MODESTUM

EURASIA Journal of Mathematics, Science and Technology Education, 2026, 22(1), em2758
ISSN:1305-8223 (online)

OPEN ACCESS

Research Paper

https://doi.org/10.29333/ejmste/17632

Saudi Arabian secondary school students' understanding of scientific models and modeling

Rouz Abdullah Almasabi [1*]

[1] Department of Curriculum and Instruction, Faculty of Education, Najran University, Najran, SAUDI ARABIA

Received 30 August 2025 ▪ Accepted 10 December 2025

Abstract

This study aimed to investigate how female students in grade 10-grade 12 in Saudi secondary schools understand scientific models, while accounting for the broader Islamic context in which science learning occurs. This contribution seeks to deepen the understanding of how social and religious factors shape students' scientific conceptions. Such a focus aligns with Saudi Vision 2030 (2016), which emphasizes advancing science education while preserving the cultural and religious dimensions that are integral to the local educational environment. A purposive sample of 400 female students from 12 schools in the Southern Province participated in the study. Adopting a descriptive quantitative approach, the students' understanding of models in science questionnaire was administered between December 2024 and February 2025. Descriptive and inferential analyses revealed naïve and inaccurate conceptions among students in four of the five assessed dimensions: models as exact replicas of reality, multiple representations, the changing nature of models, and the uses of scientific models. In contrast, students demonstrated relatively higher understanding in only one dimension–models as explanatory tools. The findings further showed no statistically significant differences across grade levels, indicating that progression through the secondary stages does not, in itself, enhance students' modeling knowledge. In light of these results, the study recommends strengthening teacher preparation and professional development programs, integrating explicit guidance within science curricula to support teachers' use of scientific models, and promoting critical thinking about the relationship between science and religion. Additionally, the study calls for further research on actual classroom practices of scientific modeling and the design and evaluation of modeling-based instructional interventions.

Keywords: models, modeling, next-generation science standards, epistemological knowledge of scientific modeling, modeling practice

INTRODUCTION

Contemporary science education in non-Western contexts has long been shaped–directly or indirectly–by Western-origin educational paradigms that embody distinct epistemological and cultural assumptions about science, knowledge, and reality. Educational concepts and approaches of Western origin represent cultural products of Western thought concerning the nature of science and the human–world relationship (Alexander, 2008).

Consequently, these approaches cannot be transferred wholesale into culturally and religiously different contexts without critical adaptation. Brinkmann (2015) cautioned against "promoting Western-originating approaches without adequately considering the challenges involved in crossing cultures."

In Saudi Arabia, several Western-inspired pedagogical frameworks (Education and Training Evaluation Commission, 2019)–such as constructivism, learner-centered education, inquiry-based learning, and curriculum frameworks like the next generation science standards and STEM education–have been adopted to modernize science instruction. These approaches are grounded in Western scientific philosophies that emphasize the empirical, tentative, and subjective nature of scientific knowledge and view science as a social and

✉ raalmasabi@hotmail.com **(*Correspondence)**

Contribution to the literature

- This study significantly contributes to the literature on scientific models and modeling by offering insights into secondary students' comprehension of scientific models in Saudi Arabia, situated within the country's socio-cultural and religious context.
- The findings revealed that students' conceptions remain limited and naïve across several dimensions.
- These results may be attributed to contextual factors, most notably the personal religious beliefs of teachers and/or students, which underscores the need to highlight the relationship between science and religion.

cultural enterprise developed within an open community of scientists (National Research Council [NRC], 2012). Such perspectives reflect the positivist and rationalist traditions of Western thought.

When applied in the Saudi context without adequate cultural alignment, a gap may emerge between the implicit epistemological assumptions embedded in curricula (Western epistemology) and the Islamic worldview, which conceives of knowledge and science as unified with divine truth and creation (Kim & Alghamdi, 2020). This dissonance may cause students to experience conceptual ambiguity when interpreting scientific knowledge, inclining some to perceive science as a fixed, faith-based truth rather than a dynamic, human endeavor. To address this, it becomes essential to examine how Saudi students conceptualize the epistemological nature of scientific modeling, as modeling offers a tangible window into how scientific knowledge is constructed, justified, and refined. This line of inquiry not only deepens understanding of how Western educational philosophies interact with local cultural and religious beliefs but also informs reconceptualizing science education to harmonize the scientific worldview with Islamic epistemology.

Within this broader context, Saudi Vision 2030 (2016) outlines an ambitious national transformation plan to shift the nation from an oil-based economy to a knowledge-based economy, with science, innovation, and education serving as the primary engines of sustainable development. This transformation is anchored in investing in human capital and cultivating scientific thinking, research, and inquiry skills, thereby enhancing the nation's capacity to generate and apply knowledge for economic and technological advancement. In this vision, scientific literacy emerges as a cornerstone for national progress, equipping citizens with the capacity for critical thinking and evidence-based decision-making. A crucial component of scientific literacy is the understanding of the epistemological nature of scientific modeling, which promotes awareness of how scientific knowledge is generated, evaluated, and revised (NRC, 2012).

Evidence from international science-education frameworks (NRC, 2012; Organization for Economic Co-operation and Development, 2023) recognizes the epistemological dimension of modeling as integral to understanding the nature of science. Modeling is viewed as a core scientific practice through which learners come to grasp how theories and explanations are developed and validated by evidence. Therefore, teaching scientific modeling is not merely about enhancing students' representational or explanatory skills but about deepening their epistemological understanding of science itself–a foundational element of scientific literacy. Such an understanding is indispensable for achieving Saudi Vision 2030 (2016), which aspires to build a globally competitive knowledge-based economy rooted in research, innovation, and scientific inquiry.

The Problem and Questions of the Study

Despite Saudi Arabia's adoption of modern, Western-derived science education frameworks–such as constructivism and inquiry-based learning–there is limited understanding of how Saudi students view the epistemological nature of scientific modeling within their Islamic and cultural context. Research shows that students' understanding of science is influenced by their social, cultural, and religious backgrounds (Mansour, 2011; Reiss, 2004). Within the Islamic worldview, moral and social principles are rooted in religious doctrine, impacting perceptions of scientific knowledge (Mansour, 2011).

As Saudi curricula integrate Western educational philosophies that reflect positivist assumptions about science (NRC, 2012), tensions may arise between these views and Islamic conceptions of knowledge (Kim & Alghamdi, 2020). This can create conceptual ambiguity, leading students to see scientific models as fixed truths rather than evolving, evidence-based representations. Thus, it is crucial to investigate how Saudi secondary school students understand the epistemological aspects of scientific modeling and how cultural and religious factors influence these understandings. Thus, the research questions (RQs) are:

RQ1. What is the level of Saudi secondary school students' understanding of the epistemological nature of scientific models and modeling?

RQ2. Are there statistically significant differences in students' understanding of scientific modeling attributable to grade level?

THEORETICAL FRAMEWORK

Scientific Models

To effectively address the objectives of this study, it is essential to first clarify the meaning of a scientific model. Models are defined as entities that represent other entities–be they objects, events, or processes– for specific epistemic purposes (Louca & Zacharia, 2012; Oh & Oh, 2011). This definition highlights that each model has a clearly defined scope and is deliberately constructed to fulfill a particular epistemological function. In discussing the types of entities that a model may represent, Frigg and Hartmann (2012) assert that models can serve two distinct representational roles: they may either represent specific aspects of the natural world or they may act as theoretical representations that delineate the fundamental laws and principles underpinning a scientific theory.

Within scientific practice, the adequacy of a model is commonly evaluated by the extent to which it can be translated into a mathematical formulation, enhancing its explanatory precision and predictive power (Frigg & Hartmann, 2012). This criterion does not apply to pedagogical models, which are deliberately simplified to support learning for students who may not possess the mathematical background required to engage with scientifically rigorous models. The present study focuses not on how learners construct scientific models, but on how they perceive and understand them.

Recent research highlights the centrality and effectiveness of modelling-based pedagogy in contemporary classrooms. A systematic review by Carroll and Park (2024) demonstrates that modelling supports expansive forms of learning by engaging students in conceptual, epistemic, and social dimensions of scientific practice, thereby fostering deeper meaning-making and more equitable learning opportunities . Similarly, Malone and Schuchardt (2023) report that sustained engagement in modelling across different scientific disciplines significantly improves students' scientific reasoning and conceptual understanding, with notable benefits for learners who traditionally underperform in science. Furthermore, recent findings from Malone and Schuchardt (2023) show that modelling-based instruction enhances the conceptual understanding of complex biological ideas, such as evolution and population ecology, even among students learning in a second language .Collectively, these studies reinforce the view that modelling is not merely an instructional aid but a core mechanism for authentic engagement with scientific knowledge, enabling students to participate in practices that resemble those of scientists.

Preconceptions About Scientific Models and Modeling

NRC (1996, 2007, 2012) identifies students' understanding of models and modeling as a primary goal of science education. Although researchers differ in how they define or categorize the epistemology of scientific models, three commonly recognized aspects consistently emerge across the literature: the nature of models, the purposes of models, and the process of modeling (Grosslight et al., 1991; Pluta et al., 2011; Schwarz & White, 2005; Schwarz et al., 2009).

Recent work in science education suggests that students do not encounter scientific models as epistemic blank slates; instead, they enter instructional environments with pre-existing views and commitments about what models are and how they function within scientific practice (Paillusson & Booth, 2024; Pieterman-Bos et al., 2024). Grosslight et al. (1991) noted that such initial ideas undergo substantial development over time: younger learners often regard models as literal, high-fidelity reproductions of reality, whereas older students gradually adopt a more sophisticated stance that recognizes models as interpretive constructs that can be revised, refined, or replaced as scientific advances unfold.

Literature employs a range of terms to describe these early cognitive structures–such as misconceptions, prior conceptions, and alternative frameworks–but Mora and Herrera (2009) offer a broader perspective by defining preconceptions as interpretive constructs individuals generate to explain phenomena in everyday life, solve practical problems, or fulfil instructional expectations. Thomas and Kirby (2020) further argue that these pre-instructional ideas exert a strong influence on how learners interpret classroom tasks, making their identification pedagogically essential. In this study, the notion of preconceptions is extended beyond learners' interpretations of observable phenomena to include their understandings of abstract scientific constructs, such as models and modelling practices. The interpersonal dimension of classroom interactions, particularly teachers' expectations about what counts as adequate understanding, also plays a significant role in shaping how these conceptions emerge and persist.

The influence of such preconceptions becomes evident in how students engage with representational models. According to Taber (2017), practical learning through models requires students to establish appropriate correspondence between aspects of the representation and features of the target system. However, because students' interpretations are shaped by their individually constructed conceptual frameworks, some learners focus primarily on superficial or literal attributes of the model, limiting their capacity to transfer understanding across different contexts or modelling situations (Chittleborough & Treagust, 2009).

This perspective resonates with the challenges identified by Ke and Schwarz (2021), which include students' tendencies to focus on the features of the model instead of the underlying concepts, to conflate the model with the phenomenon itself, to assign non-isomorphic attributes to the real system, or to combine elements from different models inappropriately. Gouvea et al. (2019) further contend that these difficulties arise from a fundamental tension in model-based instruction–between regarding models as static content and perceiving modeling as an epistemic practice. This tension often leads students to engage superficially in modeling rather than fostering meaningful conceptual understanding.

Collectively, these findings illustrate that preconceptions are neither peripheral nor trivial; instead, they form essential cognitive frameworks that influence how students interpret, assess, and utilize scientific models. Consequently, they play a pivotal role in shaping learners' epistemological development concerning modeling and its importance for scientific reasoning.

Epistemology of Science in the Religious Context

Research evidence indicates that both social and cultural contexts, whether through national developments such as educational policies and state-level scientific controversies, or through regional conditions linked to local customs and traditions, play a central role in shaping students' conceptions of the nature of science. Within this framework, numerous studies have revealed diverse cultural influences on students' views about science. Studies in Spain, for example, have shown that limited critical engagement is associated with a decline in students' interest in science (Toma et al., 2019). Meanwhile, research conducted in Korea and China has demonstrated that traditional cultural norms contribute to rigid and uncritical conceptions of scientific theories, thereby constraining the development of students' critical thinking skills (Deng et al., 2014; Kang et al., 2005). Conversely, other studies have highlighted positive cultural influences, as seen in the German context, where the rationalist philosophical tradition has supported practices of scientific critique and the adoption of critical rationality as a core dimension of students' understanding of the nature of science (Kötter & Hammann, 2017).

In the Saudi context specifically, educational policy indicates that the science curriculum is not presented as purely empirical knowledge, but rather as a domain that integrates scientific specialization with the reinforcement of religious faith. The curriculum has been designed according to the notion of "science as specialization and faith" (Almuhesin, 1999). Within this framework, the discovery of scientific laws is viewed as a means of understanding God's creation, which renders science culturally and religiously acceptable so long as it is interpreted within a religious schema that links scientific knowledge to Islamic belief (Mansour, 2011). Consequently, Islam can be regarded as a socio-cultural factor shaping the teaching and learning of science in the Saudi context.

However, misunderstanding the relationship between science and religion, as well as the principle of the unity of truth and knowledge, has led to several challenges (Mansour, 2011). These include avoiding scientific topics perceived to conflict with religious interpretations and imposing religious explanations on natural phenomena. This is reflected in some students' rejection of certain scientific concepts, such as evolution (Alanazi, 2019). As a result, science education in Saudi Arabia is not perceived as sufficiently robust, particularly regarding abstract concepts associated with sensitive topics such as reproduction, cell division, and genetics.

Furthermore, prevailing instructional practices often rely on rote teaching and the implementation of pre-structured, confirmatory laboratory activities, which limit students' opportunities to construct knowledge, engage in scientific inquiry, and develop an epistemic understanding of science (Alsaadi, 2021). In this regard, students' epistemological understanding of science is closely tied to science teaching practices: students cannot grasp the epistemic foundations of scientific knowledge unless they comprehend its content, principles, and processes. This underscores the need for science instruction that explicitly integrates epistemological understanding into classroom activities (Wang et al., 2022).

Additionally, the Saudi government has relied heavily on translating Western science textbooks rather than developing curricula that account for the local socio-cultural context. This has contributed to the introduction of pedagogical approaches with Western epistemic roots into Arab settings (Alabdulkareem, 2016). Such curricula are often adopted without thorough consideration of cultural transfer requirements or potential implications, leading to educational challenges (Brinkmann, 2015). One such challenge is reinforcing the belief that science is a Western product, especially when questions arise about whether these curricula adequately highlight the global and cumulative nature of science as a collective human endeavor shaped by diverse cultures and civilizations. These issues are further compounded by the limited capacity of science teachers to connect modern scientific knowledge to students' socio-cultural contexts (Alabdulkareem, 2016), partly due to their personal religious beliefs about the relationship between science and religion, in general and specifically regarding scientific ideas (Mansour, 2011).

As a result, the interplay between cultural and religious contexts significantly influences students' understanding of the nature of science. For instance, disciplines like engineering offer more opportunities for critique and analytical discussion because they are less closely tied to sensitive religious themes. Conversely, conversations on topics such as evolutionary theories and genetic engineering tend to be restricted due to their cultural and religious implications (Alanazi, 2019).

Students' Understanding of Scientific Models and Modeling

A growing body of systematic reviews in the field of scientific models and modeling (Carroll & Park, 2024) indicates that the available research evidence is predominantly derived from Western contexts. Numerous studies in science education have examined both students' and teachers' understandings of the epistemology of models and modeling (e.g., Grosslight et al., 1991; Krell & Krüger, 2017; Treagust et al., 2002; Villablanca et al., 2020). A recurrent pattern across these studies shows that the dimension of models as exact replicas of reality is among the least developed in students' understanding compared to other epistemic dimensions of modeling.

In Islamic contexts, the literature indicates that students' understanding of scientific models and modeling remains a relatively under-researched area. Although several Western studies have investigated learners' and teachers' conceptions of the nature of models, their purposes, and modeling processes, only a limited number of studies have explored the influence of Islamic contexts on the nature of science more broadly or on the understanding of scientific models and modeling in particular, including within the Saudi context. Existing studies focus primarily on the influence of religious context on science teachers' views of science and science education (Mansour, 2008), students' conceptions of the nature of science (Kim & Alghamdi, 2020), and their understanding of specific scientific concepts such as biological classification (Alanazi, 2018) and evolution (Alanazi, 2019).

While substantial research shows how different educational stages affect students' understanding of scientific models (Krell et al., 2015; Lee et al., 2017), the relationship between grade level and the socio-cultural factors shaping learners' perceptions of models remains insufficiently explored. This gap underscores the urgent need for a study that examines how educational stages shape students' comprehension of scientific modeling, while accounting for the significant social, cultural, and religious influences in this context. Such research is vital for a more nuanced understanding of learners' conceptual development.

Consequently, empirical evidence concerning students' understanding of scientific models and modeling in Islamic contexts remains limited and insufficient to provide a comprehensive picture of this domain. Moreover, despite the widespread use of the dimensions of Treagust et al. (2002) to examine students' understanding of scientific models and modeling, this framework has not yet been sufficiently explored in Islamic contexts. Evidence regarding how these dimensions manifest among Saudi students is particularly scarce, leaving a notable knowledge gap concerning the influence of the cultural–religious context on students' understanding of models, their purposes, and modeling processes.

METHODOLOGY

Method

In the present study, a descriptive survey design was employed to describe the phenomenon under study in terms of its nature and prevalence. It does not explore relationships or infer causes (Alassaf, 2016). This approach allows the researcher to collect accurate, objective data to answer the study's RQs.

Context and Participants

The study involved female secondary-school students in the Najran Region during the second semester of the 1446 AH academic year. A structured, self-administered questionnaire was distributed to all schools through the regional education office, in collaboration with natural science teachers. A total of 400 questionnaires were completed (102 from grade 10, 138 from grade 11, and 160 from grade 12), thus covering the three successive grade levels. Although the sample represents a limited proportion of the overall student population, the region is characterized by a homogeneous religious background (Islam) and a centralized education system; accordingly, students' educational experiences are expected to be broadly comparable. These features support the cautious generalization of the findings to similar educational settings within the region.

Due to the separation of schools by gender in Saudi Arabia, a female researcher cannot enter male schools. The study focused solely on female students, meaning only their thoughts could be considered in the findings.

Data Collection and Analysis

The instrument used in this study was the students' understanding of models in science (SUMS) questionnaire (see **Appendix A** for the whole instrument), initially developed by Treagust et al. (2002) and later translated, adapted, and culturally aligned to the local context by Almasabi (2023). Verbal permission to administer the adapted instrument for the present research was obtained (Almasabi, 2023). The SUMS includes 27 items divided into five dimensions: Models as multiple representations (8 items), models as exact replicas of reality (8 items), models as explanatory tools (5 items), uses of scientific models (3 items), and the evolving nature of models (3 items).

The questionnaire used a five-point Likert scale: (strongly agree, agree, not sure, disagree, strongly disagree). Responses were coded so that "strongly agree" received a score of 5 and "strongly disagree" a score of 1, as all items were phrased positively. Therefore, higher scores reflected a greater understanding of the construction being measured. An exception was made for the subscale "models as exact replicas of reality," which included negatively worded statements. For this subscale, scoring was reversed–"strongly agree" received a score of 1, and "strongly disagree" a score of 5–to maintain consistency in score interpretation across all dimensions.

It is important to note that the "not sure" response served as the midpoint on the Likert scale and was coded as 3. Nadler et al. (2015) emphasized the importance of clarifying the midpoint to respondents, reporting that such clarification reduced unexplained neutral responses and increased mean (M) scores in approximately 68% of the studies they reviewed. Accordingly, the meaning of this option was explained to participants in terms of its content: it does not necessarily reflect a lack of knowledge or disengagement but may instead indicate a balanced stance between agreement and disagreement with the given statement.

Analyzing the data, the "uncertain" option was seen as possibly indicating an incomplete understanding, whereas low scores–such as "disagree" and "strongly disagree" (coded as 2 and 1, respectively)–were viewed as signs of naive conceptions that conflict with current scientific perspectives (Treagust et al., 2002). This distinction is crucial for interpreting the findings, as it directly impacts the validity of the conclusions and the development of educational strategies. Incomplete conceptions require explanatory instructional support, while naive conceptions necessitate more specific corrective efforts. From this standpoint, the "uncertain" response should not be regarded as passive neutrality or a meaningless choice. Instead, in particular educational settings–especially when addressing complex scientific ideas such as models and modeling–it should be interpreted as a sign of partial or developing understanding (Lam et al., 2010).

To establish validity, Almasabi (2023) confirmed content validity through expert review by specialists in science education and educational measurement. Since the instrument was initially developed in English, it was translated into Arabic and then back-translated to ensure semantic and cultural equivalence. Construct validity was assessed using exploratory factor analysis with principal axis factoring and varimax rotation. This analysis identified five distinct factors, explaining 62.4% of the total variance. Factor loadings for items ranged from 0.53 to 0.81, indicating a stable and interpretable factor structure. Discriminant validity was supported by inter-factor correlations, all of which were below 0.80, confirming adequate differentiation among the dimensions.

Reliability was evaluated using Cronbach's alpha coefficients for each of the five dimensions, producing the following values:

- models as exact replicas of reality (0.80)
- models as multiple representations (0.84)
- models as explanatory tools (0.82)
- use of scientific models (0.83)
- changing nature of scientific models (0.81)

These values demonstrate high internal consistency across all dimensions. Together, these procedures provide strong evidence for the validity and reliability of the SUMS instrument, adapted for Arabic-speaking secondary school students.

After data collection was completed, all responses were entered into the statistical package for the social sciences for analysis. Descriptive statistics–including frequencies, percentages, Ms, and standard deviations (SD)–were initially calculated to assess the overall understanding of scientific models and modeling among secondary-school students. Next, a multivariate analysis of variance (MANOVA) was conducted to determine whether significant differences in understanding could be linked to students' grade levels.

Research Procedures

The research procedures began with obtaining all necessary ethical and administrative approvals: ethical approval was granted by the Standing Committee for Human and Social Research Ethics at Najran University (approval no. 202410-076-024648-055365) on October 15, 2024; a formal authorization letter from the Vice Rector for Postgraduate Studies and Scientific Research was addressed to the Director of the General Education Directorate in the Najran Region to approve the researcher's fieldwork; and the planning and development department of the Najran Education Directorate issued facilitation letter no. 4600488831 on May 15, 2024. Next, the SUMS questionnaire was distributed to all girls' secondary schools in Najran through the regional education office, in coordination with natural science instructors. It included clear statements about voluntary participation, the right to withdraw at any time, and strict confidentiality of responses. Lastly, the collected data were analyzed systematically, the results were interpreted and discussed, and evidence-based recommendations were made based on the study's findings.

Table 1. Descriptive statistics for the "models as multiple representations" dimension items

SN	Item	M	SD	R
1	Multiple models can be used to represent different aspects of a scientific phenomenon by presenting various viewpoints on the same object.	2.40	1.17	7
2	Multiple models constitute different versions of the phenomenon.	2.45	1.09	5
3	Models can clarify the relationships among ideas.	2.44	1.33	6
4	Multiple models are used to demonstrate how they depend on different personal conceptions of an object's form or function.	2.59	1.20	1
5	Multiple models can depict various facets or forms of the same object.	2.27	1.15	8
6	Multiple models reveal different parts of an object or display the object in different ways.	2.56	1.14	2
7	Multiple models illustrate how different information is utilized.	2.47	1.03	4
8	A model contains what is necessary to represent or explain the scientific phenomenon.	2.48	1.22	3
Dimension as a whole		**2.46**	**0.59**	**-**

Note. SN: Statement number & R: Rank

Table 2. Descriptive statistics for the "models as exact replicas of reality" dimension

SN	Item	M	SD	R
1	The model should be a replica of the real object.	2.33	1.10	1
2	The model needs to resemble the real object.	2.02	0.90	5
3	The model needs to resemble the real object by being perfectly identical so that no one can dispute it.	2.26	0.97	3
4	Everything related to the model should clearly indicate what it represents.	1.93	0.83	7
5	The model needs to resemble the real object by being perfectly identical in every respect except for scale.	2.27	0.99	2
6	The model needs to resemble the real object by providing accurate information and showing how the object appears.	1.93	0.84	7
7	The model shows what the real object does and how it looks.	1.99	0.82	6
8	Models depict a smaller scale of an object.	2.25	0.99	4
Dimension as a whole		**2.12**	**0.65**	**-**

Note. SN: Statement number & R: Rank

RESULTS

RQ1. What Is the Level of Secondary School Students' Understanding of Models and Modeling?

To address RQ1, descriptive statistics, including Ms and SDs, were employed. The results shown here specifically relate to the first dimension, "models as multiple representations," and are shown in **Table 1**.

As shown in **Table 1**, the average score for the "models as multiple representations" dimension was 2.46 out of 5, with item scores ranging from 2.27 to 2.59. These results suggest that students hold naive, scientifically inaccurate ideas about this dimension. Specifically, the sample of secondary-school students from the Najran Region seems to lack an understanding that a scientific model represents only one possible way to illustrate the targeted phenomena or events, and that each model reflects the model creator's interpretation of how the phenomenon appears and functions. The findings also indicate a limited awareness that models usually emphasize certain aspects of a phenomenon based on the specific purpose for which the model was made, and that any given model is just one of many possible representations, rather than an absolute or singular depiction of reality.

Second: Models as exact replicas of reality: The results of the analysis of participants' responses to the items under the second dimension are presented in **Table 2**.

As shown in **Table 2**, the average score for the "models as exact replicas of reality" dimension was 2.12 out of 5, with individual item Ms ranging from 1.93 to 2.33. These results indicate that students hold scientifically inaccurate ideas about this dimension. It seems that secondary school students in the Najran Region do not ontologically differentiate between real-world phenomena and their theoretical representations. The students appear to believe that models are exact replicas of the phenomena they represent, assuming that models directly mirror the appearance and nature of what they model, without recognizing their simplified, selective, and representational nature.

Third: Models as explanatory tools: The results of the analysis of the research sample's responses to the items in the third dimension are presented in **Table 3**. As shown in **Table 3**, the M score for the "models as explanatory tools" dimension was 4.12 out of 5, with item Ms ranging from 4.06 to 4.18. These results indicate that students hold scientifically accurate conceptions related to this dimension. The sample of secondary-school students from the Najran Region appeared to appreciate the role of models in making systems visible, thereby enhancing understanding and helping students to develop their own mental models to represent scientific phenomena.

Table 3. Descriptive statistics for the "models as explanatory tools" dimension

SN	Item	M	SD	R
1	Models are used to represent something visually or three-dimensionally.	4.06	0.86	5
2	Models help you form a mental image of a scientific event.	4.18	0.82	1
3	Models are used to explain scientific phenomena.	4.08	0.83	4
4	Models are used to illustrate an idea.	4.15	0.81	2
5	A model can be a diagram, map, graph, or picture.	4.14	0.86	3
Dimension as a whole		**4.12**	**0.67**	**-**

Note. SN: Statement number & R: Rank

Table 4. Descriptive statistics for the "uses of scientific models" dimension

SN	Item	M	SD	R
1	Models are used to help formulate ideas and theories about scientific events.	2.54	1.26	3
2	Models are used to demonstrate how they are employed in scientific investigations.	2.59	1.25	1
3	Models are used to make predictions about a scientific event and to test those predictions.	2.55	1.15	2
Dimension as a whole		**2.56**	**0.78**	**-**

Note. SN: Statement number & R: Rank

Table 5. Descriptive statistics for the "changing nature of scientific models" dimension

SN	Item	M	SD	R
1	A model can change if new theories or evidence contradict it.	2.51	0.95	2
2	A model can change if there are new results.	2.55	0.91	1
3	A model can change if there are changes in data or underlying beliefs.	2.49	1.00	3
Dimension as a whole		**2.51**	**0.53**	**-**

Note. SN: Statement number & R: Rank

Fourth: Uses of scientific models: The results of the analysis of the research sample's responses to the items under the fourth dimension are presented in **Table 4**.

As shown in **Table 4**, the M score for the "uses of scientific models" dimension was 2.56 out of 5, with item Ms ranging from 2.55 to 2.59. These results indicate that students have inaccurate conceptions related to this dimension. Specifically, secondary-school students from the Najran Region appear to lack an understanding of the generative nature of scientific models; that is, they do not view models as tools for developing understanding, generating explanations, and creating new ideas about natural phenomena, but rather as static representations of existing knowledge.

Fifth: Changing nature of scientific models: The results of the analysis of the research sample's responses to the items under the fifth dimension are presented in **Table 5**.

As shown in **Table 5**, the M score for the "changing nature of scientific models" dimension was 2.51 out of 5, with item Ms ranging from 2.49 to 2.51. These findings indicate that students hold inaccurate conceptions related to this dimension. Secondary-school students from the Najran Region appear to lack awareness that scientific models are inherently subject to change, whether in response to new evidence or reinterpretations of existing evidence. This flexibility is a fundamental epistemological characteristic of scientific models in modern science education.

In sum, the results indicated that students have naïve and inaccurate perceptions of scientific models in four out of five areas. The lowest scores were in "models as exact replicas of reality" (2.12), "models as multiple representations" (2.46), "changing nature of scientific models" (2.51), and "uses of scientific models" (2.56), indicating that they struggle to see models beyond mere replicas. However, they performed better in "models as explanatory tools" (4.12), suggesting some understanding of their role in explaining scientific phenomena.

RQ2. Are There Statistically Significant Differences in Secondary School Students' Understanding of Models and Modeling that are Attributable to Grade Level?

A MANOVA was performed to explore potential differences across the five questionnaire dimensions among students in the three grade levels.

Table 6 shows that the calculated F-values for examining the differences in M scores between the three grade levels (10^{th}, 11^{th}, and 12^{th}) across the five questionnaire dimensions were as follows: models as multiple representations (2.66), models as exact replicas of reality (0.47), models as explanatory tools (0.30), uses of scientific models (0.49), and changing nature of models (1.54). All of these F-values were found to be statistically non-significant at the 0.05 significance level. Thus, there are no differences in students' understanding of scientific models and modeling across grade levels.

Table 6. MANOVA results by grade level on the dimensions of understanding of scientific modeling

SV	Dependent variable (dimension of understanding of scientific modeling)	SS	df	MS	F	SL
Grade level	Models as multiple representations	1.82	2	0.91	2.66	0.07 (NS)
	Models as exact replicas of reality	0.40	2	0.20	0.47	0.63 (NS)
	Models as explanatory tools	0.27	2	0.13	0.30	0.74 (NS)
	Functions of scientific models	0.61	2	0.30	0.49	0.61 (NS)
	Changing nature of scientific models	0.88	2	0.44	1.54	0.22 (NS)
Error	Models as multiple representations	135.68	397	0.34		
	Models as exact replicas of reality	167.45	397	0.42		
	Models as explanatory tools	177.20	397	0.45		
	Functions of scientific models	244.55	397	0.62		
	Changing nature of scientific models	113.27	397	0.29		

Note. SV: Source of variance; SS: Sum of squares; MS: Mean square; F: F-value; SL: Significance level; & NS: Not significant

DISCUSSION AND CONCLUSIONS

The discussion of the results is organized around the study's objectives, beginning with an overview of secondary school students' overall understanding of scientific models and modeling. It then examined how this understanding varied across different grade levels. Based on response patterns, it is clear that participants' ideas about models and modeling often show a form of conceptual naivety that goes beyond simple incompleteness. For example, the very low M score on the dimension "models as exact replicas of reality" (M = 2.12) highlights the persistent misconceptions that confuse scientific models with literal representations of natural phenomena. This view is fundamentally misaligned with the epistemological foundations of contemporary science. Similarly, students' limited recognition of models as multiple representations (M = 2.46), multifunctional scientific tools (M = 2.56), or dynamic and evolving epistemic constructs (M = 2.51) indicates a narrow, static perspective on models, lacking the epistemological sophistication needed for advanced scientific understanding. Notably, only the "models as explanatory tools" subscale had a high average (M = 4.12), suggesting that students tend to see models mainly as visual aids or simplifications rather than as cognitive tools that develop alongside scientific theories. Overall, these findings show that students' conceptions are not only underdeveloped but also, in some key areas, inconsistent with established views in science education research. This finding is consistent with previous studies that have highlighted the deep-rooted misconceptions about nature and role models among secondary school students (Grosslight et al., 1991; Justi & Gilbert, 2003; Treagust et al., 2002).

Regarding the dimension of "models as multiple representations," the findings of this study differ from those reported by Cheng and Lin (2015) and Treagust et al. (2002), who found that most students valued using multiple models to highlight different aspects of a phenomenon and to provide diverse perspectives. In contrast, the current results agree with those of Grosslight et al. (1991), who reported that very few seventh- and eleventh-grade students understood that multiple models can coexist to represent the same phenomenon.

This result may be linked to the perception among some students in Islamic contexts that knowledge is discovered rather than constructed (Algarni & Alahmad, 2023). This view likely results from a misinterpretation of certain Qur'anic verses that portray Allah as the origin of the cosmic order. For example, the verse, We will show them Our signs in the horizons and within themselves (Qur'an, Fussilat: 53), is often understood to mean that humans are simply uncovering the laws that govern this divinely created system. Based on this interpretation, students may find it challenging to grasp that scientific explanations of the natural world are, in essence, tentative models–plausible conjectures about how phenomena work. As Alabdulkareem (2016) noted, Saudi science teachers often struggle to reconcile the dynamic and provisional nature of scientific knowledge with their religious beliefs, which can lead to resistance toward accepting the plurality of scientific models as legitimate features of science. In reality, the Islamic perspective affirms the limited capacity of human understanding (Alsalami, 2021). The ideas of pre-existing laws and human inability to fully comprehend reality are not necessarily contradictory, so long as one recognizes that it is Allah who has established this order.

Regarding the concept of "models as exact replicas of reality," the current findings align with previous research showing that students often see models as literal reproductions of real-world phenomena (Cheng & Lin, 2015; Gobert et al., 2011; Grosslight et al., 1991; Treagust et al., 2002). In contrast, these results differ from those of Sins et al. (2009), who found that students viewed models as simplified representations of reality. Sins and colleagues explained the higher level of student understanding in their study–compared to other research–by highlighting the importance of considering the contextual nature of model-based reasoning, whereas other studies (e.g., Grosslight et al., 1991; Treagust et al., 2002) assessed students' understanding in a more decontextualized way.

This finding may be explained by the difference between two types of models: scale replicas, which look exactly like the target phenomenon and focus on accuracy and physical detail, and non-replica models, which look different but offer insights into how and why a phenomenon works (Treagust et al., 2002). Students' experiences with models in everyday life usually relate to the former type. In contrast, scientific models, especially those representing abstract ideas, are more often of the latter kind. As a result, students may struggle to understand how scientific models work when they do not physically resemble the phenomena they aim to explain. In the local context, this challenge might be worsened by a religiously influenced idea that scientific knowledge is discovered rather than built. Therefore, some students might believe that models reflect reality as it is, rather than being constructed tools designed to help understand how the natural world operates.

Regarding the dimension of "models as explanatory tools," the findings of this study align with previous research (Cheng & Lin, 2015; Treagust et al., 2002). This may be because many scientific concepts are naturally complex and abstract, leading science teachers to use models to help students understand better. The visual representation of system structures–enabled by scientific modeling–offers crucial support for building mental models and enhancing reasoning through them (Gilbert & Justi, 2016). Although there is limited empirical evidence on how modeling practices are actually integrated into science classrooms, this may be due to the common use of models as learning products.

Regarding the dimension of "uses of scientific models," the findings of the current study align with previous research showing that students–especially students–have a limited understanding of how models are used to develop and test scientific ideas (Grosslight et al., 1991; Treagust et al., 2002). However, these findings differ from other studies that report that students demonstrate a relatively better understanding of modeling as a creative scientific practice than of other epistemological aspects of modeling (Cheng & Lin, 2015; Sins et al., 2009).

In the local context, previous studies have emphasized the predominance of rote-based instructional methods in Saudi science classrooms (Aldahmash & Alshamrani, 2012; Almohi & Alshamrani, 2016; Alshamrani & Alghamdi, 2019; Alzamil et al., 2016). As a result, scientific models are frequently presented as definitive products of science rather than as tools for scientific reasoning (Gilbert & Justi, 2016). This observation may also be partly explained by local research showing limited understanding of the nature of science among science teachers (Alahmad et al., 2018; Alsubaie & Omar, 2016). Therefore, it is necessary to examine the effectiveness of teacher preparation and professional development programs in transforming teachers' pedagogical beliefs, which are known to be crucial factors shaping classroom practice (Alabdulkareem, 2016). As Grosslight et al. (1991) stressed, students need learning opportunities that actively involve them in modeling-based reasoning.

Regarding the dimension of the "changing nature of scientific models," the findings of this study differ from previous research, which indicated that most students clearly understand that models can change as scientific thinking evolves (Cheng & Lin, 2015; Sins et al., 2009; Treagust et al., 2002). This dimension highlights an essential aspect of the broader nature of science, that scientific knowledge is inherently tentative. Evidence shows that students' understanding of the nature of science significantly impacts their learning in science classrooms (NRC, 2012), underscoring the need to strengthen this epistemological aspect of science education.

This result may stem from the fact that knowledge in Islam falls into two categories: relative knowledge–such as that gained through human faculties, such as science, perception, and reasoning–and specific knowledge, revealed through divine revelation, namely the Qur'an and the Sunnah. This latter type is an exception to the principle of relativity (Alsalami, 2021). Students might be influenced by this epistemological division in Islam (Kim & Alghamdi, 2021), which could shape how they perceive the nature of scientific theories. They might view these theories as absolute truths (Alghamdi & Alanazi, 2020; Alghamdi & Malekan, 2020) if they believe they reveal God's laws, or they could reject the idea of relativity in science because it conflicts with the religious belief in fixed truth. The latter involves students, influenced by religious beliefs, assuming that actual knowledge must be constant and certain–like the Qur'an and the Sunnah–and thus finding it hard to accept that scientific theories can change and are only interpretive models. Consequently, they might see the relativity of science as a weakness in the truthfulness of knowledge, rather than a strength in scientific methodology. It is also important to note that Islam itself does not promote such absolutist views of science; rather, these are influenced by individual interpretations and the way science is taught (Mansour, 2011).

Regarding the influence of grade level on students' understanding of scientific models and modeling, the results of this study align with those reported by Krell et al. (2014), who found that such understanding does not automatically improve with academic advancement. Instead, it requires explicit and systematic instruction that emphasizes the epistemological foundations of modeling. Later research (Justi & Gilbert, 2003; Krell et al., 2015) has also shown that frequent exposure to models in schools' science curricula does not necessarily lead to conceptual progress, especially when models are presented as static tools without actively involving students in their creation or evaluation.

Interpreting this result requires understanding how modeling is integrated into institutional curricula and educational standards. In the Saudi context, models are often used for illustration and usually presented as finished products. Although direct empirical evidence on classroom practices is limited–mainly due to a lack of local research on how modeling is implemented in science lessons–this interpretation is supported by the current findings. Students scored higher on the illustrative function of models than on other aspects, indicating superficial engagement. This pattern is also consistent with previous studies showing that many science teachers still rely on didactic teaching strategies emphasizing rote memorization rather than inquiry-based learning (Aldahmash & Alshamrani, 2012; Almohi & Alshamrani, 2016; Alshamrani & Alghamdi, 2019; Alzamil et al., 2016).

The limited integration of modeling as an epistemic practice in science education might explain why there are no significant differences across grade levels. As Schwarz et al. (2009) argue, students develop a meaningful understanding of modeling only when they have opportunities to construct, justify, and critically evaluate models in interactive learning environments. These teaching conditions are hard to achieve in classrooms dominated by transmissive instruction. This highlights the urgent need to update national science curricula and teacher training programs to ensure that models and modeling are integrated not just as visual aids but as core tools for engaging students in genuine scientific reasoning.

Contribution

This study significantly contributes to the literature on scientific models and modeling by offering insights into secondary students' comprehension of scientific models in Saudi Arabia, situated within the country's socio-cultural and religious context. The historical influence of Islam has been instrumental in shaping science education in Saudi Arabia. Examining this topic is especially timely, considering the lack of studies conducted in the region and the limited exploration of this area.

The findings revealed that students' conceptions remain limited and naïve across several dimensions. These include viewing models as exact replicas of reality, limited appreciation of multiple representations, insufficient understanding of models' dynamic nature, and a lack of awareness of their roles in constructing and testing scientific knowledge. In contrast, a relatively better understanding was observed in the dimension of models as illustrative tools. However, this understanding remains confined to a narrow functional perspective, reducing models to simple visual aids.

These results may be attributed to contextual factors, most notably the personal religious beliefs of teachers and/or students, which underscores the need to highlight the relationship between science and religion. They may also be influenced by educational reforms imported from contexts with distinct cultural characteristics.

Limitations

A significant limitation of this study involves the contextual sensitivity of students' epistemological beliefs about models and modeling. As Krell et al. (2015) have shown, decontextualized tools may not accurately capture learners' understanding as they appear in real, rich environments, and students' epistemological responses can vary significantly across different settings. In this study, however, students' ideas were measured only through a non-contextualized questionnaire to gain a broader view of their beliefs about scientific models. Also, the sample was limited to female secondary students from public schools in the Najran Region; therefore, the findings should be interpreted cautiously when considering generalization to male students, other regions, or various types of schools.

Recommendations

In light of the study's findings, which indicate potential cultural and religious influences on students' conceptions of scientific models and modeling, the study recommends developing teacher preparation and professional development programs that incorporate specialized training modules aimed at helping science teachers understand the boundaries between science and religion, the nature of the relationship between them, and the epistemological foundations upon which each is based. This can be achieved by designing formal training packages offered periodically through professional development centers, including practical examples and classroom-based scenarios that illustrate how to address scientifically sensitive topics within a balanced and pedagogically sound framework.

The study also recommends that science curricula include explicit guidance for teachers on how to present scientific knowledge within a framework that aligns with religious values without conflating the two domains. This may be facilitated by establishing joint committees comprising specialists in both Islamic studies and the natural sciences to participate in the development or review of curricula, ensuring that scientific content aligns with students' cultural and religious backgrounds while avoiding the portrayal of science and religion as mutually exclusive.

Moreover, the study calls for encouraging both teachers and students to reflect on religious beliefs that may hinder the understanding of the interpretive and provisional nature of scientific knowledge. This can be accomplished through classroom discussions, critical-thinking activities, and guided dialogues that help learners distinguish between religious certainties and scientific knowledge, which is inherently provisional and subject to revision based on evidence.

Suggestions for Future Research

Based on the results of the present study, future research may focus on the following directions:

1. Investigating how scientific modeling is actually implemented in Saudi science classrooms, using classroom observations and qualitative analyses to understand real instructional practices.
2. Conducting intervention-based studies that implement modeling-focused instructional units and measure their impact on students' understanding of scientific models and modeling with higher precision.
3. Examining the influence of cultural and religious factors on students' conceptions of scientific models and exploring approaches that foster alignment between Islamic epistemology and the methodological foundations of modern science.

Funding: No funding source is reported for this study.

Ethical statement: The author stated that the study was approved by the Research Ethics Committee at Najran University on 24 October 2024 with approval number 202410-076-024648- 055365. Written informed consents were obtained from the participants.

AI statement: The author stated that artificial intelligence tools (ChatGPT, GPT-5, August 2025 version) were used solely to enhance the language and phrasing of the manuscript, without any involvement in the scientific content, results, or analyses.

Declaration of interest: No conflict of interest is declared by the author.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the author.

REFERENCES

Alabdulkareem, S. A. (2016). The impact of science teachers' beliefs on teaching science: The case of Saudi science teachers. *Journal of Education and Learning, 5*(2), 233-249. https://doi.org/10.5539/jel.v5n2p233

Alahmad, N. S., Al-Shahri, J. A., Al-Turki, K. I., Al-Baqmi, M. F., & Al-Dossari, N. (2018). Science teachers' perceptions of the nature of science (NOS) according to the next generation science standards (NGSS). *Journal of Scientific Research in Education, 19*(4), 471-495. https://doi.org/10.21608/jsre.2018.22974

Alanazi, F. (2018). Saudi children's taxonomic knowledge of animal species. *Journal of Baltic Science Education, 17*(3), 395-413. https://doi.org/10.33225/jbse/18.17.395

Alanazi, F. H. (2019). The perceptions of students in secondary school in regard to evolution-based teaching: Acceptance and evolution learning experiences: The Kingdom of Saudi Arabia. *Research in Science Education, 51*, 725-753. https://doi.org/10.1007/s11165-019-9827-y

Alassaf, S. (2016). *Introduction to research in behavioral sciences* (3rd ed.). Dar Al-Zahraa.

Aldahmash, A., & Alshamrani, S. (2012). The nature of science teachers' practices of inquiry from the educational supervisors' perspectives. *Journal of Educational and Psychological Sciences, 13*(4), 439-462. https://doi.org/10.12785/JEPS/130415

Alexander, R. J. (2008). *Education for all: The quality imperative and the problem of pedagogy (CREATE pathways to access research monograph no. 20)*. Institute of Education.

Algarni, N. A., & Alahmad, N. S. (2023). Views on nature of science and attitudes toward teaching nature of science among chemistry students in Saudi universities. *Journal of Baltic Science Education, 22*(2), 204-214. https://doi.org/10.33225/jbse/23.22.204

Alghamdi, A. K. H., & Alanazi, F. H. (2020). Process-oriented guided-inquiry learning in Saudi secondary school chemistry instruction. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(12), Article em1920. https://doi.org/10.29333/ejmste/9278

Alghamdi, A. K. H., & Malekan, M. (2020). Saudi science teachers' perceptions of the cultural factors influencing elementary students' science learning. *Cultural Studies of Science Education, 15*(4), 1143-1167. https://doi.org/10.1007/s11422-019-09960-9

Almasabi, Z. (2023). *The effectiveness of a model of modeling-based teaching on developing scientific modeling practice and epistemic knowledge about it and conceptual understanding in physics* [Unpublished doctoral dissertation]. King Saud University.

Almohi, S., & Alshamrani, S. (2016). The inclusion and practice of the essential features of inquiry in the scientific activities in Saudi 10th grade chemistry textbooks. *Saudi Educational & Psychological Association, 53*, 141-170. https://doi.org/10.12816/0031430

Almuhesin, A. (1999). *Teaching science*. Alobikan.

Alsaadi, A. (2021). *An investigation of Saudi science teachers' perceptions and implementation of inquiry-based learning* [PhD thesis, University of York].

Alsalami, S. (2021). Epistemology in Islam and its educational applications. *Journal of the Faculty of Education at Tanta University, 84*(4), 203-258.

Alshamrani, S., & Alghamdi, A. (2019). Instructional practices based on the teacher's guide for middle school science teachers. *Risalat Ul-Khaleej Al-Arabi, 40*(151), 57-76.

Alsubaie, N. A., & Omar, S. H. (2016). Science teachers' perceptions of the nature of science. *Journal of*

Educational and Psychological Sciences, 17(2), 373-408. https://doi.org/10.12816/0033874

Alzamil, M., Alshayie, F., & Alzagibi, M. (2016). The inclusion of socio-scientific issues (SSI) in high school chemistry textbooks in Saudi Arabia and the teachers' awareness of them. *Educational Journal, 30*(118), 187-230.

Brinkmann, D. (2015). Cross-cultural science education: Some reflections on the transfer of Western approaches to teaching science. *Cultural Studies of Science Education, 10*(2), 341-347.

Carroll, G., & Park, S. (2024). Towards expansive model-based teaching: A systematic synthesis of modelling pedagogies in science education literature. *Studies in Science Education*. https://doi.org/10.1080/03057267.2024.2417157

Cheng, M. F., & Lin, J. L. (2015). Investigating the relationship between students' views of scientific models and their development of models. *International Journal of Science Education, 37*(15), 2453-2475. https://doi.org/10.1080/09500693.2015.1082671

Chittleborough, G. D., & Treagust, D. F. (2009). Why models are advantageous to learning science. *Educación Química, 20*(1), 12-17. https://doi.org/10.1016/S0187-893X(18)30003-X

Deng, F., Chai, C. S., Tsai, C. C., & Lin, T. J. (2014). Assessing South China (Guangzhou) high school students' views on nature of science: A validation study. *Science & Education, 23*(4), 843-863. https://doi.org/10.1007/s11191-013-9674-6

Education and Training Evaluation Commission. (2019). *Saudi Arabian national curriculum framework for science education*. Education and Training Evaluation Commission.

Frigg, R., & Hartmann, S. (2012). Models in science. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy*. Stanford University Press.

Gilbert, J. K., & Justi, R. (2016). *Modelling-based teaching in science education*. Springer. https://doi.org/10.1007/978-3-319-29039-3

Gobert, J. D., O'Dwyer, L., Horwitz, P., Buckley, B. C., Levy, S. T., & Wilensky, U. (2011). Examining the relationship between students' understanding of the nature of models and conceptual learning in biology, physics, and chemistry. *International Journal of Science Education, 33*(5), 653-684. https://doi.org/10.1080/09500691003720671

Grosslight, L., Unger, C., Jay, E., & Smith, C. L. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*, 799-822. https://doi.org/10.1002/tea.3660280907

Guy-Gaytán, C., Gouvea, J. S., Griesemer, C., & Passmore, C. (2019). Tensions between learning models and engaging in modeling: Exploring implications for science classrooms. *Science & Education, 28*(8), 843-864. https://doi.org/10.1007/s11191-019-00064-y

Justi, R., & Gilbert, J. (2003). Teacher's views on the nature of models. *International Journal of Science Education, 25*, 1369-1386. https://doi.org/10.1080/0950069032000070324

Kang, S., Scharmann, L. C., & Noh, T. (2005). Examining students' views on the nature of science: Results from Korean 6th, 8th, and 10th graders. *Science Education, 89*(2), 314-334. https://doi.org/10.1002/sce.20053

Kim, S. Y., & Alghamdi, A. K. H. (2020). Saudi Arabian secondary school students' understanding of scientific models and modeling. *International Journal of Science Education, 42*(16), 2717-2739. https://doi.org/10.1080/09500693.2020.1818327

Kim, S. Y., & Alghamdi, A. K. H. (2021). Saudi Arabian secondary school students' views of the nature of science and epistemological beliefs: Gendered differences. *Research in Science & Technological Education, 41*(3), 838-860. https://doi.org/10.1080/02635143.2021.1961721

Kötter, M., & Hammann, M. (2017). Controversy as a blind spot in teaching nature of science. *Science & Education 26*(5), 451-482. https://doi.org/10.1007/s11191-017-9913-3

Krell, M., & Krüger, D. (2017). University students' meta-modelling knowledge. *Research in Science & Technological Education, 35*(3), 261-273. https://doi.org/10.1080/02635143.2016.1274724

Krell, M., Reinisch, B., & Krüger, D. (2015). Analyzing students' understanding of models and modeling referring to the disciplines biology, chemistry, and physics. *Research in Science Education, 45*, 367-393. https://doi.org/10.1007/s11165-014-9427-9

Krell, M., Upmeier zu Belzen, A., & Krüger, D. (2014). Students' levels of understanding models and modelling in biology: Global or aspect-dependent? *Research in Science Education, 44*, 109-132. https://doi.org/10.1007/s11165-013-9365-y

Lam, T. C., Allen, G., & Green, K. E. (2010). *Is "neutral" on a Likert scale the same as "don't know" for informed and uninformed respondents? Effects of serial position and labeling on selection of response options* [Paper presentation]. National Council on Measurement in Education Annual Meeting.

Lee, S. W. Y., Chang, H.-Y., & Wu, H.-K. (2017). Students' views of scientific models and modeling: Do representational characteristics of models and students' educational levels matter? *Research in*

Science Education, 47(2), 305-328. https://doi.org/10.1007/s11165-015-9502-x

Li, K., & Schwarz, C. V. (2021). Supporting students' meaningful engagement in scientific modeling through epistemological messages: A case study of contrasting teaching approaches. *Journal of Research in Science Teaching, 58*(7), 1070-1103. https://doi.org/10.1002/tea.21662

Louca, L. T., & Zacharia, Z. C. (2012). Modeling-based learning in science education: Cognitive, metacognitive, social, material and epistemological contributions. *Educational Review, 64*(4), 471-492. https://doi.org/10.1080/00131911.2011.628748

Malone, K. L., & Schuchardt, A. (2023). Modelling-based pedagogy as a theme across science disciplines–Effects on scientific reasoning and content understanding. *European Journal of Science and Mathematics Education, 11*(4), 717-737. https://doi.org/10.30935/scimath/13516

Mansour, N. (2008). Religious beliefs: A hidden variable in the performance of science teachers in the classroom. *European Educational Research Journal, 7*(4), 557-576. https://doi.org/10.2304/eerj.2008.7.4.557

Mansour, N. (2011). Science teachers' views of science and religion vs. The Islamic perspective: Conflicting or compatible? *Science Education, 95*(2), 281-309. https://doi.org/10.1002/sce.20418

Mora, C., & Herrera, D. (2009). Una revisión sobre ideas previas del concepto de fuerza [A revision of previous ideas of the concept of force]. *Latin American Journal of Physics Education, 3*(1), 72-86.

Nadler, J. T., Weston, R., & Voyles, E. C. (2015). Stuck in the middle: The use and interpretation of mid-points items on questionnaires. *Journal of General Psychology, 142*(2), 71-89. https://doi.org/10.1080/00221309.2014.994590

NRC. (1996). *National science education standards*. National Academy Press.

NRC. (2007). *Taking science to school: Learning and teaching science in grades K-8*. National Academies Press.

NRC. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

Oh, P. S., & Oh, S. J. (2011). What teachers of science need to know about models: An overview. *International Journal of Science Education, 33*(8), 1109-1130. https://doi.org/10.1080/09500693.2010.502191

Organization for Economic Co-operation and Development. (2023). The PISA 2025 assessment framework: Key competencies in reading, mathematics and science. *OECD*. https://pisa-framework.oecd.org/science-2025/

Paillusson, F., & Booth, M. (2024). Embracing representational plurality to bypass misconceptions in science education. *Science & Education, 34*, 1955-1969. https://doi.org/10.1007/s11191-024-00590-4

Pieterman-Bos, A., Reincke, C. M., van de Schoot, R., & van Mil, M. H. W. (2024). Understanding epistemological notions underlying scientific language use: A multifaceted analysis framework. *Frontiers in Education, 9*. https://doi.org/10.3389/feduc.2024.1452111

Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching, 48*(5), 486-511. https://doi.org/10.1002/tea.20415

Reiss, M. J. (2004). Students' views of the nature of science. *International Journal of Science Education, 26*(3), 287-306.

Saudi Vision 2030. (2016). Vision 2030 Kingdom of Saudi Arabia. *Vision 2003*. https://www.vision2030.gov.sa/ar/

Schwarz, C. V., & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*(2), 165-205. https://doi.org/10.1207/s1532690xci2302_1

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654. https://doi.org/10.1002/tea.20311

Sins, P. H. M., Savelsbergh, E. R., van Joolingen, W., & van Hout-Wolters, B. (2009). The relation between students' epistemological understanding of computer models and their cognitive processing in a modeling task. *International Journal of Science Education, 31*(9), 1205-1229. https://doi.org/10.1080/09500690802192181

Taber, K. S. (2017). Models and modelling in science and science education. In K. S. Taber, & B. Akpan (Eds.), *Science education: An international course companion* (pp. 263-278). Sense Publishers. https://doi.org/10.1007/978-94-6300-749-8_20

Thomas, C. L., & Kirby, L. A. J. (2020). Situational interest helps correct misconceptions: An investigation of conceptual change in university students. *Instructional Science, 48*, 223-241. https://doi.org/10.1007/s11251-020-09509-2

Toma, R. B., Greca, I. M., & Orozco Gómez, M. L. (2019). Attitudes towards science and views of nature of science among elementary school students in terms of gender, cultural background and grade level variables. *Research in Science & Technological*

Education, 37(4), 492-515. https://doi.org/10.1080/02635143.2018.1561433

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education, 24*(4), 357-368. https://doi.org/10.1080/09500690110066485

Villablanca, S., Montenegro, M., & Ramos-Moore, E. (2020). Analysis of student perceptions of scientific models: Validation of a Spanish-adapted version of the students' understanding of models in science instrument. *International Journal of Science Education, 42*(17), 2945-2958. https://doi.org/10.1080/09500693.2020.1843735

Wang, H.-H., Hong, Z.-R., She, H.-C., Smith, T. J., & Fielding, J. (2022). The role of structured inquiry, open inquiry, and epistemological beliefs in developing secondary students' scientific and mathematical literacies. *International Journal of STEM Education, 9*, Article 14. https://doi.org/10.1186/s40594-022-00329-z

APPENDIX A

Table A1. Students' understanding of models in science

No	Items	SID	D	NTS	A	SA
1	Multiple models can be used to represent different aspects of a scientific phenomenon by presenting various viewpoints on the same object.					
2	Multiple models constitute different versions of the phenomenon.					
3	Models can clarify the relationships among ideas.					
4	Multiple models are used to demonstrate how they depend on different personal conceptions of an object's form or function.					
5	Multiple models can depict various facets or forms of the same object.					
6	Multiple models reveal different parts of an object or display the object in different ways.					
7	Multiple models illustrate how different information is utilized.					
8	A model contains what is necessary to represent or explain the scientific phenomenon.					
9	The model should be an exact replica of the real object.					
10	The model needs to resemble the real object.					
11	The model needs to resemble the real object by being perfectly identical so that no one can dispute it.					
12	Everything related to the model should clearly indicate what it represents.					
13	The model needs to resemble the real object by being perfectly identical in every respect except for scale.					
14	The model needs to resemble the real object by providing accurate information and showing how the object appears.					
15	The model shows what the real object does and how it looks.					
16	Models depict a smaller scale of an object.					
17	Models are used to represent something visually or three-dimensionally.					
18	Models help you form a mental image of a scientific event.					
19	Models are used to explain scientific phenomena.					
20	Models are used to illustrate an idea.					
21	A model can be a diagram, map, graph, or picture.					
22	Models are used to help formulate ideas and theories about scientific events.					
23	Models are used to demonstrate how they are employed in scientific investigations.					
24	Models are used to make predictions about a scientific event and to test those predictions.					
25	A model can change if new theories or evidence contradict it.					
26	A model can change if there are new results.					
27	A model can change if there are changes in data or underlying beliefs.					

Note. SID: Strongly disagree; D: Disagree; NTS: Not sure; A: Agree; & SA: Strongly agree