Investigation of Prospective Science Teachers' Grounded Mental Models by Mathematical Algorithms: Star Subject*

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ABSTRACT

In this study, it is aimed to reveal the models related to star subject as one of the concepts of astronomy of prospective science teachers before and after the current instruction through model analysis. This modeling situation is expressed as a Grounded Mental Model (GMM), since there will be a mental modeling that is revealed according to what is presented within the limits defined to the person. The research was conducted with an integrated case study and experimental design. The study group consisted of 73 prospective science teachers. In this study, the Star Subject Concept Test (SSCT) developed by the researchers was used as the data collection tool. In the analysis of the data, algorithms and matrices which are among the model analysis elements were used. At the end of the study, it was determined that the majority of the GMMs they had before teaching about the star concept were in Inconsistent Mixed Models, At the end of the teaching period, it was determined that the majority of the candidates had GMMs reflecting the status of the Consistent Dominant Scientific Model. According to the GMM tendencies of the class, prospective teachers were found to be inconsistent in star identity question group in terms of GMM in pre-test; in the post-test, it was observed that the GMM tendencies of the class of prospective teachers in terms of GMM are highly inclined towards the correct expert model but they exhibit inconsistent status. In the light of the results obtained, suggestions were made to be used to evaluate the current situation before teaching, to examine the effectiveness of different teaching methods, to do workshops on this subject and analysis software development.

Keywords: *Model analysis, mental model, grounded mental model, astronomy education, star, prospective science teacher*

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INTRODUCTION

Astronomy, one of the oldest science, is deeply rooted in almost every culture as a result of its practical and philosophical aspects (Percy, 1998). However, astronomy is still one of the contemporary topics that frequently appear in the media about planets, stars, and space studies, and is of interest to individuals of all ages. In this context, it has become an important issue not only for those who are interested in this profession, but also for science education. This importance is noted by National Research Council [NRC] (2006, p. 56) as follows:

> The process of moving from human wonder at the glory of the night sky to a scientific understanding of the structure and evolution of the universe is a remarkable study, made possible to a significant degree

by insights and inferences generated by spatial thinkers.

In addition, studies conducted in almost every country show that individuals of different age groups have different alternative ideas (such as moon phases, eclipses, life cycle of stars, etc.) about even the most basic astronomical issues (Bostan, 2008). The fact that many of the astronomical concepts such as stars are complex/difficult to learn or abstract, has led to the use of different methods to concretize these concepts (Harman, 2012). Computer-assisted teaching, augmented reality, models are some of the methods that can be used.

It is possible to say that the models are mostly used in order to facilitate the understanding of astronomical subjects and concepts by students, as is the case with many science-based subjects and concepts (Koray, 2021). Models are a simplified representation of a phenomenon, an object or an idea that is studied for a specific purpose (Gilbert, Boulter & Elmer, 2000). According to Lesh and Doerr (2003) the model is a whole of conceptual structures and their external representations to describe or explain complex systems/structures. In summary, although the model definitions made by the researchers are different, it is understood that a model is basically a representation of a target and is frequently used in daily life. These models, which we use to learn, experience or make predictions while speaking (Gilbert & Ireton, 2003).

The models have been classified by different researchers, thus creating limits to the differences between them (Greca & Moreira, 2000; Harrison & Treagust, 2000; Norman, 1983; Ornek, 2008; Philppi, 2010). Ornek (2008) classified models under two headings as mental models (internal representations) and conceptual models (external representations). Accordingly, while conceptual models are defined as external representations that are created by teachers or scientists and facilitate the teaching or understanding of the relationships of the situations or systems in the world (Greca & Moreira, 2000); mental models are expressed as internal representations of real or imaginary situations. Especially because the use of mental models is quite extensive, it has been included in many disciplines and different mental models have been suggested by different researchers. According to Vosniadou and Brewer (1992), mental models (and beliefs) are constraints that arise from the structure of previously acquired knowledge and consequently have an effect on the acquisition of new knowledge. Norman (1983) listed his observations on mental models as follows:

- Mental models are incomplete.
- The use of mental models of individuals is very limited.
- The mental model is not scientific because it reflects the beliefs of the individual regarding phenomena / processes.
- Mental patterns are not fixed.

In the studies of determining the mental models of individuals, methods such as ensuring the recall and repetition of the information that need to be known, ensuring the discovery of the given information, revealing the information depending on the interest, etc. (Ulusoy Taş, 2016). Studies conducted for this purpose are generally focused on written explanations and/or drawings and qualitative analysis is used (eg. Gobert ve Pallant, 2004; Ogan Bekiroğlu, 2007). Then, the data obtained from these data collection tools are subjected to descriptive analysis, which requires expertise in the subject area. That is, by following a qualitative path, mental models of individuals regarding their interpretation are revealed. In this sense, it can be stated that the essence of the painstaking analysis made is based on what comes from the individual - undirected, natural data. However, in the light of the information obtained from the preliminary studies on the concept, it can be said that an analysis of mental models can be made according to the situation of choosing the predefined possible answers. This kind of analysis will be the determination of a mental model with a structure that is pre-grounded (demarcated) with options (Kurnaz, 2022), and the mental models to be revealed in this way will be different from the other analyzes mentioned above, but easy in terms of data source. In this sense, in order to make the teaching environments more efficient, it is important to determine mental models and to obtain them with a grounded structure. In this context, it would be appropriate to refer to it as a 'grounded mental model' since there will be a mental modeling that is created within defined limits, that is, according to what is presented.

Grounded Mental Models

Upon examining the distribution of subject fields of studies dealing with the concept of stars (Ezberci Çevik & Kurnaz, 2016) which is handled in the present studies, it is possible to see that the majority of research studies (%55,3) concern conceptual interpretation (Baloğlu Uğurlu, 2005; Bektaşlı, 2014; Bülbül, İyibil & Şahin, 2013; Cin, 2007; Durukan & Sağlam Arslan, 2013; Göncü & Korur, 2012; Kalkan & Kıroğlu, 2007; Kalkan, Ustabaş & Kalkan, 2007; Kurnaz, 2012; Küçüközer, 2007; Türkoğlu et al., 2009). One can analyse the interpretation of the learner regarding the concept of stars based on an achievement test including multiple-choice questions that are developed well (encompassing all possible answers) using the data from similar studies. In analyses based on achievement tests, answers given to the questions are described as right or wrong; the success level of the student (regardless of the right or wrong selections of choices in other questions) is interpreted on the basis of the entire test. However, the analysis of the "wrong answers" taking the selection of right or wrong answers in other questions into account is also used to be able to reconstruct learning environments. Through this, it might be possible to formulate mental models reflecting various student types besides the classical classification of successful or unsuccessful. What must be underlined here is that the mental model to be designated will be based on the questions and choices presented to the learner. In other words, the process described above is about the examination of one's learning status within the scope of the choices presented to them and, within this framework, the designation of mental models. Therefore, it would be appropriate to name the mental model to be determined on the basis of the interpretation of all the options given in the multiple-choice questions prepared in accordance with the academic literature as GMM (Grounded Mental Model).

Developing tests to be used to designate the GMM is different from employing achievement tests focusing on conceptual comprehension. It is not about compiling a random set of multiple-choice questions. Multiple-choice questions must encompass the network of relationships about the target concept and reflect all potential interpretations –and all alternative ideas if available– without any limit. To develop such a data collection tool, it might be necessary to use methods like interviews and homework assignments in addition to a comprehensive literature review. Even though this process, requiring intensive endeavours, demands expertise, the application and analysis of a test to be developed regarding a certain concept would be easier and more evident when compared with other efforts to designate mental models. Thus, it becomes possible to define GMMs of learners through tests developed by experts, leading to significant advantages for all stakeholders, particularly teachers (Kurnaz, 2022). The ease of defining the GMM with a prepared test might also lay the ground for evaluating the GMMs of all students in a classroom with a holistic point of view and understanding the needs of the learning environment whenever necessary. To this end, the model analysis method developed by Bao (1999) can be inspired. Model analysis is a method developing algorithms to obtain a quantitative evaluation of mental model conditions and, therefore, revealing clear information on the model states of students provides the researcher by analysing student data quantitatively through multiple-choice questions. The determination of GMM in the present study differs from the Bao (1999) approach. In the model analysis method developed by Bao, the individual is considered to be an object by the modeller and interpreted accordingly. This means that there is an external approach to the individual. However, if the fact that the individual chooses their answers through interpretations based on their mental structures is taken into account, it can be said regarding the concept in question that the selection of answers reflects the individual interpretation of the concept in one's mind or the closest interpretation. This signifies the search of the right answer by the student among the given alternatives as well as the designation of the answer that is closest to the right one. In other words, in the analysis, the individual is considered to be a subject, leading to a similar and internal-oriented approach in the modelling. As noted above, inner representations are indicated by mental models (Örnek, 2008). Student-oriented GMM designation tests allow one to give the answer closest to one's mentality as the choices in such a test include all the potential learning outcomes.

Initial Studies about the Stars

Considering the importance of stars and star formation in our history and the evolution of the Universe as a whole, it should not be surprising that stars are seen as one of the main topics in the field of astronomy

(Bailey, 2006). Sadler (1992) is one of the pioneers of important studies on the star topics. He then explained the development and analysis of the Project STAR Astronomy Concept Inventory, a revised version of the scale used in his dissertation (Sadler 1998). A version of the Project STAR scale has been applied to more than 2,500 students and detailed results are obtained for the day-night cycle, seasons, and a model for the Sun and a nearby star (Bailey & Slater, 2004). Another important work was done by Neil Comins (2001) and he stated that undergraduate students had some misconceptions about stars in his Heavenly Errors book and gave examples to them. For instance, Neil Comins (2001) reported that some students hold the belief that the 'Sun is not a star'. In this context, the importance of teaching the concept of stars has started to increase.

In terms of the concept of the star underlying curriculum in schools in Turkey, primarily elementary school students make simple observations about the Sun, Earth and Moon (Ministry of National Education [MNE], 2018a). The concept of the 'star', which started teaching at the fifth grade level with the structure and features of the Sun, is taken one step further at the seventh grade level with the formation process of the star (MNE, 2018b), and in the elective course in secondary education (MNE, 2018c), at the university level, it is explained with its more micro-scale content. For prospective teachers in Turkey, 'Astronomy' course is located within the Faculty of Education in Science Education program. The two-credit course content is described below (Council of Higher Education [CHE], 2018, pp. 11):

> Meaning of astronomy, basic concepts, units in astronomy; branches of astronomy, historical development; contributions of different civilizations to astronomy, tools used in astronomy; Solar system, solar system models from past to present, earth, moon and movement of the sun; Keppler laws, time-calendar-seasons, solar system elements, stars, sun as a star, sky coordinate system, constellations, galaxies, milky way galaxy, universe and structure of the universe, formation of the universe and models of the universe from the past, space technologies and their reflections on daily life form.

In the related literature, there are studies with different purposes and qualities in the field of astronomy, especially when these studies in the national literature are examined, it is stated that the concepts/subjects of 'basic astronomy concepts' and 'Solar system and space' are among the focused astronomy concepts/subjects (Kurnaz, Bozdemir, Altunoğlu and Ezberci Çevik, 2016). In the same study, it was found that the concept of 'star' was examined on the basis of only two studies. In this context, it can be said that sufficient studies have not been done especially for the concept of star. However, it is important that the star, which is the most encountered concept in daily life, is adopted by the students. Bailey (2006) stated that just as the cell is the basic unit of biology, the star would be considered as a basic object in the Universe. The first point is that this concept is given to students in primary education level in a scientific way, and the second is to train teachers who will teach these concepts to know the subject well. In this context, it is thought that the perceptions of prospective teachers on this subject should be examined.

Significance of the Research

Multiple-choice tests seem to be a frequently-used quantitative assessment method as far as the evaluation of learning among students in the classroom setting is concerned. Such data collection tools generally constitute a significant part of a student's grade (Mavis, Cole, & Hoppe, 2001). Here, student performance is traditionally measured using the score obtained from the test concerned. When the student has a lower score, usually in preliminary tests (or in post-tests following inefficient teaching), the fact that the majority of students got the wrong answer is not reflected in the scores. In cases where multiple-choice tests are poorly structured and not used on appropriate occasions, they might be largely misleading due to the nature of the knowledge. This because the scoring method converts a significant idea within any item into a value equivalent to any other options (Biggs, 1999). While preparing multiple-choice tests, the possibility of a student to answer a question regarding the sub-concept X (e.g. brightness of the star) correctly while giving the wrong answer to another question about the sub-concept Y (e.g. radiation of the star) using their knowledge on X must be taken into account. In an analysis in which the questions are only coded as right or wrong, the student will be considered to be knowledgeable of the concept X. However, when wrong answers are analysed with the right ones, i.e. when mental models reflecting perceptions regarding different concepts are put forward, valuable clues might be revealed for educators to develop teaching strategies. The significance of mental models in teaching processes is underlined in various research studies (Lin & Chiu, 2007; Rapp, 2005; Shen, Tan & Siau, 2017; Syrmpas, Chen, Pasco & Digelidis, 2019). One of the approaches followed in the present study argues that mental models can be determined through well-structured multiple-choice questions. Fundamentally, one needs to have suitable models regarding the learning process, mathematical tools to process data, and the means to extract the necessary information to do so. In this sense, multiple-choice tests might be markedly effective if they are designed in a way that enables the analysis of wrong answers as well. Model analysis is required to achieve this end. Through the holistic examination of the right and wrong answers in a multiple-choice test using model analysis, it is possible to develop algorithms based on the numerical analysis of student data, these algorithms can be used to evaluate the conditions of GMMs. Therefore, GMMs can provide clear information that one might use to define the needs of the learning environment and to formulate teaching strategies for the entire class or a single student. As an example of the process defined here is demonstrated in the present study, it is deemed significant within the scope of the study.

The designation of the GMMs of students through multiple-choice questions displays the fundamental significance of this study. Furthermore, the selection of the concept of stars, a subject handled in research studies on science education to a limited extent, also renders the present study important. The study is expected to make considerable contributions to the academic literature as it guides the researcher in the determination of the current state regarding the concept of starts and the designation of teaching objectives. In this respect, the study aims to reveal the GMMs of senior-year prospective science teachers before and after the existing teaching process regarding stars, an astronomical concept, through the method of model analysis. For this purpose of the study, answers to the following sub-problems were sought:

- What are the prospective science teachers' GMMs based on the identity of the star, the structure of the star and the life cycle of the star before and after the instruction?
- What are the prospective science teachers' GMMs based on the star concept before and
- What are the GMM tendencies of the class regarding the identity of the star, the structure of the star and the life cycle of the star before and after the instruction?

RESEARCH METHOD

Research Model

Case study and experimental design integrated with each other were used in the research. Although the specified methods appear separate, the methods are intertwined using data derived from specific methodologies (Didiş, 2012). When the researcher wants to explore in depth why the situation is different from the others, she/he will use the case study. Within the scope of the present study, grounded mental models were handled, and a case study was applied to find an answer to the question of "What are the mental models of prospective science teachers based on the concept of star?" and to investigate the factors related to this situation (prospective teachers) with a holistic approach. In addition, a single group pre-test-post-test experimental design was used to analyze the GMMs of the students before and after the instruction.

Participants

The study group of the study consists of 73 prospective teachers who are studying in the Science Education Department of a university in the Western Black Sea Region in the last year. The purposeful sampling method was used in the formation of the study group, and the triangulation technique was used while determining the sampling types. In this sense, different types of sampling were used. In this context, criteria sampling and easily accessible sampling were used. As the criterion sampling, fourth grade prospective science teachers who took the astronomy course for the first time at the undergraduate level were taken as the basis; as an easily accessible sample, in order to provide convenience in terms of transportation and cost, the fourth grade prospective teachers from the institution where the researchers work were included in the study group. In the study, the names of the students were not used, they were specified as S1, S2, ..., S73.

Data Collection Tool

Star Subject Concept Test (SSCT), which consists of 26 questions with five options, was used as a data collection tool in the study (Ezberci Çevik, 2018). SSCT is a test consists of multiple choice questions that reflect the participants' possible learning statuses. There are three groups of questions in the SSCT: 'Identity of the Star', 'The Structure of the Star' and 'The Star's Life Cycle'. There are 9 questions in the identity of the star question group, 11 questions in the structure of the star question group, and 6 questions in the life cycle of the star question group.

The average item difficulty and discrimination indices of the test were 0.37 and 0.39, respectively; Cronbach α reliability coefficient was calculated as 0.748. An example question is given below (Ezberci Çevik, 2018):

Which of the following is one of the properties of stars?

a. It is solid.

b. It reflects the light received from the sun.

c. It can be seen during the day.

d. Their colors are the same.

e. Their temperatures are the same.

Data Collection Process and Contextual Background

Participating prospective teachers take an astronomy course on basic astronomy concepts for one semester. Before instruction, the participants are faced with smattering about the definition of stars and some of their basic features in their previous learning. In other words, the participants encounter in-depth knowledge of astronomy concepts in the astronomy course. At the beginning of instruction, SSCT was applied to the prospective teachers. Within the scope of the astronomy course, a period of three weeks is allocated to the subject of stars, 2 hours per week. In this process, the definition, characteristics and life cycle of the star are discussed in detail under general titles. The courses were conducted by the lecturer in the usual procedure. After the instruction, the same scale was applied to prospective teachers and the data were collected. The prospective teachers were given 30 minutes to answer the scale in the pre and post test. Before statistical analyzes, it was examined whether the scale was filled in completely by prospective teachers, and analyzes were carried out on 73 scales that were found to have no missing data.

Data Analysis

In the analysis of the data, matrices were used to analyze the structural information of individual student responses and to obtain a quantitative evaluation of answer states containing detailed information on students using the mixed state (if any). Then, GMM tendencies of the class were created according to the student responses obtained from three different question groups. The analysis process is explained below in order.Answers usually consists of a correct answer, an incorrect answer(s), and a null answer(s). These categories were created inspiring the Bao (1999) classification.

Table 1. *Classification Answers for a Question*

Scientific answer	Correct answer
Incorrect answer	Answer(s) with alternative ideas
Null answer	Other irrelevant ideas/incomplete answers

In the present study, answers were defined in all three question groups, and the results created for the "life cycle of the star" is given as an example below.

Table 2. *Quality of Student Responses of the "Life Cycle of the Star" Question Group*

Questions	Scientific	Incorrect	Null
2	C	A, B, D	E
13	A	D, E	B, C
14	B	A, C, D, E	
16	E	A, B, D	C
19	E	A, B, C, D	

Scientific: Each star has a specific life cycle.

Incorrect: Not every star has a specific life cycle.

Null: Irrelevant ideas/incomplete answers

This matrix holds structural information on individual student responses in terms of different qualities. For this, the answers of each student regarding each question should be matched by the basic vectors (*i, scientific; j, alternative idea; k, null-unrelated*). That is, each student's answer for each question can be matched by one of the fundamental vectors (i, j and k). For example, if a student answered five questions as incorrect, scientific, incorrect, scientific and null "a", "c", "d", "b", and "b", these five answers are translated to vectors as $(010)^T$, $(100)^T$, $(010)^T$, $(100)^T$ and $(001)^T$ respectively. The five vectors are then summed up to get the full response vector for the student, which in this case found to be $(221)^T$. Response vector of student k^{th} is defined as C_k, and C_k is specified as follows (Kurnaz, 2022).

$$C_k = \begin{pmatrix} \sqrt{i} \\ \sqrt{j} \\ \sqrt{k} \end{pmatrix}$$

The resultant vector of the whole question group is determined as follows.

$$C_k = \frac{1}{\sqrt{ss}} \cdot \begin{pmatrix} \sqrt{x} \\ \sqrt{y} \\ \sqrt{z} \end{pmatrix}$$

Here, ss indicates the total number of questions answered in the question group and is determined in relation to the unit vector length. In this way, a single student grounded mental model density matrix of k^{th} student can be created with the formula below.

$$D_k = \frac{1}{ss} \begin{bmatrix} x & \sqrt{xy} & \sqrt{xz} \\ \sqrt{yx} & y & \sqrt{yz} \\ \sqrt{zx} & \sqrt{zy} & z \end{bmatrix}$$

Within the scope of the present study, using the relevant formulas, prospective teachers' GMM status were interpreted. As an example, based on the answers given by the S1 student to the pre-test and post-test in the "identity of the star" question group, how the student's determined GMM status is calculated is presented below.

Table 3. *GMM Status of S1 Student's "Star İdentity" Question Group*

Student	Related situation	pre-test	post-test
S1	Total response	(252)	(720)
	Response vector	$\frac{1}{3}\begin{pmatrix}\sqrt{2}\\ \sqrt{5}\\ \sqrt{2}\end{pmatrix}$	$\frac{1}{3}\begin{pmatrix}\sqrt{7}\\ \sqrt{2}\\ 0\end{pmatrix}$
	GMM Density matrix	$\frac{1}{9}\begin{bmatrix}2 & \sqrt{10} & 2\\ \sqrt{10} & 5 & \sqrt{10}\\ 2 & \sqrt{10} & 2\end{bmatrix}$	$\frac{1}{9}\begin{bmatrix}7 & \sqrt{14} & 0\\ \sqrt{14} & 2 & 0\\ 0 & 0 & 0\end{bmatrix}$
	GMM status	Inconsistent Mixed Model	Consistent-Scientific Expert Model

At the end of this stage, individual GMM status of students can be revealed. Based on the categorization of the GMMs to be determined for each student separately, GMM tendencies can be determined for a group of students (class, school, or more general) if desired. For this, it is necessary to create the density matrix of the target group. The point to be noted here is that GMM belonging to a group cannot be mentioned. For this reason, GMM is mentioned individually and 'GMM tendency' is mentioned for a group (Kurnaz, 2022).

The class tendency of GMM (D) is given below.

$$D = \left(\frac{1}{N}\right)\sum_{k=1}^{N} D_k$$

The matrices mentioned here can be in different forms. In the current study, based on the D_k matrix, the following classifications are discussed (Vadnere & Joshi, 2009) in order to understand the students GMMs and what the classroom density matrix tells us.

Individual Student GMMs

Consistent Scientific Expert Model: Used when continuity is shown in different questions on the same concept. The first diagonal element (a_{11}) must be larger than the other diagonal elements and the non-diagonal elements must be nearly zero.

Consistent-Non-Scientific Expert Model: Used when continuity is shown in different questions on the same concept. The second diagonal elements (a_{22}) must be larger than the other diagonal elements and the non-diagonal elements must be nearly zero.

Null Model: It is used in situations that lead students to give random answers. The third diagonal elements (a_{33}) must be larger than the other diagonal elements, and the non-diagonal elements should be nearly zero.

Inconsistent Mixed Model: Occurs when students use multiple models inconsistently (eg. using scientific and non-scientific models for different questions on the same concept). Non-diagonal elements must be relatively greater than zero.

Class GMM Tendency

Consistent One-Tendency: Almost all students in the classroom use the same physical model (not necessarily the right one), and when they are consistently consistent in using it, this is called a consistent one-model.

Consistent Mixed Tendency: Students in the classroom have several different physical models, but each student has only one physical model and is consistent about it.

Inconsistent Mixed Tendency: If students in the classroom have different physical models and are not consistent in using these models, this indicates an inconsistent mixed model.

Examples of the specified tendencies are presented in Figure 1.

Consistent One-Tendency (a)	Consistent Mixed Tendency (b)	Inconsistent Mixed Tendency (c)
$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$	$D = \frac{1}{100}\begin{bmatrix} 60 & 0 & 0 \\ 0 & 30 & 0 \\ 0 & 0 & 10 \end{bmatrix} = \begin{bmatrix} 0,6 & 0 & 0 \\ 0 & 0,3 & 0 \\ 0 & 0 & 0,1 \end{bmatrix}$	$D = \begin{bmatrix} 0,60 & 0,27 & 0,21 \\ 0,27 & 0,30 & 0,14 \\ 0,21 & 0,14 & 0,10 \end{bmatrix}$

Figure 1. *Examples of the Specified Tendencies*

As seen in Figure 1, the matrices mentioned here have different forms. In a square matrix, if all the elements other than the elements on the prime diagonal are zero, this matrix is called a diagonal matrix. If most of the students favor a consistent tendency, one of the diagonal elements will be larger than the other diagonal elements, and the non-diagonals will be nearly zero (a). If individual students continue to use their GMMs but different students have different GMMs, the non-diagonal elements will still be zero (b). If a significant number of students are inconsistent, the non-diagonal elements will be relatively greater than zero (c). In this context, diagonal elements give the distribution of the probability of students to use different tendencies; non-diagonal elements show students' consistency in using their GMMs. In the current study, class GMM tendencies were also created according to the student responses obtained from three different question groups regarding the star concept by using the formulas specified.

FINDINGS

GMM Statuses of Prospective Teachers

The GMM states created in line with the results obtained from the individual model density matrix of prospective teachers before and after the instruction are presented below. First of all, GMM status determined for the identity of the star are included in Table 4.

Table 4. *GMM Statuses of Prospective Teachers For the Identity of Star*

Prospective Teacher	Identity of the Star							
	pre-test				post-test			
	CSEM	CNSEM	NM	IMM	CSEM	CNSEM	NM	IMM
S1				✓	✓			
S2				✓				✓
S3				✓	✓			
S4				✓				✓
S5		✓			✓			
S6				✓	✓			
S7				✓				✓
S8				✓	✓			
S9				✓	✓			
S10		✓			✓			
S11				✓				✓
S12				✓	✓			
S13		✓			✓			
S14		✓			✓			
S15				✓				✓
S16				✓				✓
S17				✓				✓
S18				✓	✓			
S19				✓	✓			
S20				✓				✓
S21				✓	✓			
S22		✓			✓			
S23				✓	✓			

S24				✓				✓
S25				✓				✓
S26				✓	✓			
S27				✓	✓			
S28				✓	✓			
S29				✓	✓			
S30				✓				✓
S31				✓	✓			
S32				✓				✓
S33				✓				✓
S34				✓				✓
S35		✓						✓
S36				✓				✓
S37		✓						✓
S38				✓	✓			
S39				✓				✓
S40				✓				✓
S41				✓	✓			
S42				✓	✓			
S43		✓						✓
S44				✓	✓			
S45				✓	✓			
S46				✓				✓
S47		✓						✓
S48				✓				✓
S49				✓				✓
S50				✓				✓
S51				✓		✓		
S52				✓				✓
S53				✓				✓
S54				✓	✓			
S55				✓				✓
S56				✓				✓
S57				✓	✓			
S58				✓				✓
S59				✓		✓		
S60				✓	✓			
S61				✓	✓			
S62				✓	✓			
S63				✓	✓			
S64		✓						✓
S65				✓	✓			
S66				✓				✓
S67				✓				✓
S68				✓	✓			
S69		✓			✓			
S70				✓	✓			
S71				✓	✓			
S72				✓	✓			
S73				✓	✓			

CSEM: Consistent Scientific Expert Model; CNSEM: Consistent-Non-Scientific Expert Model; NM: Null Model; IMM: Insonsistent Mixed Model

Considering the GMMs of the prospective teachers in Table 4, it is seen that the prospective teachers who were in IMM status before instruction regarding the identity of the star were the most. In addition, it is understood that 11 prospective teachers' GMMs before instruction are CNSEM. When the situation after the education regarding the identity of the star is examined, it is seen that there is a transition from IMM to CSEM and approximately half of the prospective teachers (n=38) are in favor of the scientifically correct model. In addition, it can be said that 33 prospective teachers are in IMM status after instruction and 2 prospective teachers (S51 and S59) are in CNSEM status, while it can be said that there are no teacher candidates in NM status.

GMM status determined for the structure of the star are included in Table 5.

Table 5. *GMM Statuses of Prospective Teachers For the Structure of Star*

Prospective Teacher	Structure of the Star							
	pre-test				post-test			
	CSEM	CNSEM	NM	IMM	CSEM	CNSEM	NM	IMM
S1				✓				✓
S2				✓				✓
S3				✓				✓
S4				✓				✓
S5				✓				✓
S6				✓	✓			
S7	✓				✓			
S8	✓				✓			
S9				✓				✓
S10		✓			✓			
S11				✓	✓			
S12				✓				✓
S13				✓	✓			
S14				✓	✓			
S15				✓	✓			
S16	✓							✓
S17	✓							✓
S18	✓				✓			
S19				✓	✓			
S20				✓	✓			
S21				✓	✓			
S22		✓						✓
S23		✓			✓			
S24				✓	✓			
S25				✓	✓			
S26				✓	✓			
S27				✓	✓			
S28		✓			✓			
S29				✓	✓			
S30				✓	✓			
S31				✓				✓
S32		✓			✓			
S33				✓	✓			
S34				✓	✓			
S35				✓	✓			
S36				✓	✓			
S37				✓				✓
S38				✓	✓			
S39				✓				✓
S40				✓				✓
S41				✓	✓			
S42				✓	✓			
S43				✓	✓			
S44				✓				✓
S45		✓			✓			
S46				✓	✓			
S47				✓				✓
S48		✓			✓			
S49				✓	✓			
S50				✓				✓

S51				✓				✓
S52		✓						✓
S53		✓						✓
S54		✓			✓			
S55		✓			✓			
S56				✓	✓			
S57		✓			✓			
S58				✓	✓			
S59				✓				✓
S60				✓	✓			
S61				✓	✓			
S62				✓				✓
S63				✓	✓			
S64				✓				✓
S65				✓	✓			
S66				✓	✓			
S67				✓				✓
S68				✓				✓
S69				✓				✓
S70				✓				✓
S71				✓				✓
S72				✓	✓			
S73				✓				✓

CSEM: Consistent Scientific Expert Model; CNSEM: Consistent-Non-Scientific Expert Model; NM: Null Model; IMM: Insonsistent Mixed Model

Considering the GMMs of the prospective teachers have regarding the structure of the star before instruction, it can be stated that the majority of the prospective teachers are in IMM status. In addition, it is understood that 12 prospective teachers were CNSEM in terms of GMM before instruction, while five prospective teachers (S7, S8, S16, S17 and S18) were CSEM. When the status after the instruction regarding the structure of the star is examined, it is understood that 44 prospective teachers are in the status of CSEM and in this sense they have scientifically correct information about the structure of the star. As can be seen from Table 4, there are no prospective teachers in the status of CNSEM and NM. However, it is also seen that some prospective teachers' GMMs after the instruction continue as IMM. In the related example, it is seen that the S69 prospective teacher is in the IMM state in the pretest and similarly in the posttest. The resolved sample of the matrix of GMM status of S69 reflecting this status is given below.

pre-test	post-test
$\begin{bmatrix} 0,36 & 0,41 & 0,26 \\ 0,41 & 0,45 & 0,29 \\ 0,26 & 0,29 & 0,18 \end{bmatrix}$	$\begin{bmatrix} 0,55 & 0,39 & 0,31 \\ 0,39 & 0,27 & 0,22 \\ 0,31 & 0,22 & 0,18 \end{bmatrix}$

GMM status determined for the life cycle of the star are included in Table 6.

Table 6. *GMM Statuses of Prospective Teachers For the Life Cycle of Star*

Prospective Teacher	Life Cycle of the Star							
	pre-test				post-test			
	CSEM	CNSEM	NM	IMM	CSEM	CNSEM	NM	IMM
S1		✓			✓			
S2		✓						✓
S3				✓				✓
S4				✓	✓			
S5				✓	✓			
S6				✓				✓
S7				✓	✓			
S8				✓	✓			
S9				✓	✓			

S10			✓	✓	
S11			✓	✓	
S12			✓	✓	
S13		✓		✓	
S14		✓		✓	
S15			✓	✓	
S16			✓	✓	
S17			✓	✓	
S18			✓	✓	
S19	✓				✓
S20			✓	✓	
S21			✓	✓	
S22			✓		✓
S23		✓		✓	
S24		✓			✓
S25			✓		✓
S26			✓	✓	
S27		✓		✓	
S28			✓	✓	
S29			✓	✓	
S30			✓	✓	
S31			✓	✓	
S32		✓		✓	
S33			✓	✓	
S34			✓	✓	
S35		✓		✓	
S36			✓	✓	
S37			✓		✓
S38			✓	✓	
S39			✓	✓	
S40			✓	✓	
S41			✓	✓	
S42			✓	✓	
S43			✓	✓	
S44			✓	✓	
S45		✓		✓	
S46			✓	✓	
S47			✓	✓	
S48			✓	✓	
S49		✓		✓	
S50			✓	✓	
S51			✓	✓	
S52			✓	✓	
S53			✓	✓	
S54		✓		✓	
S55			✓	✓	
S56			✓	✓	
S57			✓	✓	
S58			✓	✓	
S59			✓	✓	
S60		✓		✓	
S61			✓	✓	
S62			✓	✓	
S63			✓	✓	
S64			✓		✓
S65		✓		✓	
S66			✓	✓	
S67			✓	✓	

S68		✓	✓
S69	✓		✓
S70	✓		✓
S71	✓		✓
S72		✓	✓
S73		✓	✓

CSEM: Consistent Scientific Expert Model; CNSEM: Consistent-Non-Scientific Expert Model; NM: Null Model; IMM: Insonsistent Mixed Model

Considering the GMMs of the prospective teachers have regarding the life cycle of the star before instruction, it is seen that most of the prospective teachers are in IMM status. In addition, it is noteworthy that while 17 prospective teachers were CNSEM in terms of GMM before instruction, only one prospective teacher (S19) was in CSEM status. When the status after the instruction regarding the life cycle of the star is examined, it is seen that all of the prospective teachers (N=64) except nine prospective teachers (those in IMM status) are in CSEM status. This status indicates that prospective teachers show good results at the end of the instruction regarding the life cycle of the star. The resolved sample of the matrix of GMM status of S49 is given below. It is seen that S49 prospective teacher is in CSEM status at the end of the instruction.

pre-test	post-test
$\begin{bmatrix} 0{,}20 & 0{,}40 & 0{,}00 \\ 0{,}40 & 0{,}80 & 0{,}00 \\ 0{,}00 & 0{,}00 & 0{,}00 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

In general, it is seen that the GMMs of individual prospective teachers before instruction regarding the "star" concept are in favor of IMM. For the GMM status related to the star concept after instruction, it can be stated that most of the prospective teachers have GMMs reflecting the CSEM status. On the contrary, it is also understood that some prospective teachers (S2, S37 and S64) have GMMs after instruction in IMM status.

Class GMM Tendency

The grounded mental model density matrix is in different forms including different types of model statuses, and Table 7 includes the pre-test and post-test GMM tendency of the class for the star identity question group.

Table 7. *Pre-test and Post-test GMM Tendency of the Class of the Star Identity Question Group*

Identity of the star	
pre-test	post-test
$\begin{bmatrix} 0{,}01 & 0{,}01 & 0{,}01 \\ 0{,}01 & 0{,}02 & 0{,}01 \\ 0{,}01 & 0{,}01 & 0{,}01 \end{bmatrix}$	$\begin{bmatrix} 0{,}61 & 0{,}45 & 0{,}04 \\ 0{,}45 & 0{,}37 & 0{,}04 \\ 0{,}04 & 0{,}04 & 0{,}03 \end{bmatrix}$

When Table 7 is examined, it is understood that many prospective teachers in the class have many tendencies in terms of GMM (mixed model status) and they are inconsistent in using them. This shows that before instruction, most of the prospective teachers in the class consistently used the incorrect model in the questions about the star's identity. Looking at the class GMM tendency obtained from the post-test for the identity of the star after instruction (see Table 7), the model status of the classroom in terms of GMM shows that the prospective teachers are highly inclined towards the correct expert model (0.61), while the probability of being in favor of the incorrect model and in favor of the null model is (0.37) and (0.03), respectively.

The pre-test and post-test GMM tendency of the class for the star structure question group is presented in Table 8.

Table 8. *Pre-test and Post-test GMM Tendency of the Class of the Structure of Star Question Group*

Structure of the star	
pre-test	post-test
$\begin{bmatrix} 0{,}26 & 0{,}35 & 0{,}13 \\ 0{,}35 & 0{,}64 & 0{,}22 \\ 0{,}13 & 0{,}22 & 0{,}11 \end{bmatrix}$	$\begin{bmatrix} 0{,}70 & 0{,}38 & 0{,}08 \\ 0{,}38 & 0{,}26 & 0{,}05 \\ 0{,}08 & 0{,}05 & 0{,}03 \end{bmatrix}$

When Table 8 is examined, it is stated that in the pre-test, most of the prospective teachers in the class constantly used the incorrect model regarding the questions about the structure of the star, and their GMMs were close to this tendency. In addition, it is understood that prospective teachers are not consistent in using only one model, indicating the mixed model status. Looking at the class tendency obtained from the post-test for the structure of the star after instruction (see Table 8), it is seen that the prospective teachers of the GMM status of the class are quite inclined to the correct expert model (0.70). However, this does not indicate that the entire class has the same physical model.

Table 9 contains the pre-test and post-test GMM tendency of the class for the star's life cycle question group.

Tablo 9. *Pre-test and Post-test GMM Tendency of the Class of the Star's Life Cycle Question Group*

Life cycle of the star	
pre-test	post-test
$\begin{bmatrix} 0{,}34 & 0{,}35 & 0{,}11 \\ 0{,}35 & 0{,}55 & 0{,}17 \\ 0{,}11 & 0{,}17 & 0{,}11 \end{bmatrix}$	$\begin{bmatrix} 0{,}90 & 0{,}17 & 0{,}01 \\ 0{,}17 & 0{,}10 & 0{,}01 \\ 0{,}01 & 0{,}01 & 0{,}01 \end{bmatrix}$

When Table 9 is examined, it is seen that prospective teachers are tend to use the incorrect tendency in terms of GMM regarding the five questions related to the life cycle of the star in the pre-test. In addition, it is understood that prospective teachers are not consistent in using this model, and many prospective teachers have many physical models. Looking at the class GMM tendency obtained from the post-test for the life cycle of the star after instruction (see Table 9), it shows that prospective teachers are highly inclined to use the correct expert model. It is understood that almost all of the prospective teachers in the class have their GMM tendencies related to the life cycle of the star for the same physical model, but the probability of being in the incorrect model state is (0.10) and the probability of being in the null model state (0.01) (all other elements are close to zero). . In this sense, it can be said that prospective teachers' modeling statuses for the life cycle of the star are close to a consistent model.

DISCUSSION AND CONCLUSION

Considering the general results obtained from the current study, which aimed to reveal the models related to star subject as one of the concepts of astronomy of prospective science teachers before and after the current instruction through model analysis, it was determined that the majority of the GMMs they had before teaching about the star concept were in Inconsistent Mixed Models, At the end of the teaching period, it was determined that the majority of the candidates had GMMs reflecting the status of the Consistent Dominant Scientific Model. According to the class GMM tendency, prospective teachers were found to be inconsistent in star identity question group in terms of GMM in pre-test; in the post-test, it was observed that the model status of the class of prospective teachers in terms of GMM are highly inclined towards the correct expert model but they exhibit inconsistent status.

It uncovers the GMMs of prospective science teachers in their final year of studies regarding the astronomical concept of starts before and after instruction using model analysis. Initially, the GMM conditions of each prospective teacher were revealed based on the results obtained from their individual model density matrices. At the end of this step, the majority of the prospective teachers were found to have their GMMs regarding the concept of stars in the IMM before instruction. This shows that before the instruction, prospective teachers have scientific and non-scientific ideas about stars and that they are inconsistent in the use of these ideas. The formulation of each option in a way reflecting the thoughts of prospective teachers allowed the discovery of GMMs at the end of the analysis. In this respect, the GMMs of prospective teachers before and after the instruction showed both similarities and differences; the majority, however, was the teachers categorised under the title of the mixed model. The knowledge obtained at school, cultural values, and personal experiences were found to affect the formation of the mental structures of students regarding a certain concept (Vosniadou & Brewer, 1992, 1994). In this sense, it is possible to say that the GMMs of prospective teachers vary due to these individual differences. A study by İyibil (2010) shows that among memorising, relational, and inconsistent models, the majority of prospective teachers show the features of the inconsistent model signifying non-scientific answers regarding the concept of stars. Another study by Vosniadou (1991) indicates that students believe that stars, just like the Moon, get their brightness from the Sun, naming this as the synthesis model. One might say that the model proposed by Vosniadou and Brewer (1992) is compatible with the mixed model included in the present study; they define synthesis models as the method in which candidates integrate the scientific knowledge they acquired through education with their experiences. The present study demonstrated that the analysis of the GMM conditions of each prospective teacher shows most of the candidates display GMMs in the CSEM status. In this respect, the current education system might be deemed effective in the development of mental models of prospective teachers. One might indicate that this analysis reflecting the individual conditions of prospective teachers is useful for designating the status of prospective teachers in the classroom setting as far as their individual learning is concerned.

The individual model density matrices of prospective teachers were used to formulate the class tendency, revealing the preliminary test and post-test matrices for each question group. In the end, it was revealed that in the preliminary test concerning the star identity question group, prospective teachers displayed the features of several physical models in terms of GMM (the status of mixed models) and are inconsistent as far as the use of these models is concerned; the analysis of the class GMM tendency, on the other hand, shows an inclination among prospective teachers towards the correct expert model. The preliminary test regarding the structure of a star demonstrated that prospective teachers are not consistent as they do not use a only one model, yet their GMMs predispose to the incorrect model. The the class GMM tendency obtained at the end of the post-test showed that the GMM state of the class indicates the use of the correct expert model by prospective teachers, yet this was not the case for the whole class. Prospective teachers' prior knowledge and/or past experience may have caused this situation. In terms of GMM, prospective teachers tend to use the incorrect model as far as the life cycle of a star is concerned without consistency in the use of models. In the post-test, however, prospective teachers were found to be more inclined towards the correct expert model; almost all prospective teachers display similar GMMs close to the same physical model concerning the life cycle of a star. In this respect, the GMMs of prospective teachers are predisposed towards the correct expert model (correct answer) most prevalently concerning the concept group of the star life cycle. In a study on black-body radiation conducted by Vadnere and Joshi (2009), the model density matrices of the experimental group and the control group were formulated and, in the end, the class GMM tendency for the preliminary test was seen to include mainly non-diagonal large elements. Indicating that this is one of the characteristics of the inconsistent mixed model, scholars state that when a student triggers expert behaviour, it is likely to display the alternative idea state or the null state.

Studying the level of comprehension of the concept of stars, Agan (2004) listed the potential assumptions of students about the Sun and stars, the nature of stars, and the distances between stars (e.g.

the Sun is bigger than other stars or stars are made of fire or lava) at the end of the study conducted with high school students and first-year university students. In this respect, it is indicated in the study that students maintain these primitive models, yet they can advance with synthetic models including the idea that the Sun is related to the concept of stars. Finally, according to Agan (2004), students abandon this synthetic idea and attain the scientific model according to which the Sun is the closest star to Earth. At the end of the study, it was shown that the high school-level astronomy course allowed the students to improve the scientific knowledge of students regarding the concept of stars. Agan (2004) arrived at this conclusion using semi-structured interviews. Similarly, conducting a descriptive study using four open-ended questions, İyibil and Sağlam Arslan (2010) found at the end of their study that a considerable part of prospective physics teachers (41%) display the model state related to non-scientific knowledge regarding the concept of stars, indicated as the mental model 4. The present study, although producing similar results, indicates that the conditions of prospective teachers before and after their education are inclined towards the mixed model in terms of the class GMM tendency despite the fact that their scores increase after instruction. Unlike other studies, the present study also includes quantitative analyses and, through these analyses, showed that the models for prospective teachers can be revealed by this means. Furthermore, the mental models obtained in this study are delineated as GMMs because, as indicated in the introduction, the mental model to be designated is based on the questions and options presented to prospective teachers. As mental models are susceptible to changes (Norman, 1983), they are hard to define in a precise manner. Besides, prospective teachers might make use of different models while analysing different astronomical phenomena (Pundak, Liberman ve Shacham, 2017). In this respect, it might be said that describing models designated regarding a subject/concept as GMMs would be more accurate.

According to Greca and Moreira (2000), mental models are internal representations formulated by students with the aim of making sense of the world around them. These models are of individual nature as they are not consistent among all students. At the same time, as these models are also the preliminary information brought by students to the classroom setting, students may interpret this information (hybrid modelling), opt for memorisation, or create novel models suitable for and consistent with the models in their minds. In this respect, students go through a certain process of modelling. At this stage, if one wishes to reveal the modelling states of students before and/or after the teaching process through the quantitative method/model analysis method, it would be appropriate to define such models as GMMs since one sets certain limits to the learner in terms of options.

Suggestions

It is possible to say that the model analysis method differs from other analysis methods. Here, the information gathered at the end of quantitative studies to define GMMs (interviews with prospective teachers) are included in the analysis. The information is then used to assess the consistency of the answers given to the questions within the same conceptual group by the participants. In the end, a quantitative process takes place with a qualitative approach.

The following suggestions can be made in light of the findings of the present study:

- The study deals with stars, one of the basic concepts of astronomy, and the modelling of prospective teachers regarding this concept shows the characteristics of the erroneous model. Considering that the importance attached to astronomical topics and subjects increases at each level of education, the concentration factor can be used to evaluate the current knowledge of individuals regarding these matters.
- Courses on topics such as scientific research methods, data analysis, or assessment and evaluation might include the subject of designating grounded mental models.

- Providing useful information about the distribution of answers, the model analysis method can be used to examine the structure of answers given in a well-structured multiple-choice test.
- This study can be conducted longitudinally, allowing for its evaluation as the stages of change in the GMMs of participants.
- Through different teaching methods (e.g. technology-enhanced teaching for the concept of stars), the development of students/prospective teachers may be complemented and the impact of such a situation on GMMs.

REFERENCES

Agan, L. (2004). Stellar Ideas: Exploring Students' Understanding of Stars. *Astronomy Education Review 3*(1), 77.

Bailey, J. M. (2006). *Development of a concept inventory to assess students' understanding and reasoning difficulties about the properties and formation of stars* [Doctoral dissertation]. The University of Arizona, Tucson, AZ, USA.

Bailey, J. M. & Slater, T. F. 2004. A review of astronomy education research. *Astronomy Education Review, 2*(2), 20-45.

Baloğlu Uğurlu, N., (2005). İlköğretim 6.sınıf öğrencilerinin dünya ve evren konusu ile ilgili kavram yanılgıları [Misconceptions of the sixth year students of primary education on the earth and the universe]. *Gazi Eğitim Fakültesi Dergisi, 25*(1), 229-249.

Bao, L. (1999). *Dynamics of student modeling: A theory, algorithms, and application to quantum mechanics* [Doctoral dissertation]. University of Maryland, Maryland.

Bektaşlı, B. (2014). In-service science teachers' astronomy misconceptions. *Mediterranean Journal of Educational Research, 15*,1-10.

Biggs, J. (1999). *Teaching for quality learning at university*. Society for Research into Higher Education and Open University Press.

Bostan, A. (2008). *Farklı yaş grubu öğrencilerinin astronominin bazı temel kavramlarına ilişkin düşünceleri [Different age group students? ideas about some basic astronomy concepts]* [Master's thesis]. Balıkesir University, Balıkesir.

Bülbül, E., İyibil, Ü., & Şahin, Ç. (2013). Ortaokul 8. sınıf öğrencilerinin astronomi kavramıyla ilgili algılamalarının belirlenmesi [Determinatıon of elementary school 8th grade students' perceptions about the astronomy concept]. *Journal of Research in Education and Teaching, 2*(3), 182-191.

CHE (2018). Fen Bilgisi Öğretmenliği Lisans Programı [Science Education Undergraduate Program]. http://www.yok.gov.tr/documents/10279/41805112/Fen_Bilgisi_Ogretmenligi_Lisans_Programi.pdf

Cin, M. (2007). Alternative views of the solar systems among Turkish students. *International Review of Education, 53*(1), 39-53.

Didiş, N. (2012). *Lisans öğrencilerinin gözlenebilir fiziksel büyüklüklerin kuantize olması hakkındaki zihinsel modellerinin incelenmesi [Investigation of undergraduate students mental models about the quantization of physical observables]* [Doctoral dissertation]. Middle East Technical University, Ankara.

Durukan, Ü.G., & Sağlam Arslan, A. (2013). Fen bilgisi öğretmen adaylarının temel astronomi kavramlarını ilişkilendirme durumlarının analizi [Analysis of the relationship between science teacher candidates' basic astronomy concepts.]. *Science Education and Research Association Journal of Science Education,* *1*(2), 97-109.

Ezberci Çevik, E. (2018). *Fen bilgisi öğretmen adaylarinin yildiz konusundaki temellendirilmiş zihinsel modellerinin matematiksel algoritmalar yoluyla incelenmesi [Investigation of the grounded mental models in star subject of prospective science teachers by mathematical algorithms]* [Doctoral dissertation]. Kastamonu University, Kastamonu.

Ezberci Çevik, E., & Kurnaz, M.A. (2016). Türkiye'de yıldızlarla ilgili yapılan bazı çalışmaların tematik incelenmesi [Thematic review of some studies about the stars in Turkey]. *Elementary Education Online, 15*(2), 421-442.

Gilbert, J. K., Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and Technology education. In J. K. Gilbert & C. J. Boulter (Eds.), *Developing models in science education* (pp.3-17). Kluwer Academic Publishers.

Gilbert, S. W., & Ireton, S. W. (2003). Understanding models in earth and space science. NSTA Press.

Gobert, J. D., & Pallant, A. (2004). Fostering students' epistemologies of models via authentic model-based tasks. *Journal of Science Education and Technology*, *13* (1), 7-22.

Göncü, Ö., & Korur, F. (2012*). İlköğretim öğrencilerinin astronomi temelli ünitelerdeki kavram yanılgılarının üç aşamalı test ile tespit edilmesi* [Determining the misconceptions of primary school students in astronomy-based units with a three-step test]. Paper presented at the X. National Science and Mathematics Education Congress, Niğde.

Greca M. I., & Moreira, M. A. (2000). Mental models, conceptual models, and modelling. *International Journal of Science Education, 22*(1), 1-11.

Harman, G. (2012). *Fen bilgisi öğretmen adaylarının model ve modelleme ile ilgili bilgilerinin incelenmesi* [Investigation of pre-service science teachers' knowledge on modeling and modeling.]. Paper presented at the X. National Science and Mathematics Education Congress, Niğde.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education, 22*(9), 1011- 1026.

İyibil, Ü. (2010). *Farklı programlarda öğrenim gören öğretmen adaylarının temel astronomi kavramlarını anlama düzeylerinin ve ilgili kavramlara ait zihinsel modellerinin analizi [The analysis of the understanding levels and mental models of candidate teachers studying at different departments about basic astronomy concepts]* [Master's thesis]. Karadeniz Technical University, Trabzon.

İyibil, Ü., & Sağlam Arslan, A. (2010). Fizik öğretmen adaylarının yıldız kavramına dair zihinsel modelleri [Pre-service physics teachers' mental models about stars]. *Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education, 4*(2), 25-46.

Kalkan, H., & Kıroğlu, K. (2007). Science and nonscience students' ıdeas about basic astronomy concepts in pre-service training for elemantary school teachers. *Astronomy Education Review, 6*(1), 15-24.

Koray, A. (2021). Öğretmen adaylarının model temelli astronomi kazanımlarına yönelik uygulamalarının değerlendirilmesi. *Teori, Güncel Araştırmalar ve Yeni Eğilimler-3,* 1-27.

Kalkan, H., Ustabaş, R., & Kalkan, S. (2007). *İlk ve orta öğretim öğretmen adayı öğrencilerinin temel astronomi konularındaki kavram yanılgıları* [The misconceptions of primary and secondary school teacher candidates about basic astronomy topics]. VII. National Science and Mathematics Education Congress.

Kurnaz, M. A. (2012). Yıldız, kuyruklu yıldız ve takımyıldız kavramlarıyla ilgili öğrenci algılamalarının belirlenmesi [Determining students' comprehension of the star, comet, and constellation concepts].

Abant İzzet Baysal University Journal of Education Faculty, 12(1), 251-264.

Kurnaz, M. A. (2022). Temellendirilmiş zihinsel model teorisi. *Amasya Üniversitesi Eğitim Fakültesi Dergisi, 11*(1), 121-132.

Kurnaz, M.A., Bozdemir, H., Altunoğlu, B.D., & Ezberci Çevik, E. (2016). Fen eğitiminde astronomi konu alaninda yayinlanan ulusal makalelerin incelenmesi [Analysis of national articles published in astronomy subject areas]. *Erzincan University Journal of Education Faculty, 18*(2), 1398-1417.

Küçüközer, H. (2007). Prospective science teachers' conceptions about astronomical subjects. *Science Education International, 18*(2), 113-130.

Lesh, R., & Doerr, H. (2003). *Beyond Constructivism: A models and modeling perspective on mathematics problem solving, learning, and teaching*. Lawrence Erlbaum Associates, Mahwah.

Lin, J.W., & Chiu, M.H. (2007). Exploring the characteristics and diverse sources of students' mental models of acids and bases. *International Journal of Science Education, 29*(6), 771-803.

Mavis, B. E., Cole, B. L., & Hoppe, R. B. (2001). A survey of student assessment in U.S. medical schools: *The balance of breadth versus fidelity. Teaching and Learning in Medicine, 13,* 74-79.

Ministry of National Education [MNE] (2018a). *Hayat bilgisi dersi öğretim programı (ilkokul 1, 2 ve 3. siniflar)* [Life studies course curriculum (primary school 1st, 2nd and 3rd grades)] Retrieved from http://mufredat.meb.gov.tr/Dosyalar/2018122171428547-HAYAT%20B%C4%B0LG%C4%B0S%C4%B0%C3%96%C4%9ERET%C4%B0M%20PROGRAMI.pdf

MNE (2018b). *İlköğretim fen bilimleri dersi (ilkokul ve ortaokul 3-8. sınıflar) öğretim programı* [Elementary science lesson (primary and secondary school 3-8th grades) curriculum]. Retrieved from http://mufredat.meb.gov.tr/Dosyalar/201812312311937-FEN%20B%C4%B0L%C4%B0MLER%C4%B0%20%C3%96%C4%9ERET%C4%B0M%20PROGRAMI2018.pdf

MNE (2018c). *Ortaöğretim kurumlari haftalik ders çizelgesi* [Secondary education institutions weekly course schedule]. Retrieved from http://ttkb.meb.gov.tr/meb_iys_dosyalar/2018_02/21173451_ort_ogrtm_hdc_2018.pdf

National Research Council [NRC] (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum.* National Academies Press.

Norman, D. (1983). Some observations on mental models. In D. Gentner and A. Stevens (Eds), *Mental models* (pp. 6-14). Lawrence Erlbaum Associates.

Ogan Bekiroglu, F. (2007). Effects of model-based teaching on pre-service physics teachers' conceptions of the moon, moon phases, and other lunar phenomena. *International Journal of Science Education*, *29* (5), 555–593.

Örnek, F. (2008). Models in science education: Applications of models in learning and teaching science. *International Journal of Environmental & Science Education, 3*(2), 35-45.

Percy, J.R. (1998). Astronomy education: An ınternational perspective. *Astrophysics and Space Science, 258,* 347-355.

Philippi, K. H. (2010). *An examination of student understanding of the use of models in science and conceptual understanding of electricity and magnetism* [Doctoral dissertation]. University of New Orleans.

Pundak, D., Liberman, I., & Shacham, M. (2017). From conceptual frameworks to mental models for astronomy: Students' perceptions. *Journal of Astronomy & Earth Sciences Education, 4*(2), 109-126.

Rapp, D. N. (2005). *Mental models: Theoretical issues for visualizations in science education.* In Gilbert, J. K. (Ed.), *Visualization in science education, Series: Models and modeling in science education* (volume 1, pp. 43 – 60). Kluwer.

Sadler, P. M. (1992). *The initial knowledge state of high school astronomy students* [Doctoral dissertation]. Harvard University.

Sadler, P. M. (1998). Psychometric models of student conceptions in science: reconciling qualitative studies and distractor-driven assessment instruments. *Journal of Research in Science Teaching, 35*(3), 265-296.

Shen, Z., Tan, S., & Kiau, S. (2017). *Using cognitive maps of mental models to evaluate learning challenges: Acase study.* Twenty-third Americas Conference on Information Systems, Boston.

Syrmpas, I., Chen, S., Pasco, D., & Digelidis, N. (2019). Greek preservice physical education teachers' mental models of production and reproduction teaching styles. *European Physical Education Review, 25*(2), 544-564.

Türkoğlu, O., Örnek, F., Gökder, M., Süleymanoğlu, N., & Orbay, M. (2009). On pre-service science teachers' pre existing knowledge levels about basic astronomy concepts. *International Journal of Physical Sciences, 4*(11), 734-739.

Ulusoy Taş, A. (2016). *Ortaokul öğrencilerinin 'doğal ve yapay çevre' hakkındaki zihinsel modellerinin araştırılması* [Exploring secondary school students' mental models of "both the natural and artificial environment] [Master's thesis]. Adnan Menderes University, Aydın.

Unat, O. (2011). *Fizik öğretmen adaylarının yıldızlardan yıldızsılara ünitesine ilişkin pedagojik alan bilgilerinin değerlendirilmesi* [Evaluation of pre-service physics teachers' pedagogical content knowledge regarding "from stars to quasars" unit] [Master's thesis]. Marmara Unversity, Istanbul.

Vadnere, R., & Joshi, P. (2009). On analysis of the perceptions of standard 12 students regarding a physics concept using techniques of quantum mechanics. *Physics Education Journal, 26*(4), 279-290.

Vosniadou, S. (1991). Designing curricula for conceptual restructuring: Lessons from the study of knowledge acquisition in astronomy. *Journal of Curriculum Studies, 23,* 219-237.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24,* 535-585.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science, 18,* 123-183.