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Modelling in the scientific approach to teaching life and earth sciences: Views and practices of Moroccan teachers

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Abstract

Modeling is a fundamental tool in the teaching and learning processes of life and earth sciences. It serves as an investigative instrument that enables students to test hypotheses and solve scientific problems. This paper presents the findings of a survey conducted among 96 Moroccan life and earth sciences teachers teaching students at the primary, junior high and high school levels. The study aims to highlight the role of modelling in life sciences instruction and explore teachers' understanding, approaches and perceptions towards models and modeling practices. A questionnaire-based methodology was employed to collect data on teachers' awareness of the significance of models in life sciences and the instructional approaches that are adopted in these models. The findings reveal Moroccan teachers' clear grasp of models' significance in teaching life sciences. Moreover, they employ similar approaches to models and modeling practices. The research highlights instructors' awareness of models' potential to increase the effectiveness and appeal of scientific instruction. It establishes modeling's pivotal role in instructing life sciences, emphasizing the need to incorporate modeling activities into the curriculum to nurture students' scientific inquiry and problem-solving skills. The study's practical implications suggest the value of training programs and professional development initiatives for teachers to promote model use in life sciences instruction. Enhancing teachers' knowledge and pedagogical strategies related to modeling can enrich science education leading to increased student engagement and achievement in the life sciences.

Keywords: Life and earth sciences, Modeling, Models, Pedagogical strategies, Science education, Teaching and learning processes.

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Contents

Contribution of this paper to the literature
This study highlights modeling's vital role in life and earth sciences education by examining Moroccan SVT teachers' perspectives, highlighting its importance, common approaches and potential to enhance science education. The recommendation of teacher training and professional development bridges theory and practice, offering steps for pedagogical strategies and positive impacts on teaching and student outcomes.

1. Introduction

Research in the life and earth sciences is a field of investigation that has received a lot of support from educational academics as it centers "both on processes, timeless mechanisms that we seek to explain and on patterns, past events that we seek to reconstruct" (Paulin & Charlat, 2020). This subject of instruction remains crucial for all age groups as it "aims at the training of scientists and allows the acquisition of a culture allowing all students, future citizens, to understand the current issues related to health and the environment" (Boudeau & Caberty, 2018).

The main question addressed in this study is how to effectively incorporate life sciences into teaching.

The use of real-life scenarios is crucial for teaching life sciences and it requires teachers to use concrete objects to help students construct scientific concepts and skills. This approach can be challenging for teachers. However, it has been shown to be effective in enhancing student learning by providing opportunities for students to experience the impact of a particular topic on their understanding (Guglielmetto, 2018).

In French-speaking Africa, including Morocco, educational reforms in scientific disciplines such as life and earth sciences aim to embrace pedagogies centered on inquiry-based approaches moving away from deductive teaching methods. The creation of an open, varied, high-performance and creative pedagogical model is highlighted in the context of Morocco in the vision 2015–2030 at leverage which also mentions the significance of a particular "investigative approach" for elementary school students. Subsequently, the revised scientific awakening programme in the Moroccan primary school in 2019 introduced the term "the investigative approach".

The investigative approach is rooted in the socio-constructivist model which posits that knowledge is constructed by individuals. Students play an active role in the learning process and assume responsibility for their own learning within this constructivist framework (Demir & Metin, 2022).

Research such as the 2015 Programme for International Student Assessment (PISA) has demonstrated a significant positive relationship between inquiry-based learning and self-efficacy in science (Liu & Wang, 2022).

In the investigative approach, students are encouraged to explore scientific phenomena in their surroundings and formulate scientific questions based on their prior conceptual knowledge. They employ appropriate investigative methods such as observation, experimentation and modeling to seek answers or solutions to their questions or problems (Perron, Hasni, & Jean-Marie, 2020). The teacher plays a crucial role in guiding students towards understanding concepts. When a student formulates a hypothesis, it indicates that they have grasped the subject matter taught by the teacher through the curriculum's modeling. The most important thing is to get your students to model based on the data collected or observations made in the scientific inquiry process (Hasni, Belletête, & Potvin, 2018). Modeling is recognized as one of the most effective investigative methods for students, offering flexibility and value in achieving various pedagogical goals (Wilson, Long, & Momsen, 2020). According to the same researchers, models enable students to move from static to dynamic perspectives, from flat representations to three-dimensional models and from classified knowledge to integrated understanding (Wilson et al., 2020). Several studies have examined the effects of modeling-based teaching approaches in biology. Kaya and Köse (2020) investigated students' conceptual understanding of cell division and found positive effects of a modeling-based teaching approach on students' comprehension of complex biological processes. Similarly, She and Zhang (2020) developed and validated a model-based inquiry learning program on photosynthesis demonstrating its effectiveness in enhancing students' understanding.

Furthermore, researchers have explored the development of modeling-based curricula in life sciences education. Hu, Wu, and Liang (2019) designed a web-based inquiry curriculum focusing on animal classification with the aim of improving students' scientific modeling abilities. Their findings highlighted the effectiveness of the curriculum in enhancing students' understanding of classification principles and their ability to construct and use models in biology. The application of modelling in biology and geology has been extensively studied (Renard et al., 2019; Wilson et al., 2020). These studies emphasize the importance of establishing connections between the real world and the world of models in the natural sciences. These connections can be analogical, involving the construction of physical systems that replicate the phenomenon of interest to a certain extent or mathematical, involving the development of mathematical functions to describe the phenomenon.

However, modeling's goal is to create and explain the event rather than try to replicate reality. When using models to teach natural scientific subjects, teachers must consider simplicity and progression while concentrating on the important elements related to the intended objectives.

The use of models by teachers in the scientific problem-solving process also helps students enhance their comprehension. Models have a didactic and pedagogical function since they help students learn by stimulating the expansion of their knowledge and abilities. They also strive to methodically explain science. However, the responsibility of teachers is not to challenge models' efficacy or the need for reform since models have limits. The responsibility of teachers is not to challenge models' efficacy or the need for reform since models have limits. In this regard, modeling in the scientific approach greatly enhances the teaching of Life and Earth Sciences (L&ES) but often, the model can lose its status as a learning and observational tool becoming a mere object and teaching objective to the detriment of student learning. Hence, it is important to consider the various limitations associated with modeling. As mentioned earlier, modeling allows the simplification of complex phenomena which is advantageous but as a result, it only captures certain aspects of reality.

Another limitation is associated with the significance of initial conceptions. Teachers may try to build on students' prior understandings but this can also create barriers to learning new information.

Students may now directly work with models without the need to design them which raises the question: "Do students understand what a model is that they are using a model and that their interpretations must take it into account?" It is important to recognize that the teacher plays a vital role in the internal didactic transposition. Consequently, it is necessary to focus primarily on the teacher specifically on the relationship between the SVT teacher and modeling. This study carries substantial significance in the realm of science education particularly within the domain of teaching life and earth sciences. By examining the role of modeling in the teaching and learning process, it provides valuable insight on the efficacy and potential advantages of using models as investigative tools. The findings offer valuable understanding regarding the comprehension and approaches adopted by Moroccan teachers when it comes to models and modeling practices. Such insights into the importance of models in science education can inform the development of curricula, instructional methodologies and teacher training programs, thereby enhancing the quality of science education and nurturing students' abilities in scientific inquiry. This study aims to address two questions in order to determine the attitudes, conceptions and practices of Moroccan teachers regarding scientific models in life and earth science.

Do Moroccan life science teachers employ models and modeling in their teaching?

How do Moroccan life and earth teachers conceptualize models and modeling in their teaching practices?

2. Methodology

2.1. Investigation Tool

The data collection process for this study involved the distribution of a self-designed questionnaire to teachers educating students on life sciences at the primary, junior high and high school levels. The questionnaire was prepared in classical Arabic to ensure accessibility for the participants and to promote responses by promising anonymity as well. Prior to implementation, the questionnaire underwent a validation process. Experts in science didactics and specialized life sciences teachers reviewed the questionnaire and a pilot test involving 40 teachers was conducted to assess its reliability using the Cronbach's alpha test. The study included a total of 96 teachers in its final sample size.

The questionnaire was developed based on an extensive literature review and an analysis of 18 school textbooks with the aim of identifying gaps and challenges related to the utilization of models and modeling practices in the life and earth science curriculum. The researcher also drew upon their own teaching experience and practices as a secondary school life sciences teacher in crafting the questionnaire. It comprised a combination of closed-ended and open-ended questions allowing for the collection of both quantitative and qualitative data.

Data analysis was carried out using IBM SPSS statistics 20 for Windows and Microsoft Excel 365. The questionnaire was administered in a face-to-face format using paper-based forms which facilitated focused data collection and provided an opportunity for meaningful discussions and the exchange of views, reactions and comments with the participants. This method was selected to ensure the reliability of the results and to enable more in-depth engagement with the teachers.

2.2. Characteristics of the Sample

The sample comprised 96 participants with 54.17% being female and 45.83% being male. The distribution across the three school levels was as follows: 21.87% in primary school, 29.17% in junior high school and 48.96% in high school. Participants' teaching experience ranged from less than five to more than fifteen years with most of the instructors in our sample having taught for five to ten years (39.58%).

3. Results

3.1. Analysis of the Questionnaire

**Question 1:*

After conducting an analysis of the questionnaire responses, the answers provided by the teachers were categorized into four distinct categories for each part of the question.

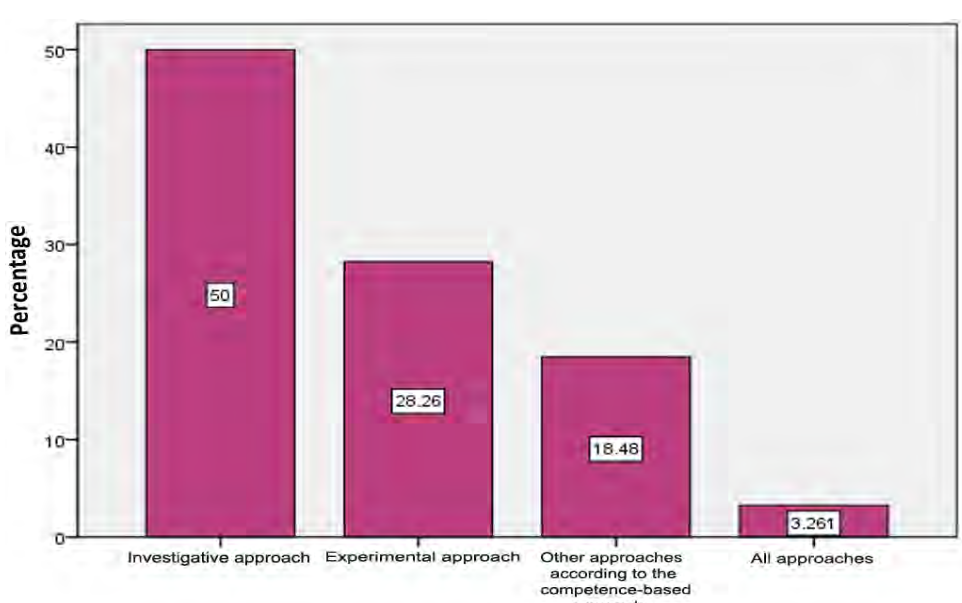

Figure 1. Percentages of approaches taken by teachers when using a model.

Figure 1 illustrates the preferences of the interviewed teachers regarding the introduction of models in their life science sessions. It reveals that 50% of the teachers favor incorporating models as part of the investigative approach while 28.26% prefer to introduce them through an experimental approach.

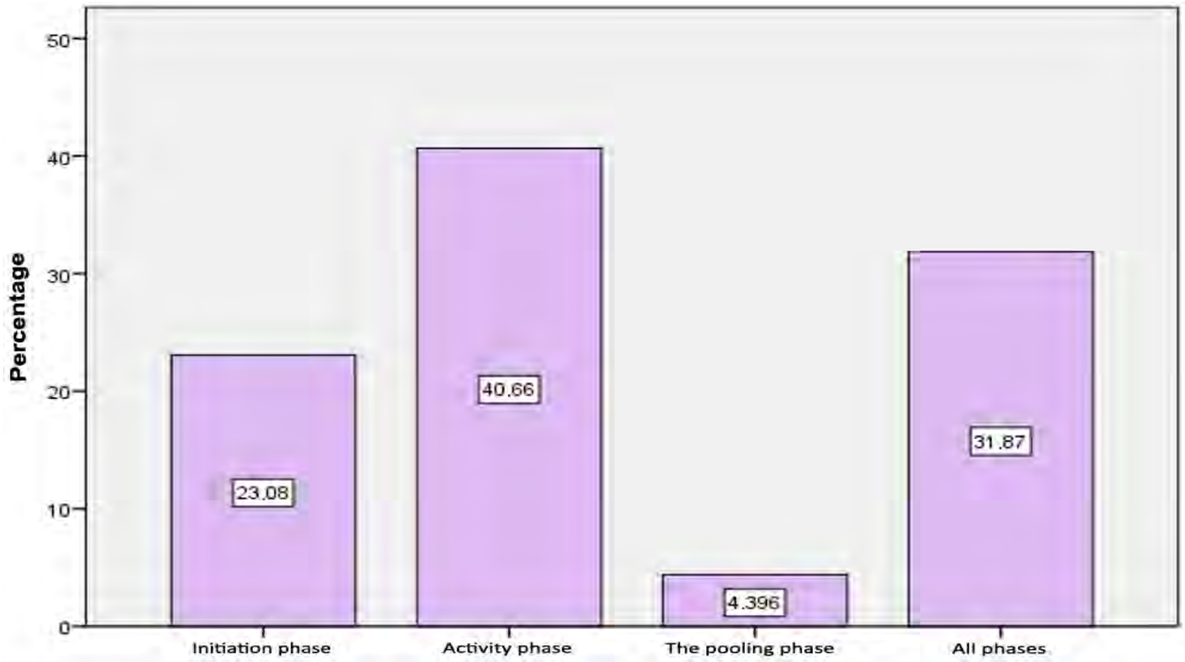

Figure 2. Percentages of session stages where teachers prefer to use a model.

A life and earth science session encompasses three distinct phases: the initiation phase, the activity phase and the pooling phase.

- During the initial phase, the main objective is to establish a problem that stimulates the curiosity of the students. This phase serves as a foundation for the subsequent activities and investigations.
- The activity phase represents the investigative stage of the session wherein students are encouraged to develop and use their own tools to explore and validate their hypotheses. This phase promotes practical and active participation in the scientific inquiry process.

On the other hand, the pooling phase focuses on the collective synthesis of knowledge generated during the session. Students work together to develop a shared understanding of the concepts and ideas covered which results in the production of a written report that presents the session's overall conclusions. Figure 2 demonstrates that 40.66% of the surveyed teachers regarded the activity phase as the most appropriate stage for incorporating models into their sessions. Additionally, a considerable portion of teachers (31.87%) believed that models could be introduced effectively in all phases of the lesson, encompassing the initiation, activity and pooling phases.

*Question 2:

In this question, we asked the teachers to specify whether the proposed themes (Table 1) are modelable. According to the literature review, all of the suggested topics may be modelled therefore, the instructor should choose "modelable" for each of them.

Table 1. Themes that teachers propose whether they are modellable or not.

Theme 1: Reproduction	**Theme 2** : Nutrition	**Theme 3 :** External geological phenomena	**Theme 4:** Classification of living organisms
Theme 5 : Conservation of health	**Theme 6 :** Internal geological phenomena	**Theme 7 :** Genetics	**Theme 8 :** Environmental conservation

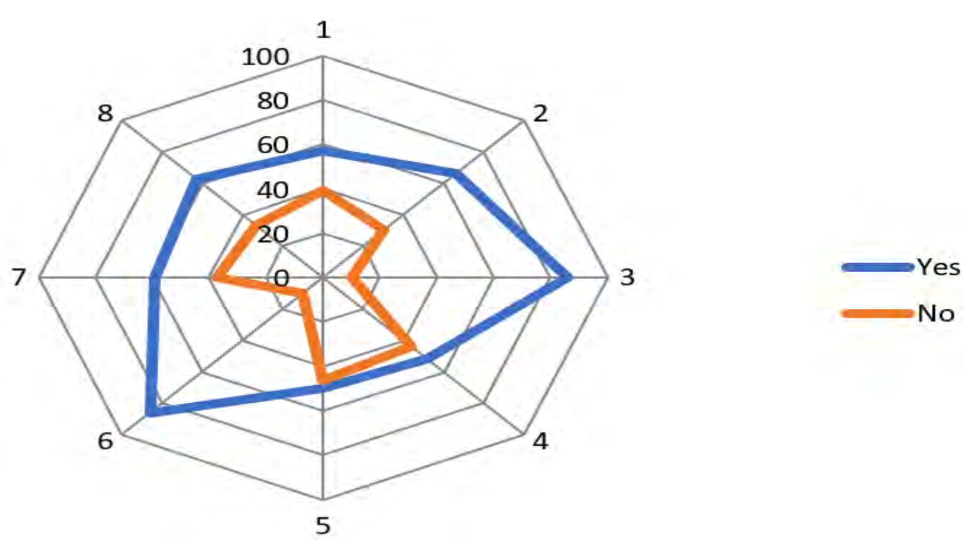

Figure 3: Distribution of the number of teachers according to their choice of modelling LES themes.

We observe that for the various themes, the majority of teachers find them modelable (Figure 3) except for themes 4 and 5 (classification of living beings and health preservation) where many teachers consider them non-modelable.

*Question 3:

In this question, teachers were asked to indicate the frequency with which they employ specific modeling practices and the models they use during their sessions. The practices in question are encapsulated in 9 propositions.

Table 2 presents nine propositions related to teachers' practices about the use of modeling and models.

Table 2. The propositions of Question 3.

1	Indicate that the model is not a reference to reality.
2	Mention the possibility that other models of the same phenomenon may exist.
3	Indicate that the model simplifies the phenomenon by reducing the complexity of reality.
4	Specify that the model does not represent reality but rather is a part of reality.
5	State that the model is a scientific product that evolves based on grade levels.
6	Ask the learners to compare the model with reality.
7	Ask learners to identify the purpose of using the model in a life science session.
8	Discuss the limitations of a model with learners.
9	Ask learners to critique a model used in life and science lessons.

A Likert scale consisting of four degrees: frequently, sometimes, rarely and never was employed to capture the teachers' frequency of adopting certain modeling practices and their utilization of models during their sessions. The chosen frequency responses will enable us to identify the teachers' pedagogical practices towards the use of modeling and models. Teachers who selected frequently or sometimes will be considered to have good pedagogical practices while those who responded rarely or never will be considered to have poor pedagogical practices in relation to models.

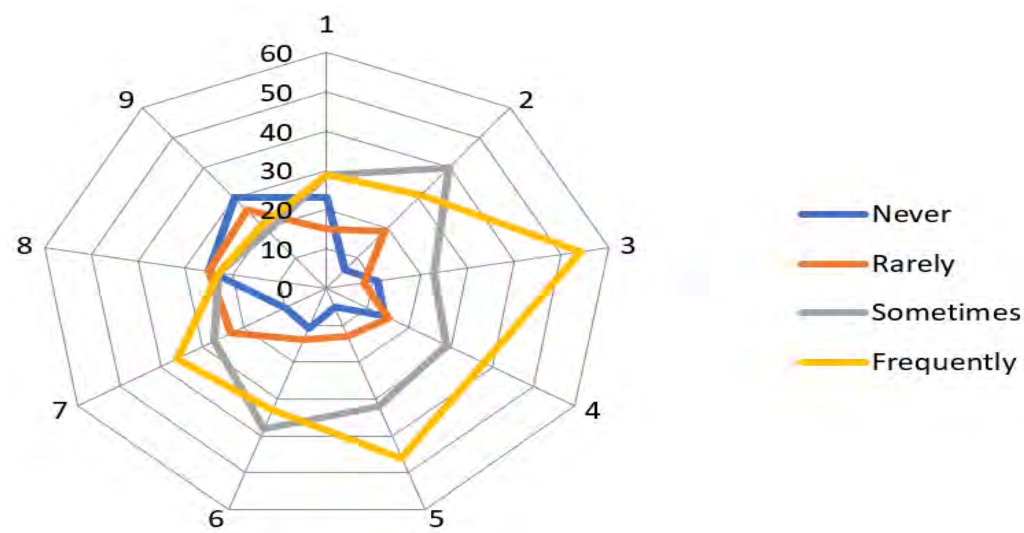

Figure 4. Distribution of the number of teachers according to the frequency chosen to express the adoption of certain practices with regard to modelling and the use of models (All levels).

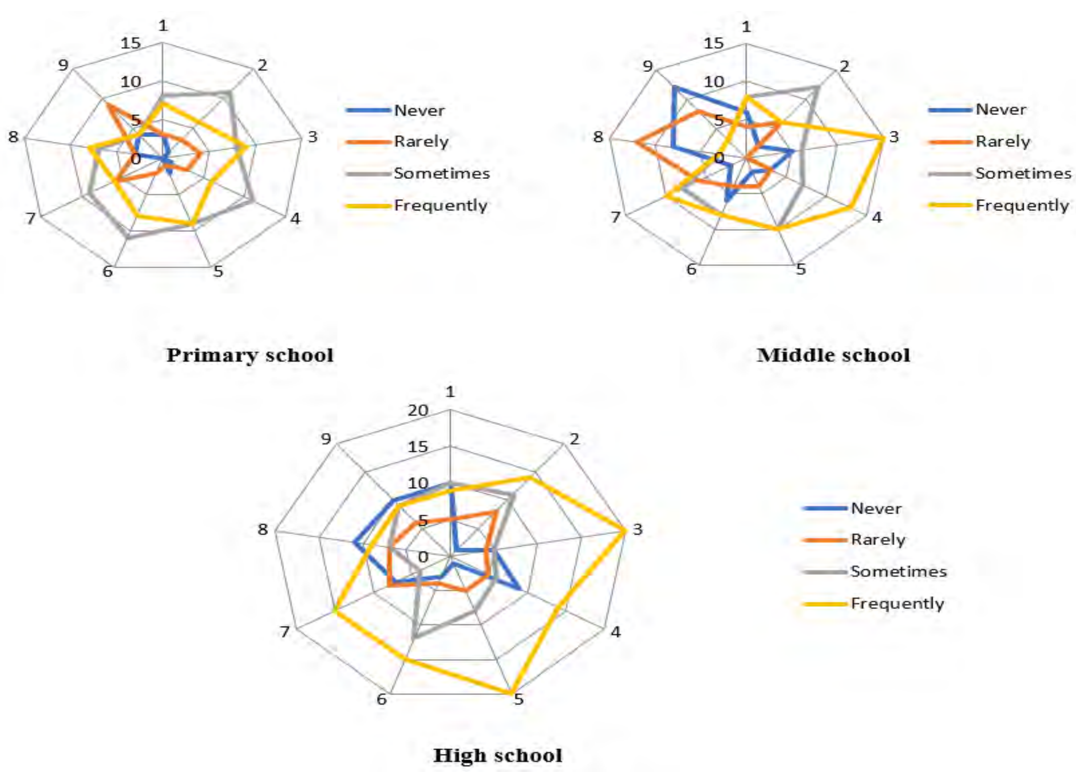

Figure 5. Distribution of teachers' numbers according to the frequency chosen to express the adoption of certain attitudes towards models (Separate levels).

The majority of teachers across all three divisions frequently or sometimes incorporate the practices outlined in the question (see Figure 4). However, there are a few exceptions worth noting.

Firstly, a significant number of elementary school teachers rarely ask learners to critique the models used in their sessions (proposition 9). Among middle school teachers, this frequency escalates for some individuals.

Additionally, the majority of middle school teachers rarely engage in discussions about the limitations of models with their learners (proposition 8).

High school instructors continue to follow this pattern, although in smaller numbers especially with reference to propositions 8 and 9 (see Figure 5).

*Question 4:

In this question, teachers were requested to indicate their levels of agreement with 15 propositions concerning scientific models, encompassing their utilization and the provision of examples.

Table 3 presents 15 propositions related to the utilization of scientific models and examples of these models.

Table 3. The propositions of Question 4.

1	The use of models can generate misconceptions among learners.
2	The use of models in the LES sessions is a secondary option.
3	The simplification of scientific concepts is not considered a model in all cases.
4	Microscopic observations can be considered models.
5	The creation of a model by learners requires a set of pre-requisites and information.
6	Schemas can be considered models.
7	Modelling replaces experimentation and manipulation.
8	The mathematical equations that explain the evolution of a given phenomenon can be considered models.
9	Geological concepts rely heavily on modelling compared to biological concepts.
10	Modelling is linked to certain school levels more than others.
11	Laboratory mice can be considered models.
12	Diagrams can be considered models.
13	Digital stimulation is a type of modelling.
14	Virtual experience is a type of modelling.
15	Training in modelling is essential for teaching scientific concepts.

A Likert scale consisting of four degrees: strongly disagree, disagree, agree and strongly agree was used to capture the teachers' level of agreement or disagreement with the propositions. This degree of agreement or disagreement serves as a determinant for assessing the teachers' knowledge and understanding of modeling and the use of models. Teachers who responded strongly agree or agree are considered to possess a strong knowledge and understanding of modeling and the use of models while those who answered strongly disagree or disagree are regarded as having a partial understanding of models.

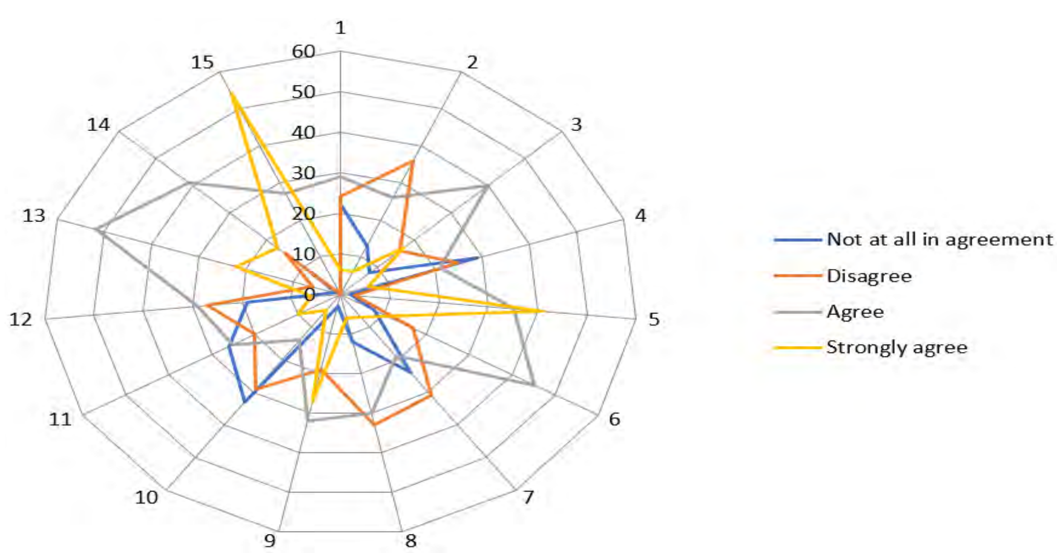

Figure 6. Distribution of teachers by selected agreement with some of the proposed statements about models and modelling (All levels).

Figure 6 reveals that the majority of teachers responded "agree" to propositions 1, 3, 5, 6, 8, 9, 11, 12, 13, and 14. Therefore, teachers in our sample demonstrate a strong understanding of model usage and modeling.

In the primary cycle, a significant number of primary teachers agreed with propositions 3, 4, 5, 6, 8, 11, 12, 13, and 14 and responded with "strongly agree" for proposition 15 (as shown in Figure 7). These propositions specifically address examples of models. Based on these responses, we can infer that primary school teachers have a certain level of scientific knowledge about models particularly when it comes to understanding and recognizing examples of models.

However, in regard to propositions 1, 2, 9, and 10, primary school teachers responded with a "disagree " rating. These propositions pertain to specific instances of using models in the teaching of scientific concepts. Consequently, these findings suggest that primary school teachers in this sample possess a limited understanding and knowledge regarding the effective use of models for teaching science concepts.

Regarding the secondary cycle (college and qualifying), a preliminary observation reveals an increase in the frequencies of disagreement with the propositions compared to the primary cycle. Additionally, among the propositions that received agreement from middle and high school teachers (particularly propositions 5, 6, 9, 13, 14, and 15), it is worth noting that most teachers disagreed with propositions 2, 4, 7, 8, 10, 11, and 12 (see Figure 7). This indicates a level of confusion among teachers regarding propositions that address the use of models versus those that pertain to examples of models.

Middle and high school teachers possess a limited understanding of models and their applications compared to primary teachers. Consequently, the initial hypothesis which suggests that primary teachers have inadequate knowledge of models compared to secondary teachers is rejected. This conclusion is supported by the significant differences found through the chi-square test of independence indicating a relationship between the level of agreement and the educational cycle to which teachers belong.

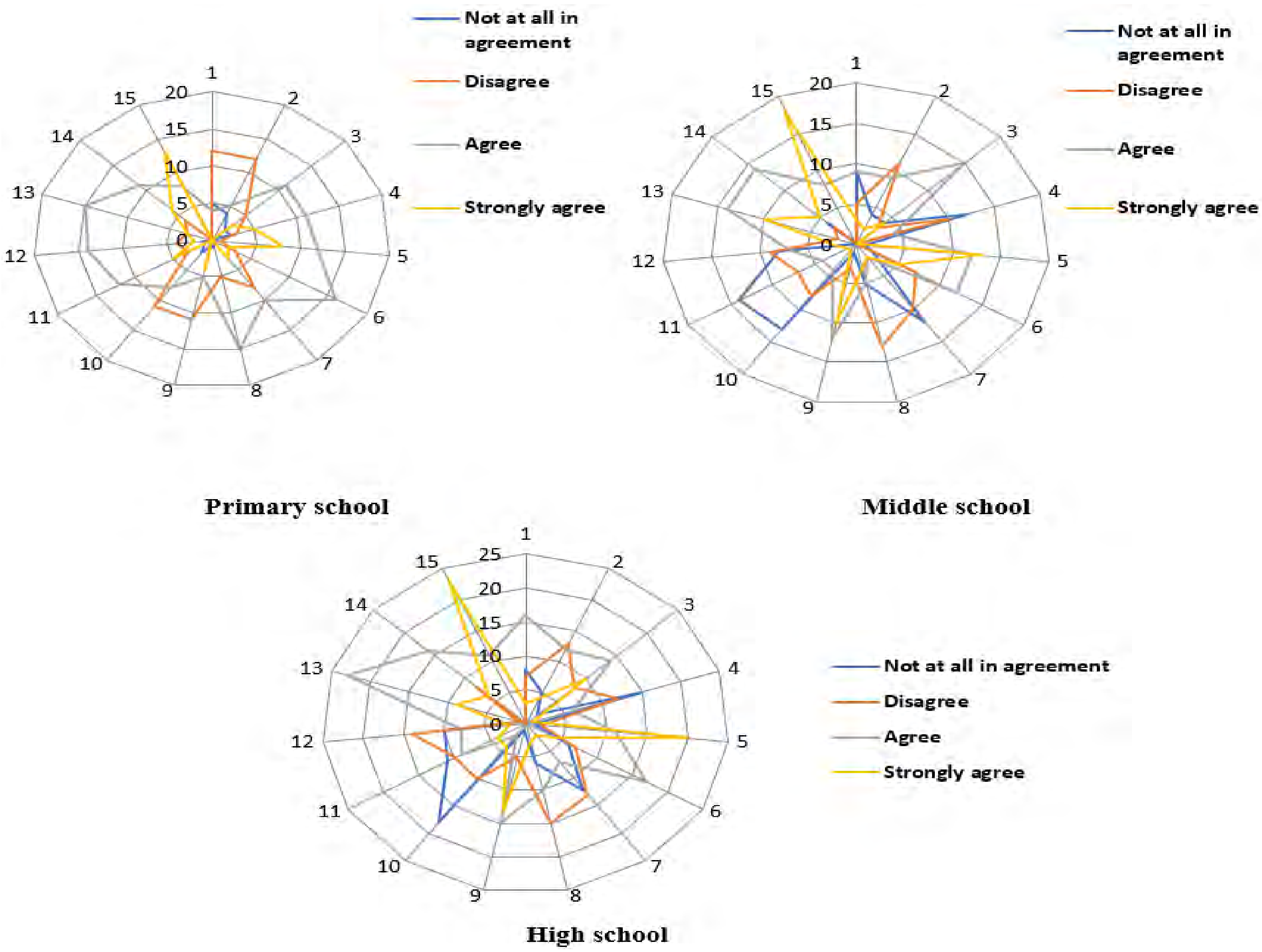

Figure 7. Distribution of teachers according to the degree of agreement chosen for some of the proposed statements about models and modelling (separate levels).

*Question 5:

The responses to open-ended questions have been categorized to facilitate the analysis. The question consisted of five parts and the participants' answers have been organized accordingly. Categorizing the responses allows for a systematic examination of the data and enables a more efficient analysis.

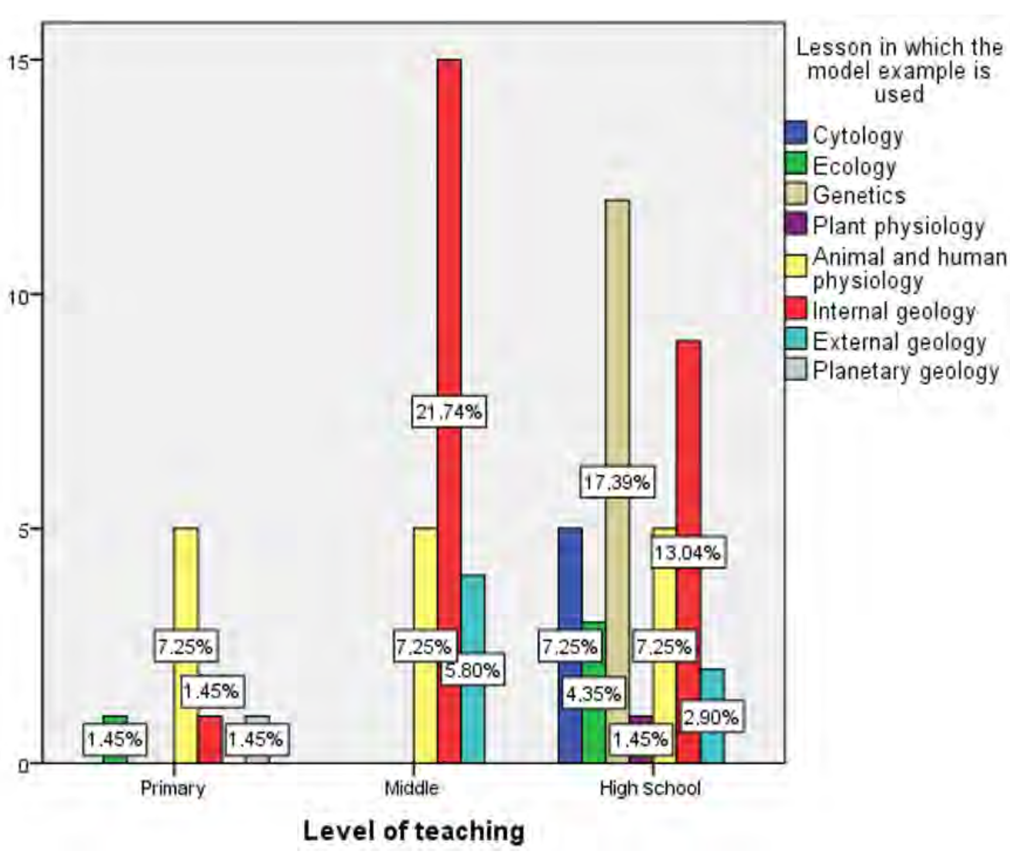

Figure 8. Percentages of teachers according to their statement about lessons where they use models.

Figure 8 shows that secondary school teachers predominantly provided examples of models related to internal and external geology, genetics and human and animal physiology aligned with the secondary school curriculum. Their responses indicated a strong emphasis on these specific areas of study.

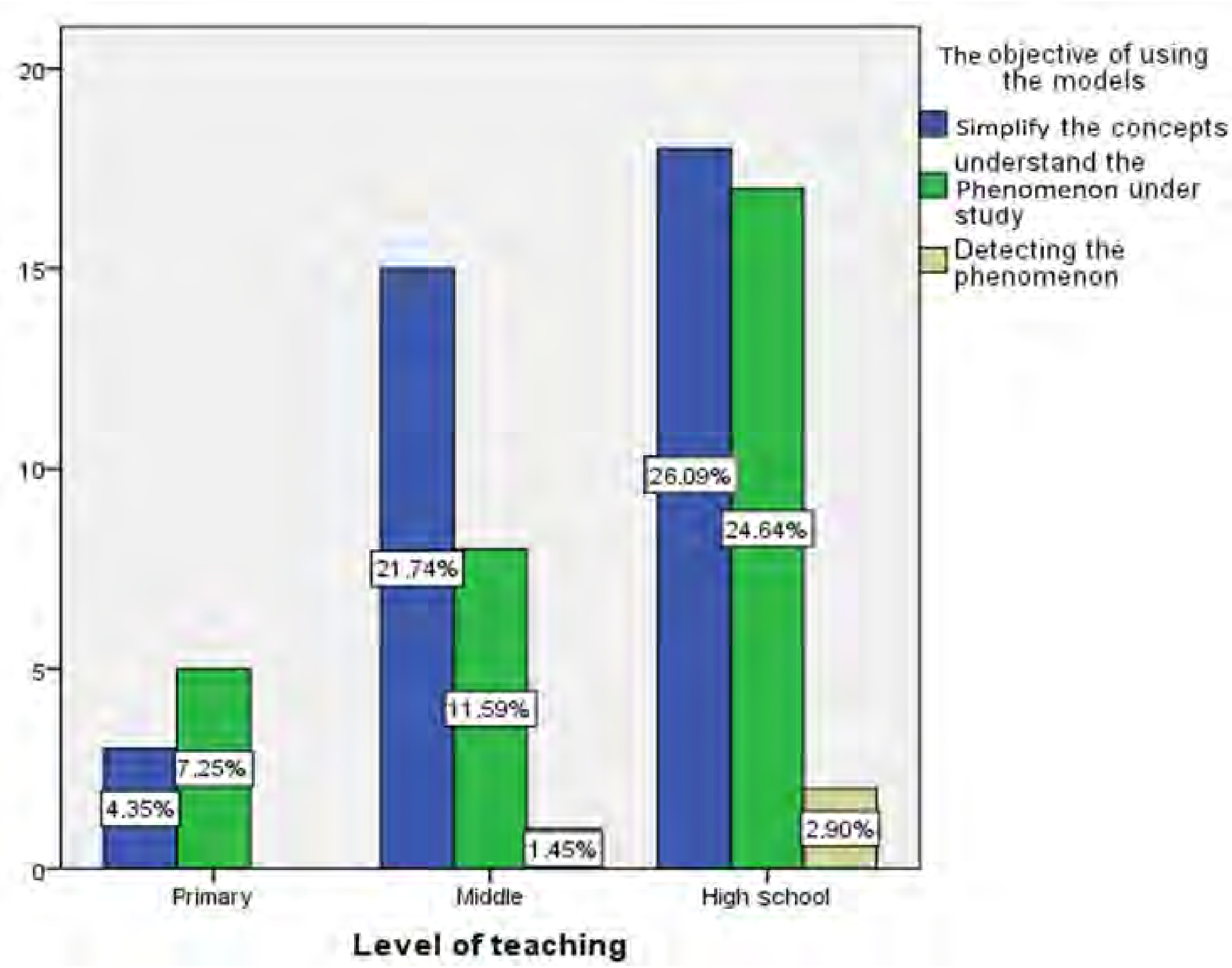

Figure 9. Percentages of teachers according to their statements about the objectives of using models.

According to Figure 9, the most commonly cited objectives by teachers for using models are simplifying concepts and helping learners understand the phenomena being studied. These objectives highlight the teachers' intention to make complex concepts more accessible and facilitate students' comprehension of the subject matter.

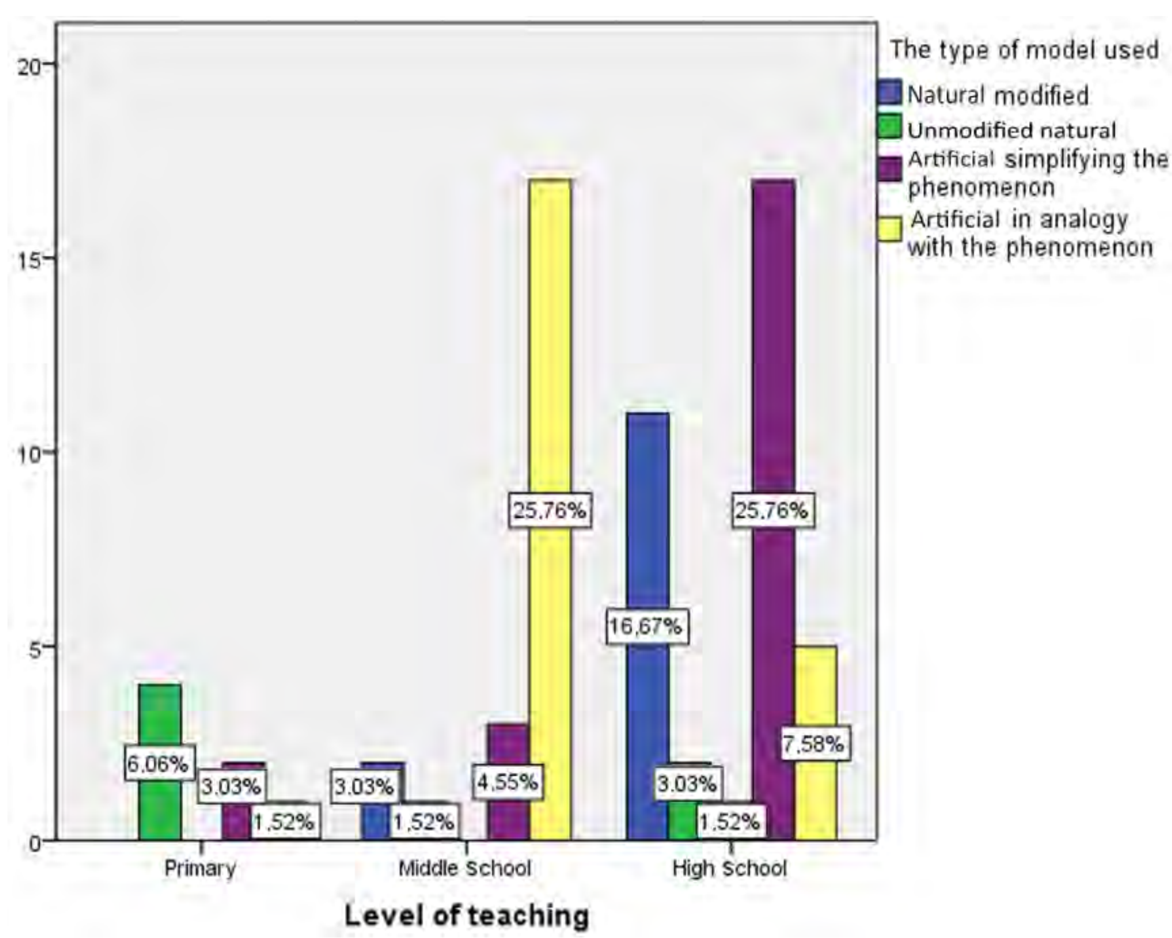

Figure 10. Percentages of teachers according to the types of models they use.

According to Figure 10, there is a noticeable difference in the preference for different types of models among teachers at different school levels. Primary school teachers tend to prefer unmodified natural models while secondary school teachers lean towards using artificial models that closely resemble the studied phenomenon. On the other hand, most high school instructors choose to study phenomena using artificial models that are simplified. This pattern can be attributed to the complexity of the content taught at each school level as well as teachers selecting models that align with the cognitive abilities and educational needs of their students.

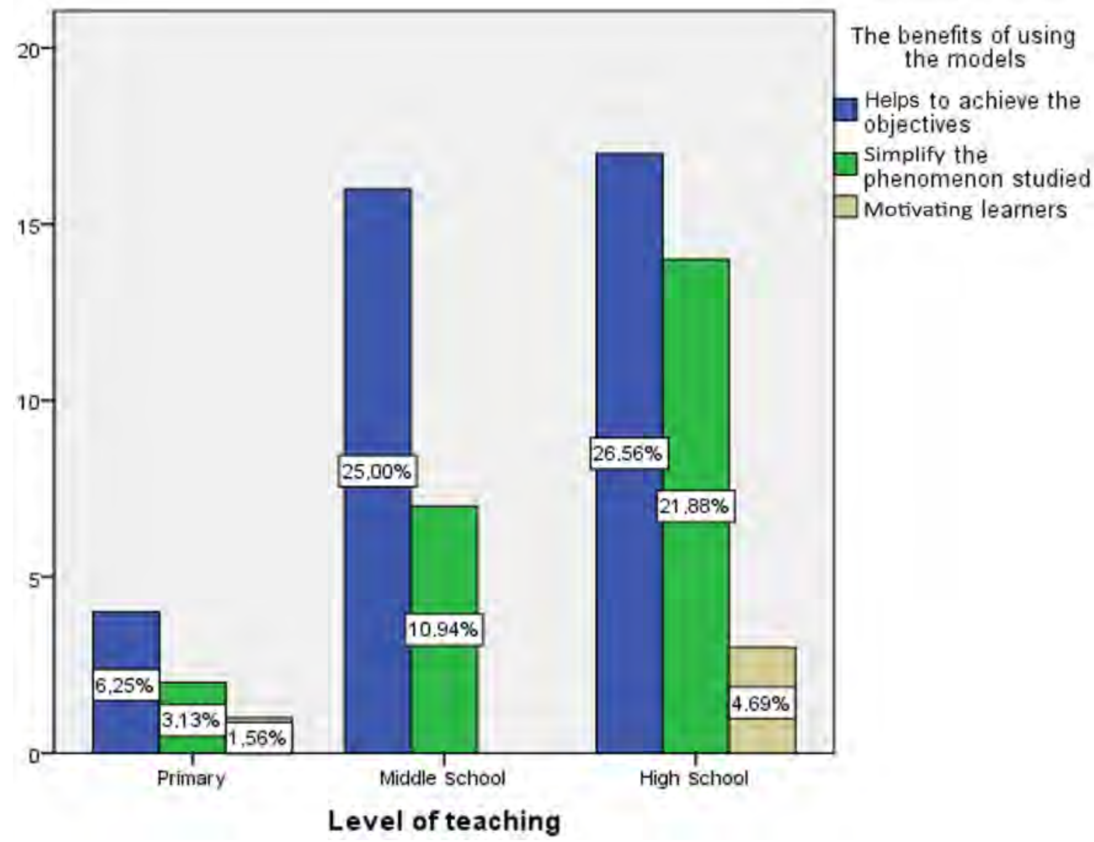

Figure 11. Percentages of teachers according to their statements about the advantages of the models they use.

According to Figure 11, the majority of teachers in all three school cycles expressed that the utilization of models facilitated the attainment of pedagogical objectives and aided in simplifying the studied phenomenon.

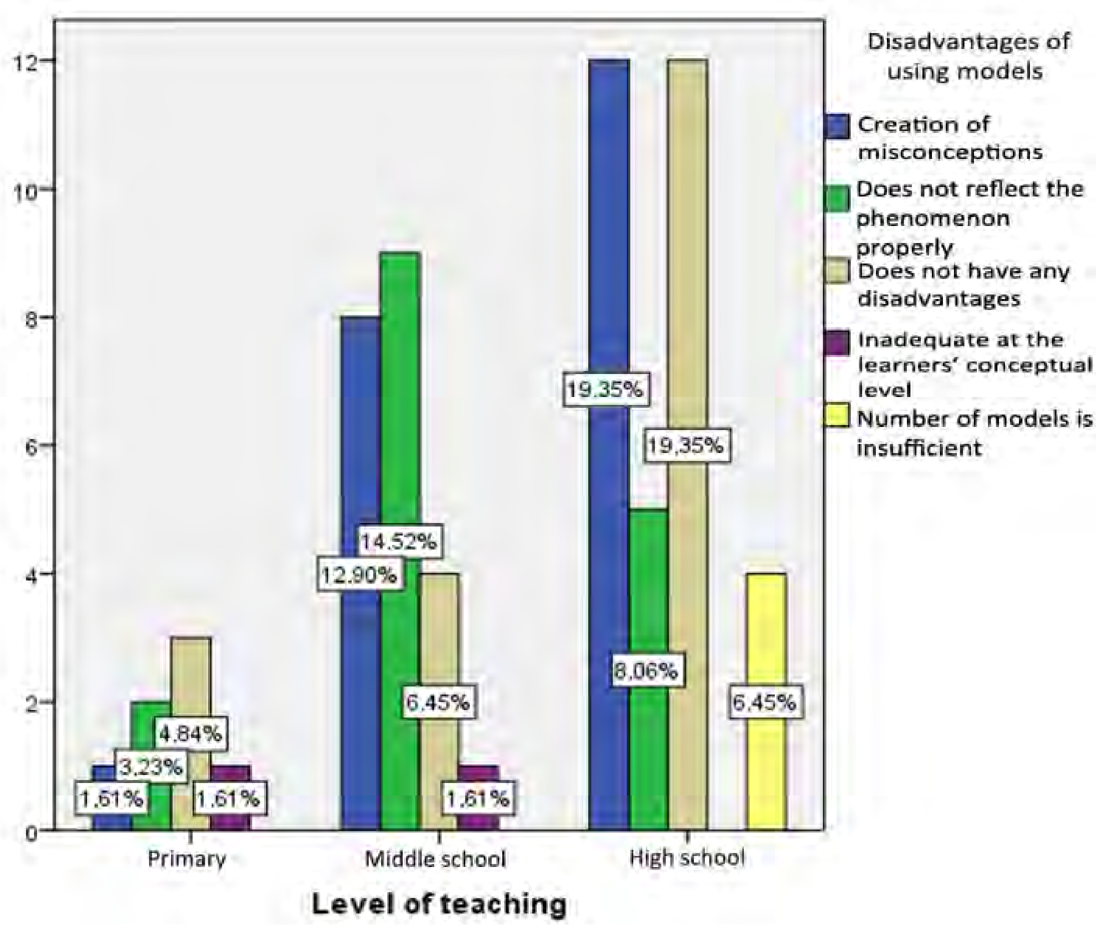

Figure 12. Percentages of teachers according to their statements about the disadvantages of the models they use.

32.25% of secondary school teachers perceive that the use of models can potentially lead to the development of misconceptions among learners or may not accurately represent the studied phenomenon (22.58% of teachers) (Figure 12). On the other hand, other teachers believe that the use of models does not have any disadvantages.

4. Discussion

The primary objective of this research is to investigate the perceptions and instructional practices of Moroccan teachers regarding scientific models in the fields of life and earth sciences based on a sample of teachers. This goal comes from the belief that instructors' conceptions and practices especially those connected to scientific models have an impact on the quality of learning, knowledge acquisition and skill development during the teaching-learning process (Loiola & Tardif, 2001).

Biology and geology are two independent disciplines within the life and earth sciences that are taught in Moroccan schools starting in primary school (Pedagogical Orientations, 2007).

The majority of teachers across all levels acknowledged the modelability of the themes (with the exception of classification of living beings and conservation of health) contrary to recent studies that have highlighted the effectiveness of modeling in the field of biology education (Hu et al., 2019; Pascarella, Guadagno, & Enea, 2022).

This suggests that the teachers in our sample are aware of the predominance of modelling in the subject of geology in contrast to the geological themes where nearly all of them recognised their modelability. Modeling in geology involves the integration and synthesis of knowledge and interpretations (Renard et al., 2019).

The introduction to the Life and Earth Sciences (L&ES) class in the fifth grade introduces experimentation and the cautious use of analogical modelling for geology in the French secondary school curriculum for mathematics, life and earth sciences, physics and chemistry (BO n°6, 19 April 2007). Teachers not only employ models for teaching purely geological topics but they also use models for biological topics related to human and animal physiology as well as genetics. This can be attributed to the lack of experimentation in Moroccan schools due to limited resources, prompting teachers to use models as a substitute for experimentation (Bouzit, Alami, Selmaoui, Zaki, & Agorram, 2020).

Recent academic work on the subject has highlighted the importance of dynamic models, virtual reality and modeling-based learning techniques in enhancing students' biology learning experiences in addition to addressing technological limitations (Lin & Tsai, 2021). These investigations propose that modeling possesses the potential to foster systems thinking and facilitate integrative learning for students (García-Carmona & Acevedo-Díaz, 2021).

The use of models during Life and Earth Sciences (L&ES) sessions aims to simplify the studied concepts and facilitate learning for students aligning with the primary roles of modeling in scientific activity.

However, using a model does not imply considering it an indisputable reference. On the other hand, it is essential to recognize its limitations and subject it to criticism to foster students' critical thinking. Unfortunately, our teachers tend to perceive the critique of models used in teaching life sciences as a practice that is rarely adopted. In contrast, Feixa (2019) defines modeling as a means of challenging students' ideas and encouraging them to think differently leading to the evolution of their conceptions.

In the investigative process, especially during the activity phase, teachers like to employ models. This reflects their awareness that models are an essential pedagogical aid to the SVT teaching-learning process and are often employed with the intention of making science teaching easier and more engaging.

Teachers frequently use modified natural and artificial models that are analogous to the original phenomenon or simplified versions of the studied phenomenon. They frequently present these models numerically using tools like data projectors despite being aware of the potential for misconceptions among learners as a result of the use of inadequate models. These types of models can convey misconceptions to learners because they deviate from reality while life and science are disciplines that draw inspiration from reality. It is crucial for teachers to establish a connection with reality and address the existing distortions between the proposed models and reality itself. The way modeling is approached in the classroom can significantly influence learners' conceptions (Feixa, 2019).

The results of the study indicate that teachers at all levels have similar practices regarding modeling. However, the primary school teachers in our sample demonstrate a good scientific understanding of models. This can be attributed to the fact that primary school teachers are accustomed to using models in teaching and learning situations. They frequently engage in practical and artistic activities such as making crafts. As Wilson et al. (2020) state, "modeling is now an indispensable and non-negotiable component of our teaching".

On the other hand, although secondary school teachers spent more time teaching scientific ideas linked to life and earth sciences than primary school teachers. In this regard, the teachers in our sample strongly support the implementation of modeling in training. They recognize the importance of benefiting from this type of training to effectively teach scientific concepts. These results are consistent with Quebec-based research of secondary school science instructors which indicated the educators' inadequate comprehension of the subjects addressed in the scientific curriculum. Thus, there is a need to establish training mechanisms aimed at developing teachers' professional skills (Roy & Hasni, 2014).

5. Conclusion

In the context of life and earth sciences, it is common practice to use modelling techniques in teaching and learning to bridge the gap between the concrete and the abstract. It is often necessary to simplify complex scientific phenomena to make them accessible to students. In a typical educational setting, models are incorporated into a scientific methodology with the goal of advancing knowledge. Models serve a dual role: a didactic role in terms of their use within a scientific approach and disciplinary cognitive objectives and a pedagogical role in engaging students in active learning.

Moroccan instructors show a propensity for employing models in an investigative method especially when their courses are in the activity phase. This indicates that teachers recognize the significance of models in the teaching of life sciences.

However, it is crucial to identify and critique the limitations of models to foster the development of students' critical thinking skills. Unfortunately, our study revealed that teachers in our sample rarely encourage learners to critique the models used in their sessions. It is crucial to address this issue in the educational environment in order to develop students' critical scientific thinking and provide them with the tools they need to anticipate the future and take action.

Moroccan teachers commonly rely on the use of artificial models that closely resemble the original phenomenon. Learners may perceive these models as reality rather than as simplified representations of reality. Therefore, teachers must guide students in understanding the nature and limitations of such models.

In our study, it was evident that the majority of SVT teachers, particularly those in primary schools, possess a solid understanding of models and their use. However, secondary school teachers showed a basic comprehension of models emphasizing the need for a training programme to improve their knowledge and abilities. This training should focus on clarifying the didactic foundations associated with models and modeling in the updated secondary SVT programs (Roy & Hasni, 2014). Teachers may successfully use the potential of models in the teaching and learning process by receiving comprehensive instruction.

The findings of this study carry significant policy implications for the field of science education in Morocco. The results indicate that Moroccan teachers possess a comprehensive understanding of the importance of models in life sciences instruction and demonstrate consistent approaches to models and modeling practices. These findings highlight the potential benefits of integrating modeling activities into the science curriculum and providing professional development opportunities for teachers, thereby offering a promising strategy for enhancing science education. Policy makers and curriculum developers are encouraged to consider the incorporation of modeling as a central element of the science curriculum while educational institutions should prioritize the provision of training and resources to support teachers in effectively implementing modeling practices.

However, there are certain limitations to this study. Firstly, the reliance on a survey-based methodology introduces potential biases in respondents' answers or a limited depth of understanding. Future research could employ mixed-methods such as classroom observations or interviews to gather more comprehensive data. Additionally, this study focuses on Moroccan teachers which constrain the generalizability of the findings to other educational contexts. It would be beneficial to conduct similar studies in different cultural and geographical settings to investigate potential variations in teachers' perceptions and approaches towards modeling in life sciences instruction.

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