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Enhancing Students' Levels of Understanding of the Sun–Earth System through a Phenomena-Driven Instruction Model Supported by Bi-Model Media

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Abstract – *Understanding Sun–Earth system phenomena remains challenging for many students because the underlying astronomical mechanisms involve cosmic-scale objects, spatial relationships, and dynamic processes that cannot be directly observed in their entirety. These difficulties often lead to an incomplete understanding and persistent misconceptions about insolation, variations in day and night lengths, and seasonal changes. This study aimed to investigate changes in preservice elementary teachers' conceptual understanding of the Sun–Earth system after the implementation of the Phenomena-Driven Instruction (PhDI) model, assisted by Bi-Model media. A pre-experimental method with a one-group pretest–posttest design was employed. The participants were 36 second-year students enrolled in an Elementary Teacher Education Program at a university in North Kalimantan, Indonesia. The instructional intervention was implemented through five stages of the PhDI model supported by Bi-Model media consisting of physical and virtual representations of the Sun–Earth system. Data were collected using the Level of Conceptual Understanding Test (LCUT), which covered four concepts: insolation, day and night duration, winter, and summer. The instrument was validated by five experts and demonstrated good internal consistency, with a Cronbach's alpha coefficient of 0.80. The results showed a consistent shift from lower levels of understanding, including partial understanding with misunderstanding, misunderstanding, and no understanding, toward higher levels, particularly partial understanding and sound understanding. The percentages of students reaching sound understanding were 52% for isolation, 58% for day and night duration, and 61% for both winter and summer. The novelty of this study lies in integrating phenomena-driven learning with dual physical and virtual model representations to support conceptual reconstruction of astronomical concepts. These findings suggest that PhDI assisted by Bi-Model media can support more scientifically acceptable explanations of Sun–Earth system phenomena and contribute to physics education by offering an instructional approach for teaching abstract, cosmic-scale concepts to preservice elementary teachers.*

Keywords: *Bi-Model media; conceptual understanding; phenomena-driven instruction; physics education; Sun–Earth system.*

I. INTRODUCTION

Science is a field of knowledge that investigates the natural world to help learners understand various natural phenomena and the underlying principles that govern them (Tala & Vesterinen, 2015). It encompasses both living and non-living entities, including objects that can be directly observed through the human senses or measured using scientific instruments, as well as objects and processes that cannot be directly perceived (Acquah, 2020). The objects studied in science vary widely in scale, ranging from submicroscopic entities, such as atoms and subatomic particles, to cosmic-scale systems, including planets, stars, galaxies, and the universe. Accordingly, scientific objects may generally be classified into three scales: (1) the submicroscopic or microscopic scale, which includes atoms, electrons, protons, neutrons, and other elementary particles (Bucat & Mocerino, 2009); (2) the macroscopic scale, which includes everyday objects that can be directly observed by humans (Van Velzen, 2023); and (3) the cosmic scale, which encompasses celestial bodies and large-scale structures of the universe (Coil, 2024).

However, not all scientific objects and phenomena can be directly observed because human sensory systems have inherent limitations. Human vision, for instance, is sensitive only to objects within a limited range of dimensions (Ramamurthy & Lakshminarayanan, 2015). Objects that are much smaller or much larger than this observable range cannot be perceived directly without technological assistance, such as microscopes or telescopes. Consequently, while some scientific phenomena can be learned through direct sensory observation, many others must be understood indirectly through representations, models, or scientific interpretations (Evagorou et al., 2015). Learning about scientific objects that are not directly observable is often more challenging than learning about observable ones because students must rely on mental imagery to visualize their structures, behaviors, and mechanisms. Students frequently have difficulty conceptualizing submicroscopic structures, cosmic systems, and invisible interactions, particularly when these phenomena involve complex spatial relationships or dynamic processes.

In addition, invisible or inaccessible objects do not provide immediate and concrete sensory experiences because they cannot be directly seen, touched, or manipulated (Von Glasersfeld, 2012). These limitations may hinder students from developing comprehensive scientific understanding and may contribute to the formation of misconceptions. Nevertheless, invisible scientific objects can still be learned effectively when appropriate instructional supports are provided. Scientific instruments, such as microscopes and telescopes, can extend human observation and make otherwise invisible objects accessible. Visualizations and dynamic representations, including animations, simulations, and three-dimensional models, can also help students conceptualize abstract or inaccessible phenomena. Moreover, scientific understanding may be developed through data analysis, sensing technologies, spectroscopy, and theoretical modeling, which enable the inference of invisible phenomena.

One course offered in the elementary teacher education program is basic science concepts (Faisal & Martin, 2019). In this course, the Solar System topic is essential because it addresses Earth-related phenomena closely connected to everyday life. Many natural phenomena observed on Earth result from interactions among members of the Solar System, particularly the Earth, the Sun, and the Moon. Phenomena such as day and night cycles, seasonal changes, ocean tides, eclipses, and other astronomical events are fundamentally related to the Sun–Earth–Moon system. However, objects within the Solar System exist on a cosmic scale and therefore cannot be directly observed in their entirety by the human eye. As a result, instructional media that can represent astronomical mechanisms are needed to support students in developing a more meaningful understanding of Earth-related phenomena.

Despite the importance of this topic, previous studies have shown that students frequently experience difficulties in understanding Sun–Earth system phenomena and often hold persistent misconceptions (Inaltekin & Akbaba, 2024; Panagiotaki et al., 2009; Sneider et al., 2011). Common misconceptions include the belief that seasons occur because the Earth moves closer to or farther from the Sun, that summer results from increased Earth–Sun proximity, and that variations in day and night duration are primarily caused by changes in the Earth's distance from the Sun (Inaltekin & Akbaba, 2024; Nobes et al., 2023). Students also commonly struggle to understand insolation and the role of the Earth's axial tilt in producing seasonal variations (Plummer & Maynard, 2014). These misconceptions tend to persist because the underlying astronomical mechanisms are not directly observable and require learners to visualize complex spatial relationships and motions (Inaltekin & Akbaba, 2024; Plummer, 2009). Consequently, students often rely on intuitive explanations drawn from everyday experience rather than scientifically accepted ones (Posner et al., 1982; Treagust & Duit, 2008).

One instructional medium that is particularly useful for representing objects that are too large, too small, too distant, or too complex for direct observation is the model. In science education, models provide representational learning experiences when direct interaction with actual objects is not possible. A model is a three-dimensional representation of a real object and may be larger, smaller, or the same size as the object it represents. It may also be simplified or detailed depending on instructional purposes. According to Sarah et al. (2026), models can represent real objects that are too large, too distant, too small, too expensive, too rare, or too complex to bring into the classroom and study in their original forms. Therefore, models are particularly valuable for supporting the teaching and learning of astronomical systems, including the Solar System, whose dimensions and mechanisms are difficult to observe directly (Cheng & Yeh, 2026).

Previous studies have reported that phenomenon-based learning, model-based learning, simulations, and various visualization technologies can support students' understanding of abstract scientific concepts (Olympiou et al., 2013; Saberi & Nouri, 2025; Ualikhanova et al., 2024; Wulandari et al., 2021). Phenomenon-based learning has been associated with improvements in conceptual understanding through engagement in authentic scientific inquiry and explanation-building activities (Hemtasin et al., 2026; Ualikhanova et al., 2024). Similarly, model-based learning and visualization technologies have been shown to facilitate students' understanding of scientific phenomena that are difficult to observe directly by providing concrete and dynamic representations of abstract concepts (Banda & Nzabahimana, 2021; Olympiou et al., 2013; Wibowo et al., 2016). However, most previous studies have examined these approaches separately. Limited research has investigated the integration of a phenomenon-driven instructional approach with multiple forms of model representations, particularly physical and virtual models, to support conceptual understanding of Sun–Earth system phenomena. Therefore, empirical evidence regarding how such an integrated approach may support students' understanding of astronomical phenomena remains limited.

The use of model-based media should also be aligned with an appropriate instructional approach. Because Solar System content is closely tied to observable Earth phenomena, the Phenomena-Driven Instruction (PhDI) model is considered particularly relevant. PhDI is an instructional approach in which science learning begins with real-world phenomena that stimulate curiosity and encourage students to seek explanations rather than merely memorize facts. This approach emphasizes the connection between learning activities and observable natural phenomena that promote inquiry, investigation, and three-dimensional learning aligned with the principles of the Next Generation Science Standards (NGSS) (Park et al., 2023). Key characteristics of PhDI include: (1) emphasizing understanding rather than memorization, in which students construct evidence-based explanations for scientific phenomena; (2) using anchoring phenomena to motivate the entire learning sequence; (3) employing investigative phenomena to guide students in answering smaller conceptual questions throughout the learning process; (4) integrating disciplinary core ideas, scientific practices, and crosscutting concepts; and (5) promoting inquiry-oriented learning in which students continuously explore "why" and "how" questions to monitor and refine their understanding.

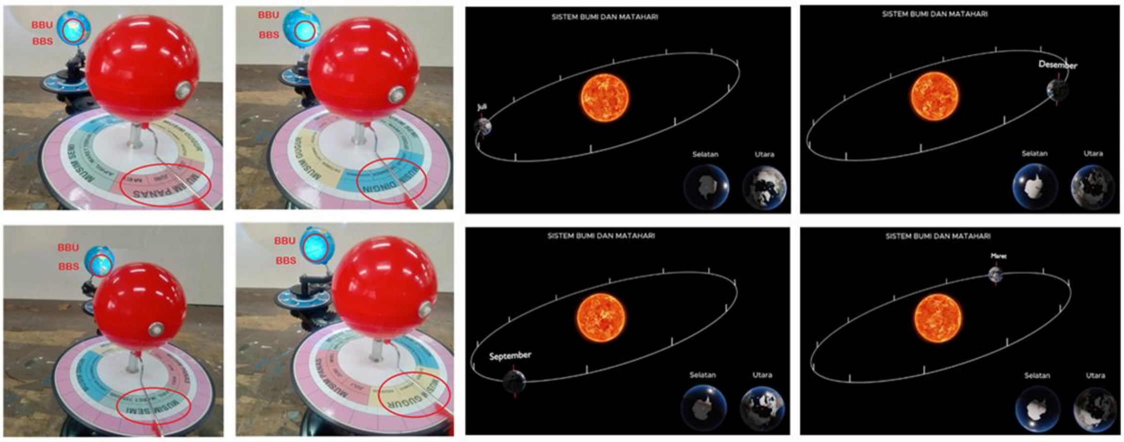
From a theoretical perspective, integrating PhDI and Bi-Model media may provide complementary learning supports. PhDI encourages students to construct explanations based on observable phenomena, thereby promoting inquiry, conceptual reasoning, and the refinement of prior conceptions. Meanwhile, Bi-Model media, consisting of physical and virtual models, provide multiple representations that help learners visualize invisible astronomical mechanisms and connect observable phenomena with underlying scientific explanations. Physical models enable students to manipulate representations directly, whereas virtual models provide dynamic visualizations of processes that are difficult to reproduce through physical models alone. Therefore, combining phenomena-based inquiry with dual-model representations may provide greater opportunities for conceptual reconstruction than relying solely on either an instructional approach or representational support. The novelty of this study lies in examining the integration of Phenomena-Driven Instruction and Bi-Model media to support students' conceptual understanding of Sun–Earth system phenomena, an area that has received limited empirical attention in previous research. Based on these considerations, this study aims to investigate changes in preservice elementary teachers' conceptual understanding of the Sun–Earth system following the implementation of Phenomena-Driven Instruction supported by Bi-Model media.

II. METHODS

This study employed a pre-experimental research design using a one-group pretest–posttest design (Özmen, 2024). In this design, students' levels of conceptual understanding were assessed before and after the instructional intervention using the Level of Conceptual Understanding Test (LCUT). The pretest was administered to assess students' initial levels of conceptual understanding of the Sun–Earth system. After the pretest, students participated in learning activities implemented through the PhDI model supported by Bi-Model media. Following the instructional intervention, a posttest was administered using the same instrument to determine students' final levels of conceptual understanding. The comparison between the pretest and posttest results was used to describe changes in students' conceptual understanding levels after the implementation of the instructional intervention.

The participants consisted of 36 second-year students enrolled in the Elementary Teacher Education Program at a university in North Kalimantan Province, Indonesia. The participants comprised 24 female students and 12 male students. The study population consisted of five classes taking the same course during the semester. To select the participants, each class was assigned an identification code, and one class was randomly selected to participate in the study. The selected class received instruction using the PhDI model supported by Bi-Model media throughout the Sun–Earth system learning unit. The instructional intervention was conducted over two weeks, with one instructional meeting held each week. Each meeting lasted approximately 150 minutes, corresponding to the three-credit Basic Science Concepts course. During the intervention, students participated in learning activities that followed the five stages of the PhDI model, supported by Bi-Model media. The instructional activities focused on four Sun–Earth system concepts: insolation, the duration of day and night, winter, and summer. Throughout the implementation, students observed relevant phenomena, developed initial explanations, interacted with physical and virtual models, evaluated their explanations based on evidence, and participated in discussions to reach scientific consensus.

The PhDI model implemented in this study consisted of five instructional stages: (1) orienting students to the phenomena; (2) constructing initial explanations of the phenomena; (3) building concepts or knowledge related to the phenomena through the presentation of Bi-Model media; (4) evaluating and revising explanations of the phenomena; and (5) discussing explanations to reach consensus. In the first stage, students were introduced to observable phenomena in the Sun–Earth system related to seasonal changes, insolation, and variations in day and night lengths. In the second stage, students were encouraged to propose initial explanations based on their prior knowledge and experiences. In the third stage, students interacted with Bi-Model media, comprising physical and virtual representations of the Sun–Earth system, to investigate the mechanisms underlying the observed phenomena. The fourth stage involved evaluating and revising students' initial explanations using evidence from observations and model-based investigations. Finally, students participated in whole-class discussions to compare explanations, resolve differences in interpretation, and reach scientific consensus on the phenomena under investigation. Figure 1 presents the Bi-Model media.



(a) (b)

Figure 1. Bi-Model media of Earth's revolution around the Sun and its relation to seasonal changes: (a) a physical model medium and (b) a virtual model medium

The Bi-Model media consisted of two complementary representations: a physical model and a virtual model. The physical model was designed to allow students to directly manipulate representations of the Earth and the Sun in order to observe the Earth's revolution, axial tilt, and variations in sunlight distribution across different regions of the Earth. Through direct manipulation, students were able to explore spatial relationships that are difficult to observe in real-world settings because of the enormous scale of the Sun–Earth system. The virtual model complemented the physical model by providing dynamic visualizations of astronomical processes that could not be adequately represented through static physical manipulation alone. Through the virtual model, students observed changes in solar illumination, seasonal patterns, and variations in day and night duration from multiple perspectives and over extended periods. During the learning activities, students first explored the phenomena using the physical model and then used the virtual model to verify, refine, and extend their explanations. The combination of physical and virtual representations was intended to help students connect observable phenomena to the underlying mechanisms responsible for them. Figure 2 presents the overall research procedure used in this study.

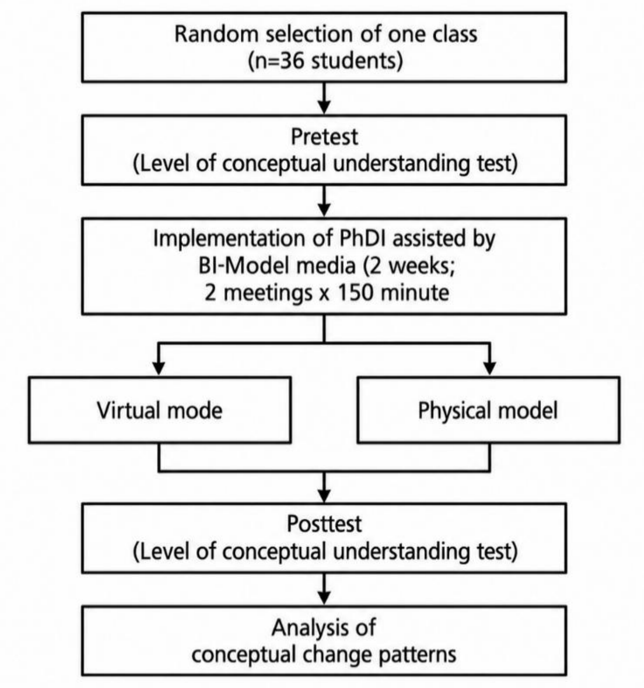
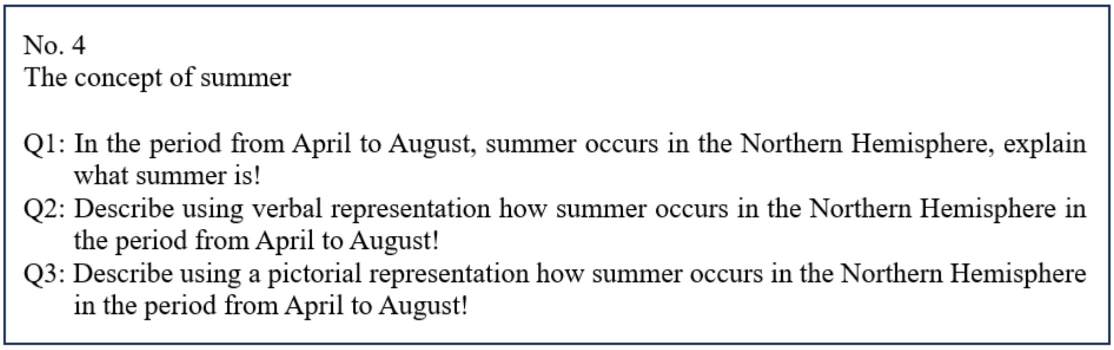


Figure 2. Research procedure and data collection flowchart

The instrument used to collect data on students' conceptual understanding before and after the implementation of the PhDI model assisted by Bi-Model media was the LCUT on the Sun–Earth system topic. The LCUT was adapted from the conceptual understanding level test developed by Kurnaz and Eksi (2015). The instrument consisted of four essay items representing four key concepts of the Sun–Earth system: insolation, duration of day and night, winter, and summer. Each item comprised three sub-questions designed to assess students' conceptual understanding from different perspectives. Question 1 (Q1) required students to explain the definition or physical meaning of a concept. Question 2 (Q2) required students to provide a verbal explanation of a phenomenon or event related to the concept. Question 3 (Q3) required students to explain the same phenomenon using graphical representations. An example of an LCUT item related to the concept of summer is presented in Figure 3.



No. 4
The concept of summer

Q1: In the period from April to August, summer occurs in the Northern Hemisphere, explain what summer is!
Q2: Describe using verbal representation how summer occurs in the Northern Hemisphere in the period from April to August!
Q3: Describe using a pictorial representation how summer occurs in the Northern Hemisphere in the period from April to August!

Figure 3. An example of the level of understanding instrument

Before being administered in the main study, the Sun–Earth System LCUT instrument was validated by five expert validators. The validation results were analyzed using Aiken's V coefficient based on the following formula (Aiken, 1985):

$$V = \frac{\Sigma s}{n(c-1)} \qquad 1)$$

where:

$S = r - l_0$
l_0 = the lowest validity assessment score
r = the score given by the validator
c = the number of categories that can be selected
n = the total number of validators

Aiken V values were used to determine the validity of the instrument items (Aiken, 1985). Items with Aiken V coefficient values ranging from 0.60 to 1.00 were categorized as valid, whereas items with coefficient values below 0.60 were considered invalid. These criteria were used to determine the appropriateness of each test item before its implementation in the study. The results of the Aiken V analysis for the LCUT instrument are presented in Table 1.

Table 1. Aiken's V values for each item

Validity score	Validity criteria
0.80 – 1.00	Very high
0.60 – 0.79	High
0.40 – 0.59	Moderate
0.20 – 0.39	Low
0.00 – 0.19	Very low

The content validity analysis indicated that all LCUT items achieved Aiken's V coefficients above the minimum acceptable threshold of 0.60. Therefore, all items were deemed suitable for use in the study. To examine the instrument's reliability, a pilot study involving 15 students was conducted prior to the main implementation. The reliability analysis yielded a Cronbach's alpha of 0.80, indicating good internal consistency (Cronbach, 1951). Based on the validity and reliability evidence, the LCUT was considered appropriate for measuring students' conceptual understanding of Sun–Earth system concepts.

The data collected before and after the instructional intervention were analyzed to determine changes in students' conceptual understanding levels following the implementation of the PhDI model assisted by Bi-Model media. Students' responses were scored and classified into five levels of conceptual understanding based on the rubric adapted from Kurnaz and Eksi (2015). The five levels were Sound Understanding (SU), Partial Understanding (PU), Partial Understanding with Misunderstanding (PU-MU), Misunderstanding (MU), and No Understanding (NU). Table 2 presents the scoring rubric used to classify students' levels of conceptual understanding.

Table 2. Scoring rubric for the level of conceptual understanding test

Level of understanding	Scores for each question	Response category
Sound understanding (SU)	(Q1, Q2, Q3) (4, 4, 4)	Responses include all required elements and are scientifically acceptable.
Partial understanding (PU)	(Q1, Q2, Q3) (4, 4, 3), (4, 3, 4), (3, 4, 4), (4, 3, 3), (3, 4, 3), (3, 3, 4), (3, 3, 3).	Responses include all required elements, and most answers are scientifically acceptable.
Partial understanding with misunderstanding (PU-MU)	(Q1, Q2, Q3) (3, 3, 2), (3, 2, 3), (2, 3, 3), (3, 2, 2), (2, 3, 2), (2, 2, 3), (2, 2, 2),	Responses include all required elements, but some answers are scientifically acceptable while others contradict scientific principles.
Misunderstanding (MU)	(Q1, Q2, Q3) (2, 2, 1), (2, 1, 2), (1, 2, 2), (2, 1, 1), (1, 2, 1), (1, 1, 2), (1, 1, 1)	Responses include all required elements, but most answers contradict scientific principles.
No understanding (NU)	(Q1, Q2, Q3) (1, 1, 0), (1, 0, 1), (0, 1, 1), (1, 0, 0), (0, 1, 0), (0, 0, 1), (0, 0, 0)	Responses do not include all required elements; some responses are blank, and the existing answers contradict scientific principles.

After students' responses were classified into the five levels of conceptual understanding, the distributions of conceptual understanding levels were calculated for both the pretest and posttest. The pretest and posttest classifications were then compared to identify changes in students' conceptual understanding for each Sun–Earth system concept. The analysis focused on transitions between conceptual understanding levels, enabling the identification of conceptual progression, stagnation, or regression following the instructional intervention. The possible patterns of changes in conceptual understanding levels are illustrated in Figure 4.

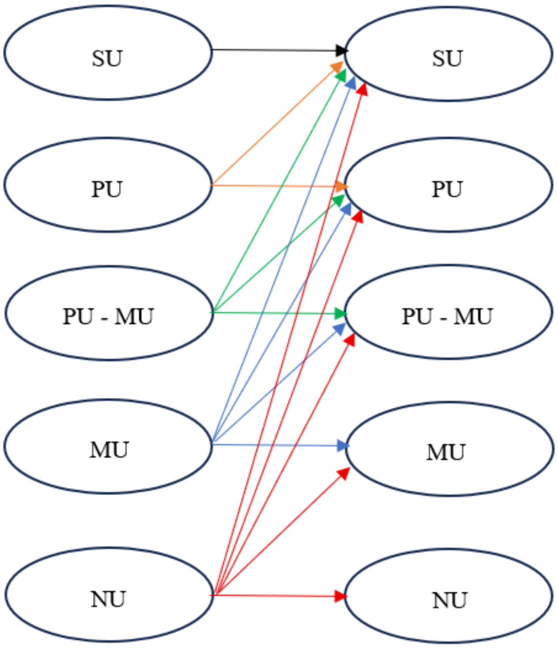


Figure 4. Diagram of possible changes in conceptual understanding levels.

III. RESULTS

To examine changes in students' conceptual understanding after the implementation of the PhDI model assisted by Bi-Model media, students' responses were analyzed using the conceptual understanding rubric presented in Table 2. The analysis focused on changes in students' levels of conceptual understanding across four concepts within the Sun–Earth system topic: insolation, day and night duration, winter, and summer.

Conceptual understanding of insolation

Table 3 presents changes in students' conceptual understanding of insolation following the implementation of the PhDI model, assisted by Bi-Model media. Prior to the intervention, most students were categorized at lower levels of understanding, particularly PU-MU, MU, and NU. After the intervention, the distribution of students' conceptual understanding shifted toward higher levels.

More than half of the students (52%) achieved the SU level, while 30% reached the PU level. Only 14% of students remained at the PU-MU level and 2% at the MU level, with none remaining at the NU level. The transition patterns indicate notable conceptual progression. Eight students moved from PU-MU to SU, seven students progressed from MU to SU, and four students advanced from NU directly to SU. In addition, 11 students initially categorized at the PU-MU, MU, or NU levels progressed to the PU level after the intervention. These results indicate a clear shift from lower levels of conceptual understanding toward more scientifically acceptable understanding of the insolation concept.

Table 3. Map of students' changes in conceptual understanding levels for the insolation concept

Initial levels of understanding		**Final levels of understanding**	**Percentage of students**
SU	→	SU	0 (0%)
PU	→	SU	0 (0%)
PU – MU	→	SU	8 (22%)
MU	→	SU	7 (19%)
NU	→	SU	4 (11%)
		Total SU	**19 (52%)**
PU	→	PU	0 (0%)
PU – MU	→	PU	4 (11%)
MU	→	PU	4 (11%)
NU	→	PU	3 (8%)
		Total PU	**11 (30%)**
PU – MU	→	PU - MU	0 (0%)
MU	→	PU - MU	3 (8%)
NU	→	PU - MU	2 (6%)
		Total PU - MU	**5 (14%)**
MU	→	MU	0 (0%)
NU	→	MU	1 (2%)
		Total MU	**1 (2%)**
NU	→	NU	0 (0%)

Conceptual understanding of day and night duration

Table 4 presents the changes in students' levels of conceptual understanding of day and night duration. Before the instructional intervention, students' responses were predominantly classified into the PU-MU, MU, and NU categories, indicating incomplete understanding and the presence of misconceptions. After the implementation of the PhDI model assisted by Bi-Model media, the distribution shifted toward higher levels of conceptual understanding. A total of 58% of students achieved the SU level, while 29% reached the PU level. Only 11% of students remained in the PU-MU category and 2% in the MU category. No students were categorized as having No Understanding after the intervention. The transition patterns show considerable conceptual progression. Nine students advanced from PU-MU to SU, eight students progressed from MU to SU, and four students moved directly from NU to SU. In addition, 10 students initially categorized at lower levels of understanding achieved the PU level after the intervention. These findings suggest that students developed more scientifically acceptable explanations of variations in day and night duration following the learning activities.

Table 4. Map of students' changes in conceptual understanding levels for the day and night duration concept

Initial levels of understanding		Final levels of understanding	Percentage of students
SU	→	SU	0 (0%)
PU	→	SU	0 (0%)
PU – MU	→	SU	9 (22%)
MU	→	SU	8 (19%)
NU	→	SU	4 (11%)
		Total SU	**21 (58%)**
PU	→	PU	0 (0%)
PU – MU	→	PU	3 (11%)
MU	→	PU	4 (11%)
NU	→	PU	3 (8%)
		Total PU	**10 (29%)**
PU – MU	→	PU – MU	0 (0%)
MU	→	PU – MU	2 (8%)
NU	→	PU – MU	2 (6%)
		Total PU – MU	**4 (11%)**
MU	→	MU	0 (0%)
NU	→	MU	1 (2%)
		Total MU	**1 (2%)**
NU	→	NU	0 (0%)

Conceptual Understanding of Winter

Table 5 presents the changes in students' levels of conceptual understanding of the concept of winter. Prior to the instructional intervention, most students demonstrated incomplete understanding or misconceptions regarding the mechanisms responsible for seasonal changes. After the implementation of the PhDI model assisted by Bi-Model media, students' conceptual understanding shifted substantially toward higher levels. A total of 61% of students achieved the SU level, which represented the highest proportion among the conceptual understanding categories. In addition, 31% of students achieved the PU level. Only 6% of students remained at the PU-MU level and 2% at the MU level, while no students remained at the NU level. These results indicate that the learning activities were associated with improved students' understanding of the mechanisms underlying seasonal changes, particularly the occurrence of winter.

Table 5. Map of students' changes in conceptual understanding levels for the winter concept

Initial levels of understanding		**Final levels of understanding**	**Percentage of students**
SU	→	SU	0 (0%)
PU	→	SU	0 (0%)
PU – MU	→	SU	8 (22%)
MU	→	SU	9 (19%)
NU	→	SU	5 (11%)
		Total SU	**22 (61%)**
PU	→	PU	0 (0%)
PU – MU	→	PU	3 (11%)
MU	→	PU	5 (11%)
NU	→	PU	3 (8%)
		Total PU	**11 (31%)**
PU – MU	→	PU - MU	0 (0%)
MU	→	PU - MU	1 (8%)
NU	→	PU - MU	1 (6%)
		Total PU - MU	**2 (6%)**
MU	→	MU	0 (0%)
NU	→	MU	1 (2%)
		Total MU	**1 (2%)**
NU	→	NU	0 (0%)

Conceptual understanding of summer

Table 6 presents the changes in students' levels of conceptual understanding of the concept of summer. The pattern of change was similar to that observed for the other concepts. Before the instructional intervention, most students demonstrated incomplete understanding and misconceptions regarding the mechanisms responsible for seasonal changes. After participating in the PhDI learning activities assisted by Bi-Model media, students' conceptual understanding shifted toward higher levels. A total of 61% of students achieved the SU level, while 28% reached the PU level. Only 9% of students remained at the PU-MU level and 2% at the MU level. No students were categorized at the NU level after the intervention. These results indicate that the instructional activities were associated with improved students' conceptual understanding of the summer phenomenon within the Sun–Earth system context.

Table 6. Map of students' changes in conceptual understanding levels for the summer concept

Initial levels of understanding		Final levels of understanding	Percentage of students
SU	→	SU	0 (0%)
PU	→	SU	0 (0%)
PU – MU	→	SU	8 (22%)
MU	→	SU	9 (19%)
NU	→	SU	5 (11%)
		Total SU	**22 (61%)**
PU	→	PU	0 (0%)
PU – MU	→	PU	3 (11%)
MU	→	PU	4 (11%)
NU	→	PU	3 (8%)
		Total PU	**10 (28%)**
PU – MU	→	PU – MU	0 (0%)
MU	→	PU – MU	2 (8%)
NU	→	PU – MU	1 (6%)
		Total PU – MU	**3 (9%)**
MU	→	MU	0 (0%)
NU	→	MU	1 (2%)
		Total MU	**1 (2%)**
NU	→	NU	0 (0%)

Across the four investigated concepts, a consistent pattern of conceptual progression was observed. Before the intervention, students' responses were predominantly classified within the PU-MU, MU, and NU categories, indicating incomplete understanding and the presence of misconceptions. After the intervention, the distributions shifted toward higher levels of conceptual understanding, particularly the SU and PU categories. The highest proportions of students achieving the SU level were observed for the winter and summer concepts (61%), followed by day and night duration (58%) and insolation (52%). In addition, no students remained in the NU category for any of the investigated concepts after the intervention. Overall, these findings indicate a general trend toward higher levels of scientifically acceptable understanding across all concepts included in the Sun–Earth system topic.

IV. DISCUSSION

The findings of this study revealed a consistent shift in students' conceptual understanding across all Sun–Earth system concepts investigated. After participating in the learning activities, most students progressed from lower levels of understanding, namely PU-MU, MU, and NU, to higher levels, particularly PU and SU. The highest proportions of students achieving the SU level were observed for the winter and summer concepts, followed by day and night duration and insolation. These patterns indicate that students developed more scientifically acceptable explanations of Sun–Earth system phenomena after participating in the PhDI learning activities assisted by Bi-Model media.

The observed conceptual progression is consistent with previous studies reporting positive associations between Phenomena-Driven Learning (PhDL) or Phenomena-Based Learning (PhBL) and students’ conceptual understanding, particularly in relation to abstract scientific concepts (Hemtasin et al., 2026; Saberi & Nouri, 2025; Ualikhanova et al., 2024). One possible explanation for this progression is that the learning process began with observable phenomena that stimulated students’ curiosity and encouraged them to seek explanations rather than merely memorize scientific facts. These phenomena may have served as cognitive anchors that linked new information to students’ prior knowledge and everyday experiences, thereby supporting the development of more coherent conceptual structures (Rivet & Krajcik, 2008; Walker & Nouri, 2025). Through the investigation of phenomena, students were required to analyze evidence, identify causal relationships, and revise their initial explanations. These processes are closely associated with conceptual change and deeper scientific understanding (Kranz et al., 2023; Posner et al., 1982).

The implementation of the PhDI model may also have supported the development of students’ logical and systematic thinking. In this study, observable phenomena served as starting points for learning, enabling students to relate abstract astronomical concepts to events they could observe or experience in everyday life. This approach helped students organize scientific concepts more systematically and coherently because the concepts were not presented as isolated pieces of information but as interconnected explanations of natural phenomena (Rivet & Krajcik, 2008; Walker & Nouri, 2025). Furthermore, PhDI encouraged students to examine relationships among concepts, such as the connection between the Earth’s axial tilt, solar illumination, day and night duration, and seasonal changes. Such learning experiences may have contributed to a more integrated understanding of Sun–Earth system phenomena, as students were guided to identify patterns, construct explanations, and evaluate the consistency of their reasoning with scientific evidence (Kranz et al., 2023; Montfort et al., 2015).

The conceptual progression observed in this study may also be associated with the use of Bi-Model media. Sun–Earth system concepts involve cosmic-scale phenomena that cannot be directly observed in their entirety. As a result, students often have difficulty visualizing planetary motions, seasonal changes, variations in solar illumination, and the spatial relationships between the Earth and the Sun. The combination of physical and virtual models provided complementary representations that enabled students to observe, manipulate, and explore otherwise inaccessible phenomena. Physical models offered tangible representations of planetary positions, Earth's revolution, and axial tilt, allowing students to directly manipulate spatial relationships. In contrast, virtual models provided dynamic visualizations of astronomical processes, including changes in solar illumination and seasonal patterns over time. Previous studies have similarly reported that model-based learning can support conceptual understanding by transforming abstract scientific phenomena into more accessible and observable representations (Banda & Nzabahimana, 2021; Olympiou et al., 2013; Wulandari et al., 2021). Thus, the integration of phenomena-based learning and model-based representations may have provided meaningful opportunities for students to connect observable phenomena with the underlying scientific mechanisms.

The stronger progression observed in the winter and summer concepts may be related to the close connection between these concepts and observable seasonal phenomena. Although seasonal changes are caused by mechanisms that are not directly visible, such as the Earth's axial tilt and variations in solar illumination, their effects are relatively familiar to students through everyday experiences and prior learning. The use of physical and virtual models may have helped students reinterpret these familiar phenomena using more scientifically accurate explanations. By contrast, the concept of insolation may have been more challenging because it requires students to understand the distribution and intensity of solar radiation in relation to angle, surface area, and Earth–Sun geometry. This may explain why the proportion of students achieving SU in the insolation concept was lower than that observed for winter and summer. Nevertheless, the overall shift toward SU and PU across all concepts indicates that the learning activities helped students improve their conceptual understanding of the Sun–Earth system.

Despite the overall improvement, a small proportion of students remained within the PU-MU and MU categories after the intervention. This finding suggests that conceptual reconstruction was not achieved equally by all students. Misconceptions related to astronomical phenomena are often deeply rooted because they are formed from everyday observations, intuitive reasoning, and incomplete interpretations of natural phenomena. Therefore, some students may require extended learning experiences, additional scaffolding, repeated model-based investigations, or alternative representations before scientifically accepted conceptions can be fully developed (Chiu & Churchill, 2015; Pellas, 2025). However, the absence of students in the NU category across all investigated concepts after the intervention indicates that all participants demonstrated at least some level of conceptual understanding following the learning activities.

V. CONCLUSION AND SUGGESTION

This study revealed a consistent improvement in students' conceptual understanding of Sun–Earth system concepts after the implementation of the PhDI model assisted by Bi-Model media. Across the four investigated concepts, namely insolation, day and night duration, winter, and summer, most students progressed from lower levels of understanding, including PU-MU, MU, and NU, to higher levels, particularly PU and SU. The highest proportions of students achieving the SU level were found in the winter and summer concepts, followed by day and night duration and insolation. These findings indicate that learning activities integrating observable phenomena with physical and virtual model representations can support students in developing more scientifically acceptable explanations of astronomical phenomena that are difficult to observe directly.

This study has several limitations that should be considered when interpreting the findings. First, the use of a one-group pretest–posttest design without a comparison group limits the extent to which the observed improvement can be attributed exclusively to the PhDI model assisted by Bi-Model media. Second, the study involved a relatively small sample from a single university, which restricts the generalizability of the findings to broader educational contexts. Future research is therefore recommended to employ experimental or comparison-group designs, involve larger and more diverse samples, and examine the implementation of PhDI assisted by Bi-Model media across other physics or science topics. Despite these limitations, this study contributes to the field of physics education by providing empirical evidence on the potential of integrating phenomena-driven learning with physical and virtual model representations to support conceptual understanding of cosmic-scale phenomena, particularly in the context of preservice elementary teacher education.

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REFERENCES

Acquah, S. (2020). Early childhood pre-service teachers' conception of living and non-living things in a Ghanaian college of education. *East African Journal of Education and Social Sciences, 1*(1), 130–138. https://eajess.ac.tz/index.php/eajess/en/article/view/24

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement, 45*(1), 131–142. https://doi.org/10.1177/0013164485451012

Banda, H. J., & Nzabahimana, J. (2021). Effect of integrating physics education technology simulations on students' conceptual understanding in physics: A review of literature. *Physical Review Physics Education Research, 17*(2), 1-18. https://doi.org/10.1103/PhysRevPhysEducRes.17.023108

Bucat, B., & Mocerino, M. (2009). Learning at the sub-micro level: Structural representations. *Multiple representations in chemical education, 4*, 11–29. Springer. https://doi.org/10.1007/978-1-4020-8872-8_2

Cheng, P. H., & Yeh, T. K. (2026). The solar system traveler: A model-based board game to advance primary student interest, knowledge and learning in astronomy. *Research in Science Education, 56*(3), 763–788. https://doi.org/10.1007/s11165-025-10296-4

Chiu, T. K. F., & Churchill, D. (2015). Exploring the characteristics of an optimal design of digital materials for concept learning in mathematics: Multimedia learning and variation theory. *Computers & Education, 82*, 280–291. https://doi.org/10.1016/j.compedu.2014.12.001

Coil, A. L. (2024). Large-scale structure of the universe. *arXiv,* 1-44. https://arxiv.org/abs/1202.6633

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*(3), 297–334. https://doi.org/10.1007/BF02310555

Evagorou, M., Erduran, S., & Mäntylä, T. (2015). The role of visual representations in scientific practices: From conceptual understanding and knowledge generation to "seeing" how science works. *International Journal of STEM Education, 2*(11), 1-13. https://doi.org/10.1186/s40594-015-0024-x

Hemtasin, C., See-Onjan, C., & Payoungkiattikun, W. (2026). Designing a phenomenon-based learning boxset to foster scientific literacy in under-resourced schools. *Social Sciences & Humanities Open, 13*, 1-15. https://doi.org/10.1016/j.ssaho.2026.102601

Inaltekin, T., & Akbaba, U. (2024). Investigation of middle school students' model of astronomy events and information sources of incorrect model. *International Journal of Contemporary Educational Research, 11*(4), 508–524. https://doi.org/10.52380/ijcer.2024.11.4.680

Kranz, D., Schween, M., & Graulich, N. (2023). Patterns of reasoning–exploring the interplay of students' work with a scaffold and their conceptual knowledge in organic chemistry. *Chemistry Education Research and Practice, 24*(2), 453–477. https://doi.org/10.1039/D2RP00132B

Kurnaz, M. A., & Eksi, C. (2015). An analysis of high school students' mental models of solid friction in physics. *Educational Sciences: Theory & Practice, 15*(3), 787-795. https://files.eric.ed.gov/fulltext/EJ1067435.pdf

Faisal, F., & Martin, S. N. (2019). Science education in Indonesia: Past, present, and future. *Asia-Pacific Science Education, 5*(4), 1–29. https://doi.org/10.1186/s41029-019-0032-0

Montfort, D., Herman, G. L., Brown, S., Matusovich, H. M., Streveler, R. A., & Adesope, O. (2015). Patterns of student conceptual understanding across engineering content areas. *International Journal of Engineering Education, 31*(6), 1587–1604. https://publish.illinois.edu/glherman/files/2016/03/2015-IJEE-Conceptual-Understanding-Across-Disciplines.pdf

Nobes, G., Frède, V., & Panagiotaki, G. (2023). Astronomers' representations of the earth and day/night cycle: Implications for children's acquisition of scientific concepts. *Current Psychology, 42*(21), 17612–17631. https://doi.org/10.1007/s12144-021-02676-6

Olympiou, G., Zacharias, Z., & Dejong, T. (2013). Making the invisible visible: Enhancing students' conceptual understanding by introducing representations of abstract objects in a simulation. *Instructional Science, 41*, 575–596. https://doi.org/10.1007/s11251-012-9245-2

Özmen, K. (2024). Health science students' conceptual understanding of electricity: Misconception or lack of knowledge? *Research in Science Education, 54*(2), 225–243. https://doi.org/10.1007/s11165-023-10136-3

Panagiotaki, G., Nobes, G., & Potton, A. (2009). Mental models and other misconceptions in children's understanding of the earth. *Journal of Experimental Child Psychology, 104*(1), 52–67. https://doi.org/10.1016/j.jecp.2008.10.003

Park, B. Y., Campbell, T., Kelly, M., Gray, R., Arnold, C., Chadwick, C., Cisneros, L. M., Dickson, D., Moss, D. M., Rodriguez, L., Volin, J. C., & Willig, M. R. (2023). Improving NGSS focused model-based learning curriculum through the examination of students' experiences and iterated models. *Research in Science & Technological Education, 41*(3), 983–1007. https://doi.org/10.1080/02635143.2021.1978962

Pellas, N. (2025). The impact of AI-generated instructional videos on problem-based learning in science teacher education. *Education Sciences, 15*(1), 1-34. https://doi.org/10.3390/educsci15010102

Plummer, J. D. (2009). Early elementary students' development of astronomy concepts in the planetarium. *Journal of Research in Science Teaching, 46*(2), 192–209. https://doi.org/10.1002/tea.20280

Plummer, J. D., & Maynard, L. (2014). Building a learning progression for celestial motion: An exploration of students' reasoning about the seasons. *Journal of Research in Science Teaching, 51*(7), 902–929. https://doi.org/10.1002/tea.21151

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227. https://doi.org/10.1002/sce.3730660207

Ramamurthy, M., & Lakshminarayanan, V. (2015). Human vision and perception. *Handbook of Advanced Lighting Technology*, 1–23. https://doi.org/10.1007/978-3-319-00295-8_46-1

Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing instruction: Leveraging students' prior knowledge and experiences to foster understanding of middle school science. *Journal of Research in Science Teaching, 45*(1), 79–100. https://doi.org/10.1002/tea.20203

Saberi, M., & Nouri, N. (2025). Three-dimensional learning through phenomenon-based science education and its application via the collapsed container phenomenon. *Journal of Educational Studies in Physics, 2*(1), 73-91. https://scholarworks.utrgv.edu/cgi/viewcontent.cgi?article=1231&context=tl_fac

Sarah, L. L., Suhandi, A., Riyana, C., Winarno, N., Amiruddin, M. Z. B, & Fenyvesi, K. (2026). Low-cost solar cell bifocal modeling tools for science experiments in secondary school. *Physica Scripta, 101*(20). https://doi.org/10.1088/1402-4896/ae694e

Sneider, C., Bar, V., & Kavanagh, C. (2011). Learning about seasons: A guide for teachers and curriculum developers. *Astronomy Education Review, 10*(1). https://doi.org/10.3847/AER2010035

Tala, S., & Vesterinen, V. M. (2015). Nature of science contextualized: Studying nature of science with scientists. *Science & Education, 24*(4), 435–457. https://doi.org/10.1007/s11191-014-9738-2

Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(2), 297–328. https://doi.org/10.1007/s11422-008-9090-4

Ualikhanova, B., Ormanova, G., Berdaliyev, D., Mussakhan, N., Anas, B., & Güdekli, E. (2024). Impact of phenomenon-based learning on high school physics education in Shymkent, Kazakhstan. *Qubahan Academic Journal, 4*(4), 225–236. https://doi.org/10.48161/qaj.v4n4a1203

Van Velzen, J. H. (2023). What is the actual world as the study object of scientific research? *RRREaT–Cognitive Psychological Phenomena in Education, 1*(02), 1-34. https://www.researchgate.net/publication/372952984_What_is_the_Actual_World_as_the_Study_Object_of_Scientific_Research

Von Glasersfeld, E. (2012). Sensory experience, abstraction, and teaching. *Constructivism in education*, 369–384. Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9780203052600-26/sensory-experience-abstraction-teaching-ernst-von-glasersfeld

Walker, K. I., & Nouri, N. (2025). Phenomenon-based learning and storylines in K-12 science education: A systematic review of current research, implementation, and future directions. *Frontiers in Education, 10*, 1-20. https://doi.org/10.3389/feduc.2025.1648234

Wibowo, F. C., Suhandi, A., Rusdiana, D., Darman, D. R., Ruhiat, Y., Denny, Y. R., Suherman, S., & Fatah, A. (2016). Microscopic virtual media (MVM) in physics learning: Case study on students understanding of heat transfer. *Journal of Physics: Conference Series, 739*(1), 1-6. https://doi.org/10.1088/1742-6596/739/1/012044

Wulandari, S., Wibowo, F. C., & Astra, I. M. (2021). A review of research on the use of augmented reality in physics learning. *Journal of Physics: Conference Series, 2019*(1), 1-7. https://doi.org/10.1088/1742-6596/2019/1/012058