Brain, Digital, & Learning

pISSN : 2384-2474
eISSN : 2586-7490

RESEARCH ARTICLE

Elementary Teachers' Understanding and Use of Scientific Models from a Resource Perspective: Analyzing the Overlapping Structure of ERM and PRT

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ABSTRACT

This study investigates how elementary teachers' understanding of scientific models (Epistemic Resources for Modeling; ERM) and their instructional practices (Pedagogical Resources for Teaching; PRT) are enacted from a resource-based perspective. Lesson videos and interviews from five teachers were analyzed using Rodriguez's framework of resource grain size. The findings indicate that ERM and PRT often appeared in overlapping structures—ERM elements (distributed or conceptual) were embedded within frame-level PRT. These resources were selectively activated depending on instructional goals such as concept clarification, inducing cognitive conflict, presenting alternative models, and expanding ideas. The grain size and combination of resources varied with the teacher's purpose and lesson flow. This suggests that teachers' model-related knowledge is not fixed but dynamically constructed from epistemic resources. The study provides a new lens to analyze teacher thinking in modeling instruction and informs directions for science teacher education.

Keywords: Scientific models, modeling instruction, elementary teachers, resource-based perspective, ERM, PRT

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OPEN ACCESS

Brain, Digital, & Learning
2025, Vol. 15, No. 2, 267-291

https://doi.org/10.31216/BDL.2025.15.2.10

Received: May 02, 2025
Revised: June 02, 2025
Accepted: June 04, 2025

Introduction

One primary goal of science education is to actively engage students with scientific models to deepen their understanding of natural phenomena and enhance scientific reasoning skills. Consequently, the educational value of scientific models has long been emphasized (Bevins & Price, 2016; Gouvea & Passmore, 2017; Ke & Schwarz, 2019; Lucas et al., 2024; NGSS Lead States, 2013; Rost & Knuuttila, 2022). This emphasis on scientific models drives changes in science education and contributes to fostering scientifically literate individuals. Moreover, scientific models play a central role in the eight science and engineering practices of the NGSS (Lehrer & Schauble, 2019) and are suitable for experiencing inquiry practices (Upmeier zu Belzen et al., 2019).

However, existing research on models and modeling has relatively underrepresented elementary students and teachers. An analysis of modeling studies from 1980 to 2013 revealed that 25 out of 30 studies focused on secondary students (Namdar & Shen, 2015), and a comprehensive study on assessing modeling competency showed that 18 out of 23 studies involved secondary students, teachers, and scientists (Valeeva et al., 2023). This indicates a scarcity of research on scientific models at the elementary level (Guy-Gaytan et al., 2019; Chen & Terada, 2021), highlighting the need for studies targeting elementary teachers. One major reason for this imbalance is the lack of well-developed modeling-based instruction (MBI) curricula and corresponding assessment tools suitable for younger learners, which makes it difficult to implement and evaluate modeling effectively in elementary settings. In addition, younger students may face greater cognitive demands when engaging in abstract scientific modeling tasks, which poses challenges for both curriculum design and research execution at the elementary level (Namdar & Shen, 2015).

Why is research on elementary teachers necessary? The elementary grades are crucial for students' initial formation of scientific understanding and the development of foundational scientific inquiry and reasoning skills (NRC, 2012). How teachers at this level understand and utilize scientific models can significantly impact students' science concept development and attitudes (Riegle-Crumb et al., 2015). This suggests a need for a detailed exploration of not only elementary teachers' level of understanding but also the process of translating this understanding into practice for effective implementation of modeling in elementary education. Therefore, in-depth analysis of elementary teachers' model understanding and use in actual classroom contexts is a prerequisite for realizing the educational benefits of scientific modeling.

To activate scientific models and modeling, science education researchers have focused on epistemic understanding of models (e.g., meta-modeling knowledge) (Engelschalt et al., 2023; Gohner et al., 2022; Unal et al., 2014), suggesting that model understanding influences teachers' use of models in science lessons (Harlow et al., 2013; Nielsen & Nielsen, 2021b). However, a clear correlation between teachers' model understanding and their classroom use has not been established (Cheng et al., 2021), and despite research indicating high levels of model understanding (Gohner et al., 2022), most elementary teachers only occasionally engage in science activities involving model construction, use, or testing (Bächtold et al., 2024). This implies that model understanding is not consistently translated into classroom practice (DeGlopper et al., 2023).

Analyzing this inconsistency between model understanding and its use through the lens of existing model research appears limited in explaining the complex interplay of elementary teachers' model understanding and use. This is particularly because it is difficult to grasp how epistemic understanding of models specifically manifests in the practical and complex context of the classroom (Harris & Rooks, 2010). Therefore, to more precisely analyze the interaction between teachers' model understanding and actual classroom situations, a new perspective is needed to approach teachers' model understanding and its use.

Accordingly, this study aims to utilize a resource-based approach (Hammer & Elby, 2003; Hammer et al., 2005), which explains teachers' model understanding and its use not as a singular, consistent structure, but as a dynamic combination and change of various small-scale cognitive resources activated depending on the context. The resource perspective views teachers' model understanding and its use as composed of multiple small cognitive units (Hammer, 2000). To analyze from a resource perspective, this study operationally defines elementary teachers' understanding and use of scientific models as Epistemic Resources for Modeling (ERM) and Pedagogical Resources for Teaching (PRT).

A qualitative case study, which deeply analyzes a specific case through various data to understand its characteristics, meaning, and context (Yin, 2018), is suitable for analyzing how teachers' model understanding is specifically reflected in actual classroom situations. Therefore, this study aims to analyze elementary teachers' perceptions of models, as revealed in science lessons and semi-structured interviews, from a resource perspective to derive implications for activating modeling education in elementary schools. The research questions of this study are as follows:

Research Question 1) What are the patterns in which elementary school teachers' resources for understanding scientific models and pedagogical resources are activated in the context of instruction? (Study 1)

Research Question 2) What are the resources for understanding scientific models among elementary school teachers that are not activated in the context of instruction? (Study 2)

Theoretical Background

Understanding and Use of Scientific Models

Scientific models are cognitive tools used to explain and predict scientific phenomena and are central components of scientific inquiry (NGSS Lead States, 2013; Schwarz et al., 2009). In science education, models are not merely visual aids or classroom props; rather, they function as explanatory and predictive tools that help learners construct, justify, and reconstruct scientific concepts (Justi & Gilbert, 2002; Passmore et al., 2009). Accordingly, recent science education emphasizes modeling practices in which students actively construct, evaluate, and revise models, rather than passively accept them (Gouvea & Passmore, 2017; Lehrer & Schauble, 2019). In sum, a scientific model can be operationally defined as a cognitive representation that serves to explain, predict, and communicate about scientific phenomena, and that evolves through iterative construction and refinement by learners.

The concepts of understanding and use of models are related yet distinct. Model understanding refers to epistemic thinking about the nature, purpose, diversity, and revisability of models (Oh & Oh, 2011; Schwarz et al., 2009), and is often conceptualized as meta-modeling knowledge (Upmeier zu Belzen et al., 2021). In contrast, model use refers to how models are actually applied in instruction by teachers or students, including practices such as explanation, comparison, justification, and prediction (Passmore & Svoboda, 2012).

Earlier studies tended to view model understanding as a stable and structured cognitive framework. For example, Upmeier zu Belzen et al. (2010) proposed a framework of modeling competence with five cognitive dimensions and three developmental levels (Levels 1–3). This framework assumes a linear progression from viewing models as direct replicas (Level 1), to idealized representations (Level 2), and ultimately as theoretical constructs (Level 3). However, recent studies have challenged this linear view. Krell et al. (2014) and Gogolin & Kruger (2018) reported that learners often hold multiple levels of model conceptions simultaneously and activate them selectively depending on context. Students may recognize models as idealized representations (Level 2) while also judging them based on visual similarity to the referent (Level 1). These findings suggest that model understanding is not a fixed structure but a flexible, context-dependent construct.

Interpreting model understanding solely as a hierarchical system may limit our ability to capture the complex thinking of teachers and students, and to explain discrepancies between understanding and actual model use in classrooms (DeGlopper et al., 2023; Göhner et al., 2022). Many teachers, for example, report an understanding that models are revisable, yet their classroom practices often reflect static or instrumental uses of models (Nielsen & Nielsen, 2021).

Therefore, a more dynamic and context-sensitive theoretical lens is needed to analyze the understanding and use of scientific models. This study introduces a resource-based perspective, which conceptualizes teachers' epistemic thinking about models as composed of various interconnected and contextually activated epistemic resources. Rather than simply categorizing understanding into levels, the resource framework allows for a fine-grained analysis of how different types and sizes of resources are activated and coordinated within actual classroom discourse and instruction.

A Lens for Shifting Research Perspectives: Resources

The concept of resources is grounded in the theory of fine-grained constructivism, which views learners' knowledge not as fixed or coherent structures, but as dynamic collections of cognitive elements that are activated contextually (diSessa, 1993; Elby, 2000). This perspective posits that student thinking emerges from the interaction of small-scale conceptual resources, shifting the focus from identifying and correcting misconceptions to understanding how resources are combined and used in context (Hammer & Elby, 2003).

While initially applied to students' conceptual learning in science, the resource perspective has recently been extended to encompass epistemic beliefs and teaching practices (Hammer & Elby, 2002; Lising & Elby, 2005; Louca et al., 2004). For example, a teacher or student might alternately activate seemingly contradictory beliefs—such as "knowledge is transmitted" and "knowledge is constructed"—depending on the instructional context. Rather than interpreting this as inconsistency, it can be understood as context-sensitive activation of epistemic resources.

In this study, teachers' understanding of scientific models is not treated as a singular, stable belief system, but as a composition of multiple epistemic resources. For instance, understanding a model as an explanatory tool, a visual representation of theory, or a means of hypothesis testing represents distinct but coexisting epistemic stances. From this viewpoint, the resource framework offers a flexible and nuanced lens for analyzing teachers' epistemic cognition.

Furthermore, teaching practices themselves can be interpreted through the resource lens. Recent studies have suggested that teachers' instructional moves—such as questioning, explaining, and providing feedback—can serve as Pedagogical Resources for Teaching (PRT), facilitating the activation of students' epistemic resources (Berland & Crucet, 2016; Louca et al., 2004). For example, a question like "Why do you think this happens?" may not simply request an explanation but may also cue the activation of a specific epistemic resource (e.g., "science relies on evidence"). Thus, ERM and PRT can be seen as continuous and overlapping constructs within the resource-based framework, often manifesting in interwoven ways during classroom instruction.

Determining the Grain Size of Resources

To analyze the understanding and use of scientific models from a resource perspective, distinguishing the grain size of resources is essential. Rodriguez (2024), based on fine-grained constructivism, presented four types of resources according to their grain size (Figure 1): 'p-prim,' intuition-based knowledge fragments such as "it melts better when it's hot"; 'Distributed element,' fragmentary components of scientific concepts like "a lever requires less force when the fulcrum is in the middle"; 'Concept projection,' the way of applying a concept to a specific situation, such as "a typhoon is ultimately a phenomenon caused by pressure differences"; and 'Frame,' an epistemic frame that interprets an entire problem or situation, such as asserting, "we need to conduct a direct experiment to know this."

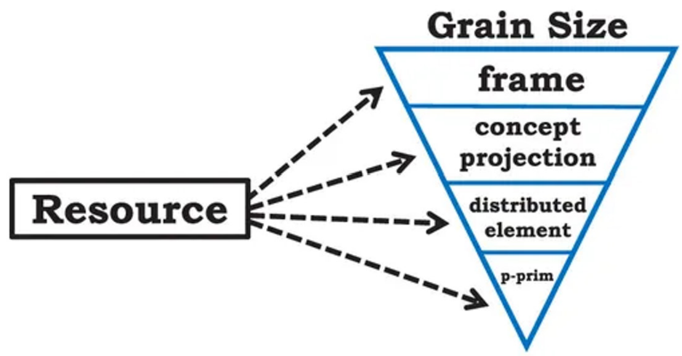

Fig. 1. Grain size of resource (Rodriguez, 2024)

These four categories are not entirely new constructs but rather represent an organized hierarchy of concepts that have appeared across multiple prior studies on resource-based learning and cognition. By systematizing them according to grain size, Rodriguez offers a clarified lens through which to view the diverse scales of knowledge resources—from fine-grained intuitive responses to broader conceptual and epistemic frameworks.

This classification is particularly suitable as an analytical framework because it allows researchers to capture the layered nature of learners' cognitive resources—ranging from momentary intuitions to broader epistemological stances. By specifying the grain size, researchers can more precisely interpret how learners engage with scientific models at different levels, from intuitive ideas to strategic reasoning. Moreover, this framework offers flexibility to trace not only what resources are activated but also how they are reorganized or refined through instruction, making it a powerful tool for analyzing model-based reasoning in science education.

It is necessary to determine the grain size of elementary teachers' resources related to the understanding and use of scientific models. First, regarding the Frame size, judging whether teachers operate with a perception that understanding scientific phenomena through models is important when structuring lessons can be informed by prior research. Hammer et al. (2005) define a frame as an individual's interpretation of the question "What's going on here?" and view it as the activation of a set of 'locally coherent' resources. Analyzing the understanding and use of scientific models at the Frame size requires elementary teachers, the research participants, to possess sufficient resources regarding scientific models. Vasconcelos and Kim (2020) noted a lack of comprehensive synthesis in the literature regarding effective practices implemented in professional learning to prepare teachers to teach scientific models and modeling. This implies that current teachers may not possess enough resources to exhibit a Frame regarding scientific models. Additionally, knowledge of scientific models is a learned concept, not based on intuition or senses, thus it does not correspond to the smallest grain size, p-prim.

Concept projection appears to be the most suitable grain size for analyzing the understanding and use of scientific models from a resource perspective. Concept projection is the resource grain size used when applying the entire concept of "scientific model" to a specific context. For example, if a teacher says during a lesson, "This is about explaining a volcanic eruption by using the model concept we learned," it represents a case where a resource projecting a known model concept onto a new situation is activated. It can also appear at the Distributed element grain size level. The Distributed element size refers to cases where only a part of the understanding of scientific models is activated, appearing in the form of fragmented information such as "a model is not a replica of reality" or "models are iteratively revised." For instance, stating, "a model should be revised if it differs from the experimental results," can be seen as mentioning only the fragmented element of the modifiability of models. Therefore, this study sets the grain size of ERM as Concept projection or Distributed element.

PRT exists in various grain sizes depending on the situation, and the level of these resources can appear differently according to the teacher's pedagogical utterances. For example, a statement like, "Using models is effective because we can experience real phenomena," is a perspective that interprets the educational purpose of using models at a higher level and can be classified as a Frame-size resource, representing an epistemic frame for viewing the entire lesson. On the other hand, the statement, "The materials used to create models should be appropriate for the students' level," deals with specific implementation plans for modeling activities and can be understood as a Distributed element-size resource reflecting a part of the pedagogical practice. Furthermore, the statement, "We use models with various representation methods depending on the learning objective," is an example where a Concept projection-size resource is activated, as it strategically selects the properties of models according to a specific teaching goal, applying the concept of science teaching and learning to a particular instructional context. Thus, PRT can be analyzed on multiple levels depending on whether the teacher's utterances or actions reflect the overall teaching and learning philosophy (Frame), apply specific teaching strategies (Concept projection), or mention individual implementation conditions (Distributed element).

Therefore, this study sets elementary teachers' ERM as resources composed of Concept projection or Distributed element grain sizes, and PRT as resources composed of Distributed element, Concept projection, or Frame grain sizes depending on the situation. By analyzing how these are activated in classroom settings, this research aims to precisely examine teachers' understanding and use of models from the perspective of resource grain size.

ERM (Epistemic Resources for Scientific Model) & PRT (Pedagogical Resources for Teaching)

ERM refers to the epistemic understanding of the nature, purposes, diversity, and revisability of scientific models (Oh & Oh, 2011; Schwarz et al., 2005; Upmeier zu Belzen, 2021). It encompasses resources that reflect what scientific models are, what features they exhibit, and when, where, and why they are used in scientific practice (Chiu & Lin, 2019). For example, one learner may perceive a model as a scaled-down replica of a real phenomenon, while another may view it as a conceptual tool for explanation. Even within the same instructional activity, different epistemic resources—such as “models must accurately reflect reality” versus “models can be selected and revised depending on their purpose”—

can be activated depending on context (Hammer & Elby, 2002).

PRT refers to the diverse epistemic resources that teachers and students draw upon in science teaching and learning contexts. Traditionally, pedagogical resources have been understood as tangible elements such as instructional materials, representational strategies, or visual aids. However, recent studies emphasize the significance of teachers' epistemic resources as essential components of pedagogy (Louca et al., 2004). PRT includes a teacher's language, questioning strategies, task framing, and feedback, all of which function as pedagogical mediators that support students in accessing and developing their own epistemic resources.

Research Methodology

Design

To achieve the purpose of this study, prior research was reviewed concerning scientific models, modeling practices, and instructional approaches for using models in science classrooms. Subsequently, interview questions were developed to examine participants' understanding of scientific models, and instructional topics for implementing modeling lessons were selected. Five elementary teachers with prior science teaching experience were recruited as research participants. Interviews were conducted and their lessons were observed. Data sources included two rounds of interviews regarding scientific models, classroom video recordings, the researcher's field observation notes, and student work samples. The collected data were analyzed inductively to examine how teachers understood and used scientific models. Based on the findings, this study offers implications for supporting elementary teachers' engagement with scientific models and modeling practices in science education.

Participants

The participants in this study were five elementary school teachers who were currently teaching science. They served either as homeroom teachers or subject-specific science teachers. While all participants were responsible for science instruction, their academic backgrounds in science-related majors varied to some extent. Detailed information about the participants is provided in Table 1.

Table 1. Participant teachers' professional backgrounds

Participants	Teaching Experience	Teaching Role	After-School Science Teaching Experience
P1	9 years	Science specialist	None
P2	7 years	Homeroom (Grade 5)	Gifted science instructor
P3	6 years	Homeroom (Grade 5)	None
P4	12 years	Science specialist	Gifted science instructor
P5	13 years	Science specialist	None

Interview Item

To explore the understanding and use of scientific models in depth, interviews were conducted in two sessions. The first interview focused on the nature of scientific models and topics related to model-based instruction, while the second interview addressed the purpose, diversity, construction, and use of scientific models. Particularly in the second interview, considering the common characteristic that elementary teachers lack formal training experience regarding scientific models, a semi-structured interview was conducted using eight statement cards related to scientific models. Research participants randomly selected a card, read the statement written on it, and explained their thoughts. The interview questions for the first and second sessions are presented in the following Table 2 and Table 3.

The first interview questions were developed based on a literature review on the purpose and nature of scientific models, while the second interview questions were constructed by synthesizing prior studies on the purpose, diversity, construction, and use of scientific models. Both sets of interview questions were reviewed and refined through a seminar that included three science education experts, and the final questions were selected after modifications based on their feedback.

Table 2. First interview questions

No.	Interview Question
1	Could you describe the content you taught in today's science lesson?
2	What strategies or tools do you typically use to help students explain natural phenomena?
3	When you hear the term "modeling," what comes to mind?
4	What do you think a scientific model is?
5	Do you use scientific models in your instruction?
6	What conditions do you think are necessary for a model to be effective? Please provide an example.
7	When explaining or predicting a phenomenon, what is your process for constructing and evaluating a model?
8	Do you think using models is an effective way to teach scientific concepts?

Table 3. Second interview questions

No.	Interview Question
1	Models help explain or visualize scientific phenomena, thereby supporting understanding of nature.
2	Models are used to obtain information about phenomena that cannot be directly observed or measured.
3	Scientists may use different models to explain various aspects of the same phenomenon.
4	Researchers develop hypotheses from models and test them while investigating phenomena.
5	Some phenomena represented by models are intentionally simplified or omitted, so models differ from the actual phenomenon.
6	Models are revised when new data emerge or when new ideas are developed.
7	Models are tested through repeated processes and further developed through additional research to meet specific goals.
8	A model should provide accurate information and closely resemble reality.

Modeling Lesson

The modeling lesson topics that the research participants were to conduct were selected from the Earth Science domain. Pedagogical analogy models can be usefully employed in Earth Science as they can provide intuitive understanding of phenomena (Harrison & Treagust, 2000). Furthermore, the objects explored in Earth Science (e.g., volcanoes, Earth's internal structure, atmospheric phenomena) often have limitations in terms of scale or accessibility for direct observation or inquiry through experimentation (Kastens & Rivet, 2010), and it is frequently challenging to conduct experiments under controlled conditions (Gobert & Clement, 1999). Therefore, the modeling lesson topics were determined to be within the Earth Science content area.

The following table Table 4 presents the modeling lesson topics for each research participant.

Table 4. Modeling lesson topics by participant

Participant	Lesson Topic
P1	Comparing the relative distances between planets
P2 / P3	Comparing the relative sizes of planets
P4 / P5	The process of fossil formation

Data Collection

Data Collection on Participants' Understanding of Scientific Models

To explore the research participants' understanding of scientific models, semi-structured interviews were conducted. Data were collected through audio recordings and the researcher's interview notes. During the interviews, the researcher recorded key points of participants' responses and asked follow-up questions to gain deeper insight into their thinking.

To ensure the reliability of the interview data, all audio recordings were transcribed verbatim and analyzed through peer debriefing to verify consistency among researchers. Additionally, a member checking process was implemented in which selected interview content was reviewed by participants to minimize researcher bias. Both the first and second rounds of interviews followed the same format, with each interview lasting approximately 60 minutes.

Data Collection on Participants' Use of Scientific Models

To examine how the participants used scientific models in instruction, multiple sources of data were collected: classroom video recordings of modeling lessons, the researcher's field observation notes, and student work samples. All video recordings were transcribed and coded for analysis.

To conduct a more in-depth analysis of how teachers used models during instruction and how students responded, the researcher's field observation notes were used in conjunction with the transcripts. The observation protocol included the teacher's instructional language, frequency and type of model use, and student reactions. Student work samples were also collected as supplementary data to support the analysis of modeling practices.

To enhance the validity of data analysis, triangulation was employed by comparing multiple sources—interview data, classroom observations, and student artifacts. This cross-analysis strengthened the trustworthiness of the research findings.

Data Analysis

This study employed a qualitative case study approach to analyze elementary teachers' understanding of scientific models and their instructional practices from a resource-based perspective. Multiple data sources were analyzed, including classroom video transcripts, semi-structured interview data, the researcher's field observation notes, and student work samples. Data analysis was conducted using the Constant Comparative Method (Glaser & Strauss, 1998), which enabled iterative comparison and refinement of emerging categories. Transcribed utterances were segmented into resource units, coded, and then categorized to identify the types and structures of resources.

In particular, the analysis focused on how Epistemic Resources for Modeling (ERM) and Pedagogical Resources for Teaching (PRT) were constructed and overlapped within teacher discourse and instructional actions. To do so, Rodriguez's (2024) framework of resource grain size—Distributed element, Concept projection, and Frame—was applied. Each identified resource was categorized according to its grain size and then classified as either ERM or PRT. Additionally, overlaps between the two resource types were analyzed. This allowed for the identification of structures in which PRT, especially at the Frame level (e.g., teacher questioning), encompassed ERM elements at the Distributed or Concept projection level.

To better understand the contextual activation of resources, teachers' instructional intentions and lesson flow were categorized into four instructional contexts: (1) conceptual clarification, (2) induction of cognitive conflict, (3) presentation of alternative models, and (4) conceptual extension. These four contexts served as key analytical lenses for interpreting when and how ERM and PRT were activated and interrelated.

To ensure the trustworthiness of the findings, several validation strategies were employed. First, triangulation across multiple data sources (interviews, classroom videos, observation notes, and student work) was used to ensure consistency and complementarity. Second, peer debriefing and member checking were conducted to verify the accuracy and credibility of interpretations. Third, the researchers engaged in repeated discussions to review coding consistency and collaboratively refine categories, thereby minimizing subjective bias during the analysis process.

Research Results

Study 1

The findings for the first research question were organized into four analytical categories. The first category was the type of activated resource, classified as either Epistemic Resources for Modeling (ERM) or Pedagogical Resources for Teaching (PRT). The second category concerned the grain size of the resource, which was coded according to Rodriguez's (2024) framework as Frame, Concept projection, or Distributed element. The third and fourth categories described the contextual features under which the resources were activated. These were further divided into two dimensions: the content context and the instructional context. The content context referred to the intended learning goals and the target scientific concepts set by the teacher. The instructional context referred to the actual classroom interactions, such as questioning, explaining, and other real-time teaching actions observed during the lesson.

Based on this framework, the analysis further explored the overlap of resources. This analytical category was developed to capture instances in which ERM and PRT did not operate in isolation but appeared to be interconnected or nested within each other. The overlapping patterns provided insights into how epistemic and pedagogical resources were dynamically coordinated during model-based instruction.

Using Models When Phenomena Cannot Be Directly Observed

Research results, research results, research results, research results, research results, research results, research results. P1 explicitly stated during the lesson that models were used because the phenomenon could not be directly observed. Table 5 summarizes P1's instructional episode across four analytical categories. P1's statement, "Other planets··· the universe is unimaginably larger than Earth," functions as an epistemic resource (ERM) and corresponds to the Distributed element level of grain size. This utterance serves to introduce the scientific concept of interplanetary distance to students. In terms of instructional context, it functions as the presentation of a problem situation and plays a role in guiding the direction of subsequent learning. The second statement by P1—“Do you think we can represent that distance here on Earth?”—is classified as an overlapping resource that integrates both ERM and PRT. At the Concept projection level, this resource facilitates the transfer of conceptual thinking. It invites students to move beyond a surface-level understanding of "distance" and encourages them to distinguish between relative and absolute distance. This supports the exploration of representational possibilities through modeling. Instructionally, it aligns with the purpose of inducing cognitive conflict and serves as a pivotal moment for conceptual restructuring. In the following discourse between P1 and the students, the resource type and grain size become less explicit. However, P1’s statement—“We are not comparing absolute distances but relative distances”—clearly guides learners toward a focused conceptual understanding. This utterance resolves the previously introduced cognitive conflict and functions as a scaffold to clarify the learning objective.

Table 5. Analysis of a segment of P1’s lesson

Protocol	Resource Type	Grain Size	Context	
			Content	Instructional Context
P1: “If we line up the planets, we can compare which one is closer or farther.”	ERM	Distributed element	Interplanetary distance	Presenting a problem situation
P1: “Do you think we can represent that distance here on Earth?”	ERM / PRT	Concept projection	Relative vs. absolute distance	Inducing cognitive conflict
Students: “Is it the absolute distance between the planets?”	Unclassified		Absolute distance	Distinguishing types of distance
P1: “We are not comparing absolute distances but relative distances.”	Unclassified		Understanding of relative distance	Conceptual clarification

Notably, this episode from P1 illustrates a clear instance of resource overlap. The question “Do you think we can represent that distance here on Earth?” does more than pose a surface-level inquiry—it provides an epistemic resource (ERM) that prompts students to consider both the necessity and limitations of modeling. Simultaneously, it operates as a pedagogical resource (PRT) by creating cognitive dissonance to promote deeper engagement. This kind of resource overlap demonstrates how scientific modeling is not merely about replication but also about offering students opportunities for critical reflection and conceptual reconstruction.

Differences in Instructional Effectiveness Based on Representational Modes of the Same Model

In the case of P1, the analysis focused not on classroom discourse but on statements made during a post-lesson interview. Table 6 summarizes the resource-related statements from the interview using the four analytical categories. P1’s statement, “If we line up the planets, we can compare which one is closer or farther away,” represents an overlap between epistemic resources for modeling (ERM) and pedagogical resources for teaching (PRT). The resource appears at the Distributed element level of grain size and emphasizes students’ ability to construct and use a model to directly compare relative distances between planets. This statement reflects an instructional context focused on exploratory activities using representational models to support intuitive understanding. The next statement by P1, “That diagram of the planetary system is actually split into sections,” does not clearly indicate a resource type, but it highlights the limitations of the visual structure in the original materials. This statement suggests that the spatial separation of planetary diagrams may hinder students' conceptual understanding of distance. It aligns with an instructional context of recognizing limitations in existing representations. The third statement, "So it's difficult for students to grasp who's closer and who's farther away," is classified as a PRT and corresponds to the Concept projection level. Here, the teacher diagnoses students' difficulties in interpreting visual model representations and acknowledges challenges in concept formation. This statement demonstrates the teacher's instructional awareness of conceptual barriers, which carries significant pedagogical implications. The final statement, "So when we laid them out in a row, it worked," indicates that an alternative representational model helped students better understand the concept of distance. While the resource type is not explicitly defined, the statement corresponds to a moment of confirming the effectiveness of an instructional representation. It reflects the cognitive impact of model structure within a real classroom context. The overlap of ERM and PRT in P1's initial statement illustrates how epistemic understanding of scientific models and pedagogical strategy can operate simultaneously in science instruction. The explanation, "lining up the planets makes comparison possible," goes beyond a simple instructional remark—it demonstrates how scientific models serve as tools for supporting conceptual development (ERM). At the same time, the visual structuring of the model is intended to support student cognition, functioning as a pedagogical resource (PRT). This overlap suggests that the teacher's instructional design is informed by both the epistemic features of scientific concepts and the cognitive needs of learners.

Table 6. Analysis of a segment of P1's lesson

Protocol	Resource Type	Grain Size	Context	
			Content	Instructional Context
P1: "If we line up the planets, we can compare which ones are closer or farther."	ERM / PRT	Distributed element	Relative positions of planets	Construction and use of specific models
P1: "That diagram of the planetary system is actually divided across different sections."	Unclassified		Initial understanding of relative distance	Recognition of limitations in existing materials
P1: "So it's difficult for students to grasp the concept of who's closer and who's farther."	PRT	Concept projection	Understanding of distance concept	Diagnosis of students' cognitive difficulties
P1: "So when we laid them out in a row, it actually worked."	Unclassified		Effectiveness of alternative model	Confirmation of instructional impact

Connecting the Modeling Process to Real-World Phenomena

P4 demonstrated an instructional approach in which the process of creating a model was explicitly connected to the corresponding natural phenomenon. Table 7 presents four resource-related statements from P4's lesson, categorized using the resource-based framework.

Table 7. Analysis of a segment of P4's lesson

Protocol	Resource Type	Grain Size	Context	
			Content	Instructional Context
P4: "This is not a real clam fossil, but a fossil of the clam's body."	Unclassified		Distinction between real fossil and model	Conceptual clarification
P4: "So, the alginate filled the space where the clam used to be."	Unclassified		Process of fossil formation	Explanation of model construction
P4: "Right, a real fossil was found in the space where the clam had been, resembling its body."	ERM	Distributed element	Relationship between model, organism, and fossil	Model–phenomenon connection
P4: "Then what do you think the long imprint on the other side might be?"	ERM / PRT	Frame	Application of body fossil concept in a new context	Concept transfer and expansion

P4's statement, "This is not a real clam fossil, but rather a fossil of the clam's body," does not explicitly indicate a resource type or grain size, but it shows an intention to clarify the distinction between an actual fossil and a fossil model. The goal of this utterance appears to be promoting conceptual clarification. The second statement, "So, the alginate filled the space where the clam used to be," also lacks an explicitly coded resource type, but it supports students' understanding of the fossilization process. By explaining that the model preserves the shape of the clam not through the organism itself but through the material filling its space, the teacher reinforces a key scientific principle underlying fossil formation. The third statement, "Right, a real fossil was found in the space where the clam used to be, resembling its body," is categorized as an epistemic resource for modeling (ERM), with a grain size of Distributed element. This utterance helps students conceptualize the distinction and relationship between the real organism, the fossil, and the model. It fosters students' understanding of how scientific models represent real phenomena, aligning with an instructional context focused on model–referent connections. The fourth statement, "Then what do you think the long imprint on the opposite side is?", represents an overlapping resource, integrating both ERM and PRT, and corresponds to the Frame level of grain size. P4 encourages students to apply their newly learned concept of body fossils to a new situation (e.g., a tire track analogy), promoting concept transfer and extension. This represents a shift from knowledge acquisition to application, situated within a model-based learning environment. This final statement reflects a clear overlap between ERM and PRT. The reference to an "imprint on the opposite surface," formed during the modeling activity, prompts students to transfer their conceptual understanding of fossil models to a novel context. As a pedagogical resource (PRT), it guides students in applying their learning, while as an epistemic resource (ERM), it fosters deeper insight into the representational role of models in science.

Promoting Understanding of the Differences Between Models and Real Phenomena

P5 employed instructional prompts aimed at helping students understand the differences between scientific models and the real-world phenomena they represent. Table 8 summarizes four resource-related statements identified from P5's lesson using the resource-based framework.

Table 8. Analysis of a segment of P5's lesson

Protocol	Resource Type	Grain Size	Context	
			Content	Instructional Context
P5: "Real fossils take a very long time to form, but this one didn't—it only took us 5 minutes."	ERM	Distributed element	Awareness of differences between model and actual phenomenon	Highlighting the model–phenomenon gap
P5: "But how long do real fossils take? Hundreds or even thousands of years, right? Not something made in 5 minutes."	ERM	Distributed element	Understanding that fossilization takes a long geological time	Reinforcing the concept of timescale
P5: "When you poured the alginate, what real process do you think that represented?"	ERM	Concept projection	Understanding of the scientific meaning behind the activity	Guiding connection between activity and concept

The first statement—"Real fossils take a very long time to form, but this one didn't. We made it in just five minutes, right?"—is categorized as an Epistemic Resource for Modeling (ERM) at the Distributed element level. This statement prompts students to recognize the temporal difference between actual fossil formation and the classroom model, encouraging reflection on the model–phenomenon gap. Similarly, P5's second statement—"But how long does it take for real fossils to form? Hundreds or even thousands of years, right? Not something you can make in five minutes."—is also classified as ERM and falls within the Distributed element level. In this case, the teacher reinforces a scientific understanding of geological timescales and fosters students' awareness of the significant time investment required for fossilization. This aligns with an instructional context focused on expanding and deepening the concept of time. The third statement—"When you poured the alginate, what real process do you think that represented?"—represents an overlap between ERM and Pedagogical Resources for Teaching (PRT), and is categorized at the Concept projection level. This prompt encourages students to move beyond perceiving the activity as a mere hands-on task and begin to infer scientific meaning from the process. Instructionally, it fosters conceptual transfer by connecting classroom activity to real-world processes. In addition, this third statement functions as a pedagogical strategy by guiding students to reinterpret their experimental actions (e.g., pouring alginate) not as simple imitation but as a meaningful representation of scientific processes. This type of resource overlap demonstrates a core instructional approach in model-based science education—linking student activities with underlying scientific concepts to support epistemologically grounded learning.

Study 2

Models Can Be Revised or Replaced Based on Theories or Evidence

ERM stating that "models can be tested or revised and may change depending on new theories or evidence" was explicitly mentioned by several participants but was not enacted in classroom practice. For instance, P3 stated, "I think that as scientists continue their research, theories can change, and that can lead to changes in models." This statement clearly reflects the idea that models are not static, but rather are subject to modification or replacement in light of new theoretical developments or empirical data. Similarly, P1 explained, "If a new theory emerges, a different model could be used to explain the same phenomenon. For example, Einstein proposed the theory of relativity, which offered a new paradigm for understanding time." P2 noted, "Only after being verified by data can a model be included in textbooks—or it might disappear over time." These statements directly align with the ERM that recognizes the dynamic and revisable nature of scientific models. However, despite their conceptual understanding, the participants did not translate this ERM into instructional actions. None of the statements were connected to activities in which students were invited to critically examine, revise, or test models based on new evidence or reasoning. In all three cases, the teachers articulated a theoretical awareness of model change and revision, but this remained at the level of verbal explanation. There was no indication that students were engaged in scientific practices that would allow them to experience or explore this aspect of modeling. As a result, although the ERM was cognitively acknowledged, it was not activated within the classroom context.

In conclusion, while P1, P2, and P3 all demonstrated an understanding that models can change based on theories or evidence, this ERM was not operationalized in their instructional design or student activities. Therefore, the resource remained recognized but unactivated in practice.

Models Are Both Concrete and Idealized Representations—They Are Simplified Depictions

ERM stating that “models are both physical representations and idealized forms, simplified for conceptual clarity” was clearly recognized by both P2 and P3, yet not fully enacted in classroom practice. P2 reflected on prior instructional practices, stating, “When teaching earthquakes, I’ve used sliced bread to demonstrate faults or used Styrofoam to simulate seismic activity. I’ve also brought in anatomical models to explain body systems. I use models quite frequently.” This response reveals P2’s awareness of the frequent and practical use of concrete models to support science instruction. P3 elaborated further on the nature and necessity of simplified models: “Models are learning tools that are reduced or simplified versions of reality. For example, when it comes to geological strata, if a model looks too much like the real natural structure, students may find it difficult to identify patterns or principles. So, simplified models are necessary.” Here, P3 emphasizes that idealization through simplification is not a flaw, but a pedagogical strength—one that makes underlying scientific principles more accessible to learners. Both statements indicate a clear conceptual understanding of the representational and functional nature of scientific models, specifically their role as idealized simplifications rather than exact replicas. These ideas align closely with ERM perspectives that emphasize the epistemic function of models in representing, rather than reproducing, phenomena. However, similar to previous cases, the teachers’ understanding of this ERM remained at the level of theoretical awareness. There was no evidence that this understanding was explicitly enacted in instructional design or student activities. That is, while both P2 and P3 articulated the importance of simplification in modeling, they did not describe or implement learning experiences in which students actively engaged with or critically reflected on the simplification process or its epistemological implications.

In conclusion, P2 and P3 clearly recognized and articulated the ERM that models are simplified representations of real-world phenomena. Nevertheless, this resource was not activated in a way that engaged students in epistemically meaningful model-based reasoning. The ERM was thus present in teacher cognition but remained unutilized in classroom practice.

Models Are Constructed from Theories, and Multiple Models Can Coexist

ERM stating that “models are constructed based on theories or evidence and may be revised or replaced” was acknowledged by both P2 and P5. Their statements reflect an understanding of the relationship between scientific theories and models, as well as the provisional and revisable nature of scientific knowledge. P2 stated, “There must be a theory that led to the creation of a model, right?” This remark illustrates an awareness that models are not arbitrary or imaginative tools, but are grounded in scientific theories. P2 implicitly recognized the generative function of theories in model construction—that is, models serve to visualize, explain, or test theoretical ideas. In doing so, P2 verbally articulated a core ERM concept: that models emerge within scientific contexts as representations of underlying theoretical frameworks. P5 added, “All scientific theories can be overturned by a single counterexample.” This statement reflects an understanding of the tentativeness of scientific knowledge and implies that models, as products of theory, are also subject to revision. P5 continued, “If we assume people in the past created a model to explain Earth…”, suggesting that older models were eventually replaced due to shifts in theory or emerging evidence. This demonstrates P5’s recognition of the evolving relationship between theories and models, and that models are contingent, rather than fixed, explanatory tools. While both P2 and P5 displayed a conceptual understanding of the epistemic relationship between models and theories, these resources were not translated into instructional practices or student activities. As with other previously analyzed cases, these ERMs remained at the level of teacher cognition and were not activated through classroom experiences that might have allowed students to engage with the tentative, theory-based nature of models.

In conclusion, although P2 and P5 expressed an awareness of the theoretical foundations and changeability of models, this ERM was not enacted in a way that allowed students to explore, critique, or revise models. Thus, the resource was conceptually present but remained unutilized in practice.

Models Serve as the Best Available Explanations and Are Selected Based on Their Explanatory Power

P4 expressed an epistemic understanding that scientific models are not singular or fixed but evolve through the scientific process, where multiple models may be proposed and tested. This is illustrated in the following statement: “As more data and observational results are collected, a particular model is eventually accepted. I think during the development process, many models can emerge, but over time, the one that best explains the phenomenon becomes the optimal model.” This remark reflects a recognition that model selection in science is not a static decision but a dynamic process influenced by accumulating empirical evidence and explanatory adequacy. P4's perspective illustrates a key Epistemic Resource for Modeling (ERM): models are judged and refined based on how well they explain observed phenomena. The notion of an “optimal model” suggests that models compete on the basis of explanatory power, and only those that are most useful or robust survive scientific scrutiny. Furthermore, P4 notes that it is through application—not merely construction—that a model’s adequacy is determined. This highlights an important scientific practice: models are not accepted solely upon creation but must prove their explanatory utility through use. This aligns with the idea that models function as epistemic tools, and their value lies in how effectively they represent, explain, or predict aspects of the natural world. However, as in other cases of unactivated ERMs, this understanding remained within the teacher’s conceptual framework and was not extended into classroom practice. There was no indication that students were engaged in comparing, evaluating, or refining models based on explanatory criteria. Despite P4’s recognition of the role of model selection and the provisional nature of models, the lesson did not include learning activities that would allow students to experience this aspect of scientific modeling.

In conclusion, while P4 demonstrated an epistemic understanding that models are evaluated and selected for their explanatory power within a dynamic scientific process, this resource was not activated in classroom instruction. It remained a cognitively held idea that was not enacted through student-centered modeling practices.

Model Construction Involves Deduction, While Validation Requires Induction

P4 provided two statements that articulate a sophisticated epistemic understanding of the logical processes underlying scientific modeling. These statements reflect a clear grasp of how models are constructed, tested, and justified in scientific practice. P4 stated: “I think the process of constructing a model is deductive. And the process of validating a model must be inductive—through experiences and observations—to make it a complete and acceptable model.” In a follow-up statement, P4 added, “The model we are currently using can also be seen as the most reasonable explanatory framework suited to our current level of understanding.” These statements demonstrate a deep and nuanced view of modeling as both a logical and epistemic process. P4 distinguished between the deductive reasoning involved in model generation and the inductive reasoning required for model validation. Furthermore, P4 acknowledged that models are context-dependent representations, shaped by the limits of current knowledge and understanding. This reflects a high-level application of ERM, positioning scientific models as provisional yet rational constructs derived from theoretical assumptions and empirical testing. However, consistent with other cases of unactivated ERM, this sophisticated teacher-level epistemic insight was not translated into instructional practices or student learning experiences. There was no indication that students were engaged in activities where they constructed models through deductive reasoning or tested them inductively through data interpretation and evidence-based argumentation. Nor were there opportunities for students to reflect on the epistemic limits or justification of the models they used.

As a result, while P4's remarks illustrate a mature conceptualization of scientific modeling processes, the epistemic resources remained unactivated in the classroom. The resource was recognized at the teacher cognition level but not enacted in ways that supported students' conceptual development or modeling practices.

Models Are Perceptible Through the Senses and Enable Engagement with Scientific Practices

P5 expressed a view of scientific models that emphasizes their sensory accessibility and experiential dimension. In the first statement, P5 remarked: "I think something can be a model even if it isn't visible—like a sound, for example. You have to experience it somehow. A model should be something you can see, hear, smell, or touch. It shouldn't just be something you imagine in your head—it should be something you can feel."

This comment highlights a key epistemic perspective that scientific models are not limited to abstract visual representations. Rather, they can be embodied in multiple sensory modalities and experienced physically. This aligns with an Epistemic Resource for Modeling (ERM) that emphasizes the affordances of models as manipulable and perceivable tools through which learners can engage meaningfully with scientific phenomena.

In the second statement, P5 reflected on a prior instructional activity: "I've done an activity where students excavated fossils to understand how they form. They dug out insects preserved in amber, and through that process, inferred the environmental conditions and formation processes of different fossils—just like scientists do."

This description illustrates a learning experience in which students physically engaged with models—amber-embedded insects—as part of an inquiry-based lesson. Through the act of excavation and inference, students used the model as both a representation of the fossilization process and a tool for generating scientific explanations. This enactment demonstrates an alignment between the teacher's epistemic understanding of models and the instructional design, providing students with a tangible experience of scientific practices.

Unlike other cases where ERMs remained unactivated, P5's statements represent a partial activation of epistemic resources. The teacher not only articulated an understanding of models as sensory and experiential but also described a lesson in which students actively engaged with a model to construct scientific meaning. However, it is important to note that this experience was referenced in a prior teaching context and did not explicitly appear in the modeling lesson analyzed in this study.

In conclusion, P5's perspective foregrounds the sensory and experiential dimensions of modeling and illustrates how models can function as embodied tools for learning and inquiry. While the ERM was not fully enacted in the lesson under investigation, it was clearly linked to past instructional practices and thus represents a partially activated epistemic resource.

Discussion

The Overlapping Structure of PRT and ERM in Modeling Lessons

Lesson observations of elementary teachers' modeling instruction revealed multiple instances in which Pedagogical Resources for Teaching (PRT) and Epistemic Resources for Modeling (ERM) were activated simultaneously(Fig. 2). Notably, PRTs were rarely enacted in isolation; instead, they were frequently expressed in ways that included embedded ERMs. For example, P1's question—"Can we represent this distance here on Earth?"—not only activated an ERM related to model-reality correspondence but also functioned as a deliberate pedagogical strategy to induce cognitive conflict. This is a representative case in which a PRT operated as an instructional frame while containing epistemic content.

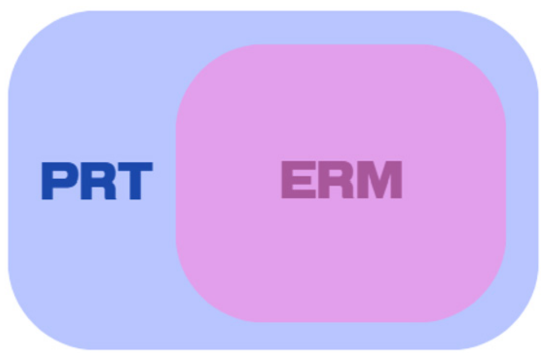

Fig. 2. Overlap of PRT and ERM in modeling lesson

This finding aligns with Ke and Schwarz's (2021) assertion that teachers often struggle with modeling instruction due to limited understanding of what scientific modeling entails. In line with Russ (2018), who emphasized the importance of epistemic messages such as "How can our model be justified?", this study positions teacher discourse as a site where epistemic and pedagogical resources converge. While prior work has addressed epistemic messaging as an instructional support, it has not analyzed such messages from a resource-based perspective. Consequently, the overlap between instructional strategies (PRTs) and epistemic reasoning (ERMs) has remained underexplored. Teacher discourse—particularly in the form of questioning and prompting—often draws on Frame-level resources (Hammer et al., 2005). Within the lesson context, including the teacher's instructional goals, teaching strategies, content, and student responses, certain pedagogical resources for teaching (PRTs) are activated. Especially in modeling lessons, where explanation, justification, and abstraction are central, these PRTs rarely operate in isolation. Instead, the activated PRTs frequently embed epistemic resources for modeling (ERMs), such as concept projection or distributed elements, as part of their function. For instance, a prompt like "Can we represent this distance here on Earth?" not only serves a pedagogical purpose by provoking cognitive conflict, but also conveys epistemic meaning—emphasizing that scientific models are not replicas but representational tools with specific functions.

As the attached Fig. 3 illustrates, these resources often overlap in real classroom practice, forming a hybrid structure in which PRTs and ERMs are interwoven. This overlapping is not incidental but rather a pedagogically meaningful configuration that emerges in response to the complex cognitive and instructional demands of modeling-based science teaching. While prior studies have tended to analyze teaching strategies as procedural routines (Boschl et al., 2022; Zhang et al., 2024) or treated model understanding as static knowledge (Gobert et al., 2010; Treagust et al., 2002), this study highlights that teacher discourse involves a dynamic and selective activation of resources, shaped by the lesson context. Specifically, Frame-level PRTs often encompass ERMs at finer grain sizes, revealing that modeling instruction is inherently resource-integrative—both epistemically and pedagogically.

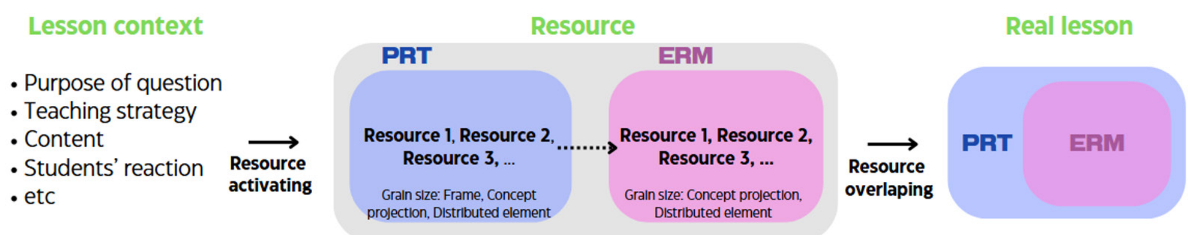

Fig. 3. Process of overlaping resources in the context of lesson

Contexts for the Activation of ERM and PRT

The activation of EResources for Modeling (ERM) and Pedagogical Resources for Teaching (PRT) was found to vary depending on specific instructional contexts and the teacher's intended purpose behind questioning. In particular, classroom situations involving conceptual clarification, induction of cognitive conflict, presentation of alternative models, and promotion of conceptual extension served as key contexts in which these resources were frequently activated. For instance, P4 activated a Frame-level resource while explaining the difference between the model and the actual process of fossil formation, encouraging students to transfer their understanding to a novel situation. Such instructional moments—where conceptual transfer or structural comparison is required—tend to broaden the grain size of the activated resource and increase the likelihood of simultaneous activation of both ERM and PRT.

However, ERMs were not automatically activated in every classroom situation. Instead, they tended to emerge selectively and only under certain conditions. In some cases, teachers demonstrated a rich awareness of ERMs during interviews, yet failed to enact those resources during instruction. This gap between teacher understanding and classroom practice has also been noted in previous studies (Sin et al., 2009; Louca & Zacharia, 2012). Such findings suggest that the activation of ERMs is not solely dependent on the teacher's epistemic knowledge, but also shaped by a complex interplay of variables such as lesson structure, questioning style, student responses, and content domain.

Therefore, future research should aim to investigate more systematically the conditions under which ERMs are actively mobilized in classroom practice. This could involve large-scale analysis of diverse instructional cases across different science topics and grade levels, employing both quantitative and qualitative methods to trace patterns of ERM activation. Such efforts would contribute to a more comprehensive understanding of how epistemic resources function within the dynamic ecology of science teaching and learning.

Elementary Teachers' Rich ERM

During interviews, the participating elementary teachers demonstrated a rich and multifaceted understanding of scientific models, revealing a wide range of epistemic resources for modeling (ERM). Contrary to concerns raised in prior studies (e.g., Nielsen & Nielsen, 2021), the findings suggest that elementary teachers already possess substantial epistemic awareness related to the nature, diversity, revisability, and functionality of scientific models within inquiry-based practices. In particular, P4 and P5 articulated high-level ERMs, emphasizing that models are not only tools for representation but also experientially accessible artifacts that reflect the cognitive processes of scientists.

However, these ERMs were primarily activated during interviews and were often not transferred into classroom instruction—a pattern similarly reported in previous studies (Berland & Crucet, 2016). This suggests that possessing rich epistemic resources at the conceptual level does not automatically translate into effective classroom enactment. For ERMs to be operationalized in practice, additional pedagogical strategies and instructional design supports are required.

In other words, professional development must focus on facilitating the integration of epistemic resources into pedagogical practices. This includes helping teachers recognize opportunities to embed their conceptual understanding of models into lesson structures, discourse strategies, and student activities. Future teacher education programs and instructional design workshops should therefore place greater emphasis on developing teachers' capacity to mobilize ERMs during instruction, ensuring that their rich conceptual knowledge is meaningfully connected to their classroom teaching.

Conclusions and Implications

This study explored elementary teachers' understanding and classroom use of scientific models through a resource-based perspective. By conducting semi-structured interviews and modeling lessons with five elementary teachers, the study analyzed how Epistemic Resources for Modeling (ERM) and Pedagogical Resources for Teaching (PRT) were activated in instructional contexts. The following conclusions were drawn:

First, the participating teachers demonstrated a rich repertoire of epistemic resources related to scientific models—including understandings of their nature, diversity, revisability, and functions within inquiry. These ERMs were clearly evident during interviews, suggesting that, contrary to concerns in previous research (e.g., Nielsen & Nielsen, 2021), elementary teachers do not merely hold fragmented misconceptions about models. However, most of these ERMs were not activated in classroom instruction, indicating a disconnect between teachers' conceptual understanding and pedagogical enactment. Second, ERMs and PRTs were rarely activated independently. Instead, they frequently overlapped during instruction, particularly in teaching situations that involved conceptual clarification, cognitive conflict, or alternative model generation. In such cases, the interaction between ERM and PRT played a key role in facilitating students' conceptual development and epistemic shifts. This overlapping phenomenon demonstrates that interactions among resources are central to enhancing the quality of science learning. Third, the activation of ERM and PRT was highly context-dependent. The teacher's utterances—shaped by lesson goals, the nature of the scientific content, students' cognitive responses, and the representational form of the model—varied in their grain size, appearing as distributed elements, concept projections, or frame-level resources. These findings confirm that a resource-based perspective serves as an effective analytical tool for capturing the nuances of teacher understanding and classroom practice in science education.

Based on the findings of this study, several important educational implications can be drawn. First, it is essential that professional development programs are designed to support teachers in transforming their epistemic resources (ERMs) into tangible classroom practices. Rather than focusing solely on the transmission of theoretical knowledge, teacher education should prioritize the development of instructional strategies that foster the integration of ERMs with pedagogical resources (PRTs). In particular, interventions at the lesson planning stage may play a critical role in helping teachers bridge their epistemic understanding with pedagogical enactment. Second, teacher learning should be grounded in practice. That is, it should go beyond acquiring theoretical knowledge about scientific models and instead emphasize how this knowledge can be applied and extended in real classroom contexts. To this end, methods such as case-based simulations, structured lesson analysis, and guided post-lesson reflections can be effectively employed to promote deeper engagement with classroom modeling practices. Finally, future research should explore the ways in which teachers' epistemic and pedagogical resources interact with those of students. In particular, it will be important to examine how teacher discourse and the activation of ERMs and PRTs influence students' conceptual development and engagement in modeling practices. A comprehensive investigation of this interaction can provide valuable insight into how resources operate not only at the teacher level but also within the broader ecology of classroom learning.

In conclusion, this study offers a structured analysis of elementary teachers' understanding and use of scientific models through a resource-based lens. By identifying the interactions between ERM and PRT and analyzing how they are activated in classroom contexts, the study contributes both theoretically and practically to the improvement of science instruction and teacher education. This approach is expected to offer valuable insights for advancing model-based science education in both research and practice.

Limitations of the Study

While this study provides an in-depth analysis of elementary teachers' understanding and use of scientific models through a resource-based lens, it has several limitations. Conducted with five teachers, the small sample size limits generalizability, and resource structures may vary widely based on individual contexts. Data collection was restricted to interviews and a single lesson per teacher, making it difficult to trace patterns of ERM and PRT activation across topics or over time. The analysis relied on Rodriguez's (2024) framework and involved researcher interpretation, raising the possibility of subjectivity. Moreover, the study focused solely on teachers' resources, without examining how these interacted with students' thinking during modeling. Despite these constraints, the study offers important insights into the dynamic interplay of ERM and PRT in classroom practice and lays a foundation for improving science instruction through resource-based teacher education.

Acknowledgements

This is a revision and reconstruction of th master's thesis by the Lee Yeonhee (2025).

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