitate initial observations, it is appropriate for teachers to present students with diverse observational perspectives rather than simply asking them to observe a phenomenon. For example, when exploring phenomena related to the weathering of rocks, students should be encouraged to make sufficient observations of the shape of the rock, condition of the surface, and features of the natural environment surrounding the rock so that the information gathered from their observations serves as a resource for model development.

Resources and Methods of Model Development (R: Rt, Rs; M: Mt, Ms)

Resources required for model development are classified into two categories: one in which the model development materials and science concepts are presented in the textbook (Rt) and another in which these materials are presented in the textbook but students are also encouraged to draw on their own experiences or ideas for them (Rs). Rt appeared in 59 of 69 experimental activities, but none of the experimental activities showed Rs. This finding implies that the geological, astronomical, and atmospheric domains all explicitly present materials or scientific concepts for model development in their textbooks but do not use student experience or ideas about the resources required for model development. Moreover, the categories of resources required for model development materials and methods do not show significant differences among geological, astronomical, and atmospheric domains.

Fig. 4 is an example of a textbook specifying the resources required for model development materials and methods.

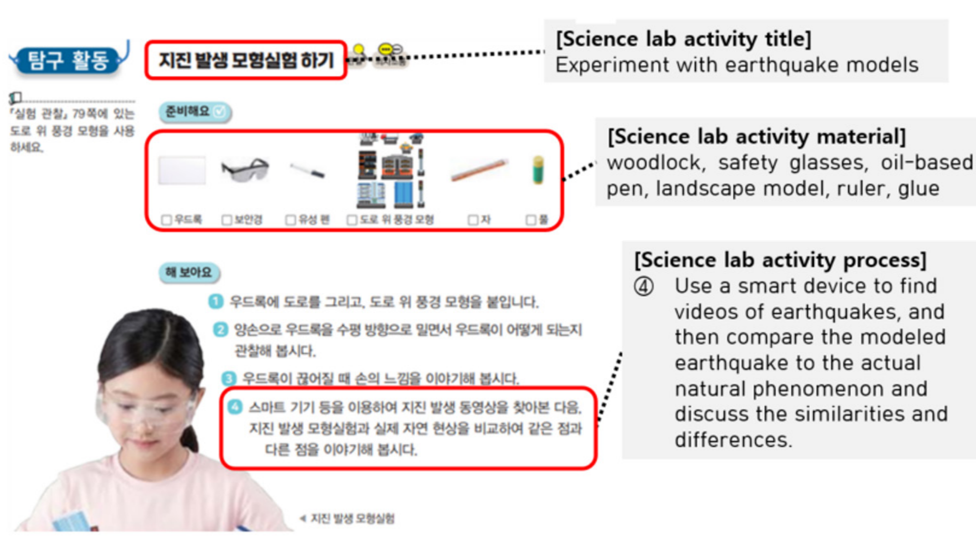

Fig. 4. "Experimenting with an earthquake model" science lab activity (Textbook B).

In the lab activity in Fig. 4, students develop a model using the materials presented in the textbook. Students also follow the exact process outlined in the textbook to develop a model from the materials presented. As such, students are provided with all the materials to develop a model and are explicitly instructed on how to use the materials and develop the model.

Model development is a creative process, and the students' experiences and the materials they need to realize their ideas play an important role in the process. The presence of Rt in 59 of 69 experimental activities can indicate efficiency in terms of guiding students to achieve learning objectives in limited time. In terms of the effectiveness of model development, the fact that teachers prioritize the content knowledge contained in the model over the modeling process or metacognition (Rix, 2021; Valeeva et al., 2023) or the argument that the process of students developing, evaluating, and modifying their own models is not important (Nielsen & Nielsen, 2021) can be highly persuasive. However, if students' experiences and ideas are not utilized as ingredients for model development, this development can be regarded as a cookbook-style experiment rather than a creative process (Wellington, 2000). Therefore, engaging students creatively in model development requires achieving a balance between allowing students to explore the resources needed to develop a model on their own (Windschitl et al., 2008) and receiving textbook or teacher support in integrating prior conceptions regarding the phenomenon with newly learned information (Buckley & Boulter, 2000). This means that depending on the cognitive level of students, it is necessary to vary the ratio of self-directed work to assisted work. This also requires a systematic analysis of content knowledge and model development perceptions and a discussion on the role of teachers in providing appropriate resources and methods as well as utilizing students' experiences and ideas in model development.

Evidence-based Model Development, Evaluation and Modification, and Cyclic Features of Modeling (P/E/C)

The evidence-based model development (P) category appeared in only 3 of the 69 experimental activities, whereas the evidence-based model evaluation and modification (E) category and the cyclic features of modeling (C) category did not appear at all. In other words, in all domains, there was no evidence suggesting that students developed, evaluated, or modified models. The cyclic features of modeling were also not identified.

As shown in Table 4, the evidence-based model development category was identified in only three of the experimental activities in the 6th grade: "Exploring the relationships among solar elevation, shadow length, and air temperature over the course of a day." Fig. 5 shows an example of an activity classified into evidence-based model development.

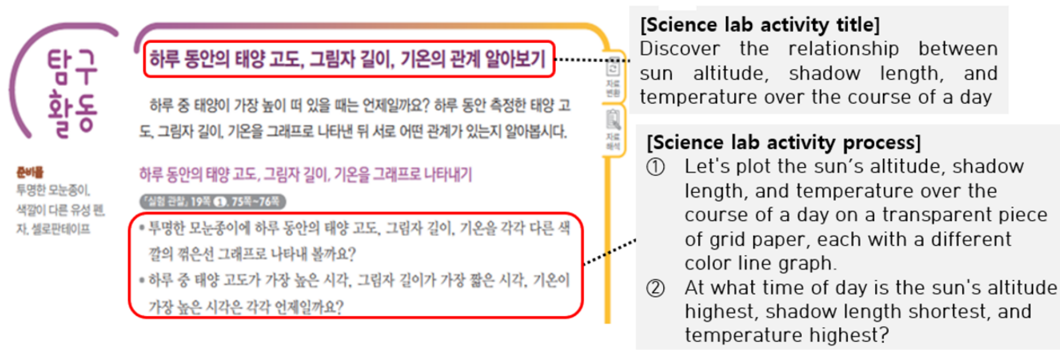

Fig. 5. "Exploring the relationships among solar elevation, shadow length, and temperature over the course of a day" science lab activity (Textbook A).

Fig. 5 shows a lab activity involving the development of a model for understanding the relationships between solar elevation, day and night length, and temperature. In the previous lesson, students measured solar elevation, shadow length, and temperature over the course of a day, and in the second lesson (Fig. 5), the goal is to develop a model in the form of a line graph based on their measurements. All three types of textbooks that include this lab activity use real-world evidence collected by students to develop models. Developing models based on empirical evidence is necessary (Louca & Zacharia, 2012), so such a construct is considered desirable. Meanwhile, three Korean science textbooks lacked the process of developing and using models based on evidence. Students' use of evidence and reasoning to develop, evaluate, use, and modify models is a necessary component of modeling competence (Bielik et al., 2020) and should have been actively reflected in the design of the inquiry activities, but it was not.

Evaluating and modifying evidence-based models and the cyclic features of modeling were not found in the experimental activities in science textbooks. Given their level of cognitive developmental, it has been suggested that typical elementary school students find it challenging to evaluate and modify evidence-based models (Louca & Zachria, 2019).

In addition, the cyclic features of modeling refer to the nonlinear process of developing, evaluating, and modifying models (Gilbert, 2004). To reveal the cyclic features of modeling, textbooks should explicitly show the elements of developing, evaluating, or modifying a model. However, there was no process for evaluating and modifying models in any of the experimental activities in the three textbooks.

Purpose of Model Use (U: Ud, Up)

The purpose of model use is divided into explanatory (Ud) and predictive (Up) categories. Sixty-six of 69 experimental activities were categorized as Ud, while Up was not found. This result means that the geological, astronomical, and atmospheric domains all use models for the purpose of explaining concepts about natural phenomena. Further, there was no difference in this category between the geological, astronomical, and atmospheric domains.

First, the purpose of model use was shown directly or indirectly in every experimental activity in Textbooks A, B, and C. Fig. 6 shows an example of an experimental activity that reveals the purpose of using the model.

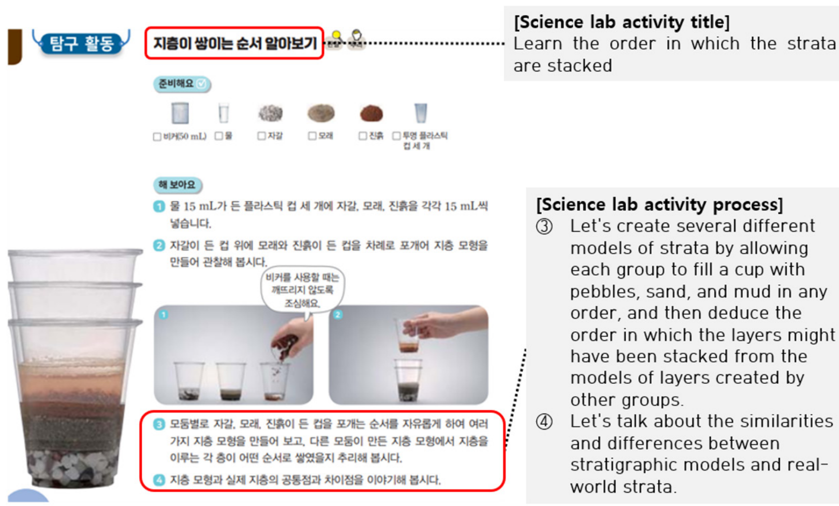

Fig. 6. "Exploring the order in which strata are stacked" science lab activity (Textbook B).

Fig. 6 depicts an activity aimed at inferring the order in which strata are stacked using a model. As it is difficult to directly observe the process of stratification, the textbook suggests developing a model to observe it. Students can understand the order in which layers build up by filling cups with gravel, sand, and mud in that order to create a model of strata.

The activity uses the model for explanatory purposes only, presumably because teachers engage students in model development activities with the goal of explaining rather than predicting (Boschl et al., 2023; Nielsen & Nielsen, 2021). Using a model for predictive purposes requires a high level of understanding or awareness of the model. However, research has shown that even adults with superior cognitive development than elementary school students do not have higher levels of model recognition (Oh & Oh, 2011); thus, elementary school students perceive models as end products that show results that have already been found or as a means of representing the outcomes of science learning, rather than as predictions (Campbell et al., 2015; Cheng & Lin, 2015; Gilbert, 2004; Gogolin & Kruger, 2018). As most elementary school students have little experience of developing models and perceive models as a teaching tool for difficult concepts, textbooks seem to limit models to explanatory purposes.

Limitations of Models (L)

The limitations of models (L) were identified in 18 of 69 cases: 16 in the geological domain, 2 in the astronomical domain, and none in the atmospheric domain. This result indicates that the astronomical and atmospheric domains do not generally include the limitations of models in experimental activities. However, more than half of the experimental activities in the geological domain include the limitations of models category in their experiments.

The activity of talking about the similarities and differences between the stratigraphic models and real-world strata in process ④in Fig. 6 can be seen as a process of identifying the limitations of the model. When there are temporal and spatial limitations to observing a phenomenon, such as strata, a model is used to conduct experiments. The use of models abstracts or idealizes phenomena (Winkelmann, 2023), and too much abstraction or idealization makes it difficult for students to make connections between the model and the phenomenon. This tendency is most pronounced in the geological domain. The geological domain often presented simplified representations of phenomena, such as shaking sweets in a plastic container to learn about how soil is made, or building sand dunes and letting water run over them to see how running water changes the ground surface. Thus, it can be interpreted that students were asked to think about the similarities and differences between the model and the phenomenon to understand the limitations of the model and to comprehend the real phenomenon.

The astronomical domain, in contrast, provides direct observations of real-world phenomena or models that resemble them. For example, in a stargazing activity, students are instructed to directly observe the sky at night or use a stargazing program if this is not possible. Hence, compared to the geological domain, the astronomical domain, where actual natural phenomena or analogous model observations are possible, is deemed to be less concerned with model limitations.

Meanwhile, the atmospheric domain mainly describes models by introducing the concept of particles. However, the science curriculum in Korean elementary schools does not introduce the concept of particles because it is abstract. Therefore, atmospheric phenomena are addressed at the level of laboratory reproduction and phenomenon-focused investigation. For example, a textbook might develop a model in which a breeze is generated by differences in air pressure but not by the movement of air particles. It helps students learn about wind direction according to air weight by comparing air weights and understanding that heavier air signifies high pressure and lighter air signifies low pressure. It is suggested that student-level models that do not include particle concepts are less likely to address model limitations because they are not comparable to real-world natural phenomena. Thus, we believe that the limitations of models are relatively more prominent in the geological domain. Furthermore, the limitations of models were often presented at the end of the activity, after students had finished developing their models, by encouraging reflection on the similarities and differences between the model and the real phenomenon, as shown in process ④ in Fig. 6.

Discussion and Educational Implications

Differences in Model Development and Usage Patterns Across Domains

Model development and usage patterns showed little, if any, differences between the geological, astronomical, and atmospheric domains. This finding can be attributed to the fact that textbooks are developed to closely reflect the national curriculum (Rillero, 2010). Consequently, the content and methods of the experimental activities follow this curriculum. For example, the science curriculum suggests “Build a mound of dirt, run water through it, and observe where it is washed away and where it builds up” as an activity to learn about changes in the ground surface caused by running water. If the textbook is organized exactly as described in the curriculum, it will consist of straightforward model building and observation without any exploration of phenomena, such as the observation of real terrain. Therefore, model development and usage patterns are not underscored in the studied textbooks, and the curriculum descriptions do not differ significantly between the geological, astronomical, and atmospheric domains; thus, model development and usage patterns are composed similarly across the domains.

Another possible reason for the lack of differences between the domains is the lack of detailed guidelines for model education in Korean science curriculum. In the case of the Next Generation Science Standards, subcategories such as model development and nature of models are subdivided and explicitly stated in sentences that require higher levels of achievement as the grade level increases. However, in Korean science curriculum, there are no model education standards for different levels of students (MOE, 2015). As a result, when it comes to model development, textbooks simply follow the curriculum with no differences in model development and usage patterns between the domains.

In the categories of investigating a phenomenon and limitations of models, there were differences between the three domains. The investigating a phenomenon category was more prevalent in the astronomical domain than in the geological and atmospheric domains. This difference may be attributable to the fact that the curriculum description for the astronomical domain emphasizes investigating phenomena, unlike other domains. The limitations of models category was only identified in the geological and astronomical domains and not in the atmospheric domain. It was particularly noticeable in the geological domain. It is suggested that the differences in the object of investigation led to the differences between domains for this category. In the geological domain, models were often used to simplify or abstract natural phenomena (Winkelmann, 2023), whereas in the astronomical and atmospheric domains, the focus is on exploring actual natural phenomena.

Measures for Improving Model Development Activities in Textbooks

None of the experimental activities in the geological, astronomical, and atmospheric domains of South Korean textbooks covered all categories from investing a phenomenon to model development, evaluation, modification, and cyclic features. It is not easy to cover these aspects all at once in a classroom setting as the models used in classrooms are simplified and streamlined compared to those used by scientists (Bhattacharya et al., 2021) and there are limitations in terms of time and space for students to experience the full process of model development.

As seen in Table 4, most of the experimental activities in the geological, astronomical, and atmospheric domains involve building models and explaining phenomena. To explain natural phenomena, we need the models most effective for explanation, but it is challenging for students to develop these effective explanatory models independently, such as the model for determining the order in which the strata are stacked (Fig. 6). In this way, if model development is beyond the students' ability, they will not feel the need to evaluate or modify the model. This is likely due to the nature of the textbooks, which prioritize effectively communicating concepts to students.

To improve these aspects and to have students evaluate and modify their models, and even experience the cyclic features, model development activities that consider the cognition level of elementary school students are necessary. Oh & Oh (2011) proposed five modeling pedagogies (exploratory, representational, experimental, evaluative, and cyclic modeling) to reflect the way scientists use models. Representational modeling, one of these pedagogies, can be an effective teaching method for elementary school students who have no experience with model development. Representational modeling pedagogy is an activity in which students express their ideas to create new models or use existing models to explain scientific phenomena without focusing on the process of model evaluation or modification (Campbell et al., 2015). An activity should be designed for elementary school students to enhance their understanding of models through representational modeling pedagogy that focuses on model development; this activity should later include exploratory and cyclic modeling as well as model evaluation and modification.

Detailing the materials and methods required to develop a model, as in current science textbooks, forces students to be passive participants in model development(Bächtold et al., 2024). Louca & Zacharia (2023) claimed that even preschool students with low cognitive skills are capable of model development activities if given sufficient guidance. Students begin model development by drawing on their experiences (Louca & Zacharia, 2015); therefore, appropriate questioning that allows students to recall their experiences and background knowledge related to a particular phenomenon can lead to student-driven model development (Louca & Zacharia, 2019).

For students to take initiative in model development, it is important for them to have metacognitive knowledge of the modeling process (Papaevripidou et al., 2007), and explicit prior instruction is necessary for students to gain this knowledge. In terms of organizing activities, it is necessary to introduce tasks that allow elementary school students to develop models independently. For example, black-box tasks involve inferring an invisible internal structure based on evidence, such as observable phenomena (Gohner et al., 2022; Krell et al., 2019), and are frequently used in science education to study scientific thinking and model development processes (Lederman & Abd-El-Khalick, 2002; Passmore & Svoboda, 2012). THowever, since textbooks are developed based on the curriculum, it is not easy to introduce effective tasks for model development in textbooks if there is no description of the model development process in the curriculum. Although the 'process and function' section of South Korea's 2022 revised science curriculum explicitly mentions activities such as utilizing models and explaining with models, it does not provide specific standards or guidelines on which learning topics to link with models or which natural phenomena to explain using models. However, studies by Kim & Yang (2024; 2022), and Suk & Yoon (2023) show that modeling and model-based education can play a crucial role in elementary science education(Téllez-Acosta et al., 2024). Based on such foundational research, it is necessary to develop a concrete framework that can be applied in the curriculum through systematic research on model and modeling-based education.

Conclusion

This study compared and analyzed the development and usage patterns of domain-specific models in experimental activities in Korean elementary school science textbooks and inferred the following. First, the model development and usage patterns in experimental activities in Korean elementary school science textbooks were mostly similar, with some differences. Second, the geological, astronomical, and atmospheric domains showed similar patterns of the resources required for model development materials and methods, evidence-based model development, evaluation, modification, and the cyclic features of modeling; however, the limitations of models were salient in the geological domain and the process of investigating a phenomenon was salient in the astronomical domain. The atmospheric domain did not show a prominent category compared with other domains.

Limitations and Suggestions

This study is a textbook analysis study, and as textbooks are written based on the national curriculum, experimental activities are determined based on this curriculum. Regardless of the will of the textbook authors, the curriculum may impose restriction on the themes and processes of experimental activities. Another limitation of this study is that it only analyzed the top three elementary science textbooks rather than all nine textbooks.

This study can suggest the following implications in supporting the development and use of practical, student-driven models in Korean primary science education. First, the results can be used as baseline data for textbook developers when designing activities that involve student-driven model development. Second, this study can contribute to the creation of teacher training materials to increase teachers' awareness of models and model development.

Conflicts of Interest

The author(s) declared no conflicts of interest.

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