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RESEARCH ARTICLE

Students’ knowledge of the apparent motion of the Sun and stars across four European countries

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Abstract

In the context of the European Erasmus+ project Teaching ASTronomy at the Educational level (TASTE), we investigated to what extent secondary school students of four participating countries (Belgium, Germany, Greece and Italy) have insight in the Apparent Motion of the Sun and Stars. The systematic design of the AMoSS test instrument allowed us to detect differences in understanding of the apparent motion of the Sun and stars. We administered the test with 12 multiple choice questions to 13-17 years old students of 5 European secondary schools (*N*=348) during a science lesson in school. We also asked them to explain their choices. We found similar results in the four countries: most students only demonstrate a rudimentary understanding of the apparent motion of the Sun and stars for different times during the day, different times during the year and different locations of the observer on Earth. Moreover, we see a clear distinction between the responses to the Sun-related and the star-related questions. In general, the questions about the Sun are answered more correctly than the questions about the stars. By using one classification system for the four countries we were able to compare written explanations in different languages. In combination with a latent class analysis, we identified different mental models that students use to answer questions about the apparent motion of the Sun and stars.

Keywords: Conceptual understanding, mental models, apparent celestial motion

1 Introduction and problem statement

Astronomy is undoubtedly one of the sciences that can appeal to a wide audience as it focuses on the origin of the universe, stars, planets and even life itself. Therefore astronomy can act as a 'gateway science' to other sciences and is a possible entry point to science education. Unfortunately research shows that even basic astronomical phenomena like the day/night cycle, the Moon phases, the cause of the seasons, … are difficult to grasp and teach (Bailey and Slater (2003); Lelliott and Rollnick (2009); Plummer et al. (2011); Testa et al. (2015); Trumper (2000)). The European Erasmus+ project Teaching ASTronomy at Educational level (TASTE), which is a collaboration between four planetaria or science centres and four schools, aims at improving this teaching by designing, testing and exchanging teaching/learning materials that support student understanding of crucial elements like spatial scales and time. By taking an international approach, carrying out research on students' scientific thinking and testing the materials in diverse educational settings with one secondary school and one university, science centre or planetarium in each of the participating countries (Belgium, Germany, Greece and Italy), it will be possible to identify essential elements for teaching. In particular, we look for elements that are 'universally' important, independent of the local educational system.

Although the approach to astronomy education can be very different in different European countries, teaching astronomy shows similar difficulties (Wagner and Ros (2003)). In none of the four participating countries is astronomy a separate course in the national curriculum of primary or secondary school students. The only exceptions are a few federal states in Germany, where a specialised course in astronomy is organized for one or two years at grade 9 or 10 (IAU (2021)). In all four countries astronomy topics do appear in natural sciences lessons. Students are taught basic astronomical phenomena in primary school: day/night cycle, the Sun's path, seasons, the solar system. Italian primary school teachers have the freedom to teach more content depending on their competences. In some Italian primary school books, astronomical themes as stars, galaxies and even the evolution of the universe are briefly discussed. In secondary school, astronomical subjects are merely taught at an advanced level in geography, physics or natural sciences classes. In Germany, secondary school students learn about the phases of the Moon, lunar and solar eclipses, and are taught main physical concepts like Newton's laws of motion and basic concepts of gravity. Newton's general law of gravity will however only be taught in higher classes (grade 10), if the students major in STEM education or if their teacher chooses to do more than required by the educational plan. In Belgium and Italy, students in general education learn about gravity, Kepler's law and all the main physical processes and concepts to understand astrophysics at an elementary level (e.g. the study of light). During the last year Belgian, German and Italian students with an advanced science curriculum can study modern physics theories as special relativity and quantum mechanics, elementary particles, astrophysics and cosmology. In all countries teachers have the freedom to organize school trips to a science centre or planetarium to study or experience astronomical phenomena.

Given the fact that all students of the participating countries in the TASTE project have been taught some basic astronomy concepts in school and since the main topics of this Erasmus+ project are time and space, we decided to focus in our study on the apparent motion of the Sun and stars. There are at least two reasons for this choice.

First, although people experience the Sunrise and Sunset every day, previous research has shown that young children, students and adults have difficulties properly describing and explaining the Sun's apparent motion (Bailey and Slater (2003); Lelliott and Rollnick (2009); Plummer et al. (2011); Testa et al. (2015); Trumper (2000); Bekaert et al. (2022)). When it comes to stars it seems to be worse: they think that the stars' apparent motion does not differ from the Sun, stars are fixed in the sky or move opposite to the Sun (Vosniadou and Brewer (1994); Plummer (2009); Bekaert et al. (2020)). In the context of the European TASTE project we aim at investigating whether these conclusions hold true also for the four participating countries.

Second, our choice relates to the fact that one of the goals of the TASTE project is to study the role a planetarium can play in learning basic astronomical phenomena. As visualizing the (night) sky is one of the main goals of a planetarium, planetariums might be a powerful setting to support and enhance student learning of apparent celestial motions.

In this article we report on findings on student thinking about the apparent motion of the Sun and stars, based on the administration of the Apparent Motion of the Sun and Stars (AMoSS) test (Bekaert et al. (2020)) to a group of 13-17 years old students of four European countries (Belgium, Germany, Greece and Italy). We are interested in examining students' basic knowledge and the mental models that they use while explaining their answers.

In Section 2, we summarize different studies about students' difficulties in learning the apparent motion of the Sun and stars and refer to the definition of a mental model we use in this study. In Section 3, we describe how we have organized the test and how we analyzed the answers of the multiple choice questions. We elaborate on the patterns found in the answers which lead to the delineation of different mental models. Section 4 lists the results of the various steps in the study. The last sections conclude with a discussion and ideas for further research.

2 Background

2.1 Students' difficulties in learning about the apparent motion of the Sun and stars

Although astronomy may be the oldest of all natural sciences, we know from previous studies that young children, students and adults have difficulties in developing a good understanding of basic astronomical concepts (Plummer et al. (2011); Bailey and Slater (2003); Lelliott and Rollnick (2009); Testa et al. (2015); Trumper (2000)). As in other science classes, in astronomy lessons students have to digest concepts that are presented using a multitude of different disciplinary specific resources, including different representations, tools and activities. Before being able to understand basic concepts they have to adjust to these resources (Eriksson (2019)).

In the following, we highlight a few studies about different aspects of the understanding of the apparent motion of celestial bodies by students and teachers in different countries all over the world.

In their study about students' thinking of the day/night cycle, Vosniadou and Brewer (1994) report that American primary school children have alternative ideas to explain the day/night cycle. They don't have a clear view on the actual motion of the Earth: they explain that the Sun revolves around the Earth or that the Earth revolves around the Sun in one day. Most children think that the stars are fixed and do not move in the sky.

Plummer (2009) reports that most first-grade students in the United States (approximately aged 6-7) do not yet understand that all celestial objects appear to move across the sky in the same direction and along similar paths. As they grow up they shift to viewing celestial objects as moving slowly across the sky, rather than staying fixed in the sky, but concerning the apparent motion of the stars or the idea that we see different stars at night throughout the year there is no significant improvement.

Sharp (1996) interviewed sixth grade British students (approximately aged 11-12) and asked them to explain their ideas about the apparent motion of the Sun and stars. He found that most students were able to describe the rising and setting of the Sun, but only a small minority had a correct view on the stars.

Chae et al. (2013) found that sixth grade Korean students (approximately aged 11-12) have a good insight in the Sun's apparent motion: they are capable of switching from a geocentric point of view to a heliocentric point of view while explaining the Sun's motion. Unfortunately they were not able to transform this knowledge to the stars: most students could not explain the stars' apparent motion.

Bekaert et al. (2020) report in their validation study of the AMoSS test that both Belgian secondary school students (16-17 years old) and university students only have a rudimentary understanding of the apparent motion of celestial bodies: they can not describe how the apparent motion of the stars differ from the Sun. Most students do not know for example that the culmination height of the stars stays fixed throughout the year.

Trumper (2006) found also that university students have difficulties in describing the Sun's path during the day. Only one of the 19 interviewed future Israeli primary school teachers was able to predict correctly the Sun's path: most students thought that the Sun rises exactly east, that the Sun sets exactly west and that the Sun is in the zenith at noon every day. According to Trumper these alternative ideas are due to the fact that the correct scientific explanations do not match with the student's daily observations. Heywood et al. (2013) found in their study on British pre-service teachers' reasoning about the Sun's apparent motion that for most participants it was not clear that this motion is due to the Earth's spinning on its axis.

From the above studies, we can summarize that students of different ages and coming from different places in the world often reason alternatively about the apparent motion of the Sun and stars. This seems to be related to the fact that most students can not connect the observed celestial motions from a geocentric point of view to the allocentric view from space. In the literature, several studies (Lopresto and Murrell (2011); Plummer and Krajcik (2010); Testa et al. (2015); Yu et al. (2015)) suggest that it seems to be essential that students learn to think and alter between a geocentric and an allocentric frame of reference in order to understand the apparent motion of the Sun and stars and link these to the actual motion of the Earth. Probably, specific instructional strategies are needed: students must be trained to switch between different frames of reference, to be able to really understand apparent celestial motions.

2.2 Students' mental models of the apparent motion of the Sun and stars

To gain a better insight in how students explain the phenomena of apparent motions, we try to identify their underlying mental models. Although in literature there is some discussion about the exact definition of a mental model, in general, the term refers to the internal representations that people form of the outside world through their interaction with it. Craik (1943) introduced the notion of a mental model by postulating that people carry in their minds a small scale model of how the world works. Johnson-Laird (1983) developed this idea and states that "mental models are structural analogues of the world as perceived and conceptualized". According to Vosniadou and Brewer (1994) a mental model is an analog to the world it represents, which can be manipulated to make predictions and provide explanations. Greca and Moreira (2001) define a mental model as an internal representation which acts out as a structural analogue of situations or processes. Ubben et al. (2022) state that "mental models are individual types of mental modal patterns that possess a functional potential and are based on outside experiences". In our research we take the definition of Corpuz and Rebello (2011) as a guideline: they define a mental model as "students' way of understanding a certain physical phenomenon," which can also be an unseen physical phenomenon. We follow the view of Gilbert and Boulter (1998) who suggest that a mental model essentially is inaccessible and that we, as researchers, only can rely on an expressed version of it. This means that the description of a mental model always refers to what researchers discovered based on the expressed version of the mental model.

We also follow the arguments of Brown and Hammer (2013) who consider students' conceptual thoughts as a complex dynamic system: student reasoning can be stable, but can also differ from one context to another. In our study we will look for both consistency and inconsistency in student ideas about the apparent motions of the Sun and stars.

According to Collins and Gentner (1987), mental models can be formed through analogical thinking: when describing a concept with which you are unfamiliar, you tend to make a comparison with an equivalent concept with which you are more familiar and which you perceive as similar (Rickheit and Sichelschmidt (1999)). For example, the mental model of the solar system may be used to explain Rutherford's atom model.

Bekaert et al. (2022) recognized this idea in the results of their study with Belgian school students of 16/17 years old where they interpreted the students' mental models about the apparent motion of the Sun and stars. By administering the AMoSS test, analyzing the answers of the multiple choice questions with a Latent Class Analysis and categorizing the written explanations, they found five different mental models of which the first two can be linked to analogical thinking:

1. Model 1: Students think that the stars behave exactly like the Sun: for both the Sun and the stars the path of the apparent motion is higher and wider in summer than in winter. When the observer's latitude decreases, this path becomes higher and wider both for the Sun and the stars.
2. Model 2: For this student group the stars behave opposite to the Sun: while the Sun's path is lower and smaller in winter, they think that when nights are longer in winter, the star trails are higher and wider.
3. Model 3: These students have a good view on the apparent motion of the Sun, but they are completely confused about the stars.
4. Model 4: This group has difficulties with the correct interpretation of the culmination height of the Sun and the stars: they think that that the culmination height is proportional to the latitude.
5. Model 5: This group thinks that the position of Sun/star rise is always exactly in the east and the position of Sun/star set is exactly in the west. Some students think that the stars move from west to east, or do not move at all during the night.

In the present study in the context of the TASTE project, the main questions are:

1. What results do Belgian, German, Greek and Italian secondary school students achieve when they take the AMoSS test?
2. What mental models do Belgian, German, Greek and Italian secondary school students use when answering questions about the apparent motion of the Sun and the stars?

Table 1. Framework of the AMoSS test: similarities and differences between the apparent motion of the Sun and stars

(I)	Apparent motion of the Sun		(II)	Apparent motion of a star	
	(A)	Daily Sun position changes: Sun's path. (Question I.A)		(A)	Nightly star position changes: star trail. (Question II.A)
	(B)	Sun culmination changes during a year. (Question I.B)		(B)	Star culmination does not change during a year. (Question II.B)
	(C)	Sunrise and sunset position change during a year. (Question I.C)		(C)	Star-rise and star-set position do not change during a year. (Question II.C)
	(D)	Sun culmination depends on observer position. (Question I.D)		(D)	Star culmination depends on observer position. (Question II.D)
	(E)	Sunrise and sunset position depend on observer position. (Question I.E)		(E)	Star-rise and star-set position depend on observer position. (Question II.E)
(III)	Seasons: colder and warmer periods on a specific location during a year, due to Earth's revolution. (Question III)		(IV)	Sky map changes on a specific location during a year, due to Earth's revolution. (Question IV)	

Table 2. Number and age of participating students (*N*=348)

Country	Number	Age
Belgium	97	16-17
Germany	47	13-14-15
Greece	51	14-15
Italy	153	14-15-16

By investigating these two questions we also aim at verifying if the five mental models, as described by Bekaert et al. (2022), apply for the students of the four countries participating in the study. Since these five models may be related to the Belgian education system, we are wondering whether new mental models can be identified by examining different countries.

3 Methods

3.1 AMoSS test: multiple choice questions

We used the AMoSS test instrument to investigate to what extent students have insight in the apparent motion of the Sun and stars (Bekaert et al. (2020)). This test consists of 12 multiple choice questions, which focus on distinctions between different aspects of the apparent motion of the Sun and stars (See Table I). For each question about the Sun, there is a parallel question about the stars. For an example we refer to Figure 1. Teaching experts and science center or planetarium staff members of each country within our collaboration verified if the test questions were feasible for their students. They decided that the test is difficult, but was well suited for the intended study. Based on the recommendations of the test developers (Bekaert et al. (2022)) we reformulated question III about the cause of the seasons to a multiple-choice question. We also modified one figure of question I.E to improve the distinction between the different alternatives (See Figure 2). Finally, we translated the reworked test (See Appendix) into the different languages of the participating students (Dutch, German, Greek and Italian) and adapted the questions to the local situation so that the mentioned cities became familiar for the students (e.g. Brussels, Heidelberg, Thessaloniki and Modena). In addition, we adapted the mentioned culmination heights of the Sun and the stars to correspond correctly to the local situation.

We administered the AMoSS test to secondary school students (13-17 years old) of the four participating countries (*N*=348) during a science lesson at school (See Table 2). The students were not specially prepared to the test. The test was taken at the end of the schoolyear, in the weeks before the final exams.

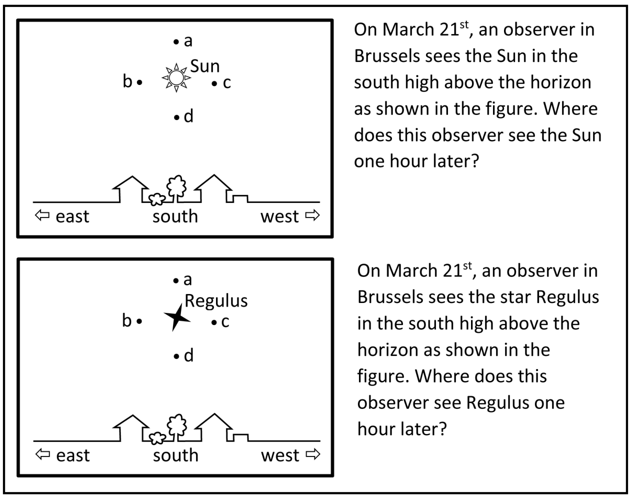

Figure 1. Question I.A and II.A of the AMoSS Test Bekaert et al. (2020) for Belgian students.

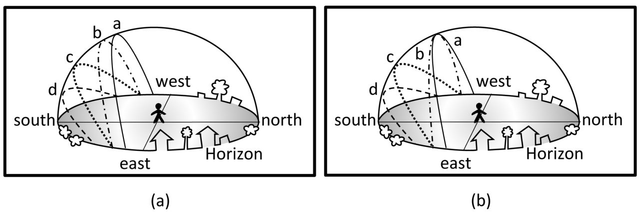

Figure 2. (a) Original figure of question I.E Bekaert et al. (2020) and (b) modified figure of question I.E used in this study

We asked the twelve questions in a random order. To exclude a bias in the results due to this order, we created two different series, each with a different order.

A protocol was written and explained to all teachers so that the test was administered the same way in all schools. The students were free to decide whether or not to participate. Only the students who signed the informed consent form (or their parents, depending on local legislation) are included in the study. No incentive was given to the students. The test lasted 45 minutes.

For the analysis of the multiple choice answers a score of 1 was given if the correct alternative was chosen and 0 if an incorrect alternative was chosen or if no answer was given.

To look for possible differences between the means of the Sun questions and the star questions, we performed a paired samples t-test.

Other than only looking at the simple statistics of the students' answers, we also applied a Latent Class Analysis (LCA) on the multiple choice answers to look for possible patterns in the students' answers. By running a LCA, we verified if answer patterns were present in the checked alternatives. Because we assume that latent classes exist (Weller et al. (2020)), LCA is an appropriate statistical tool to uncover these. We used the LCA functionality of software Mplus and entered a data file with the answers of the multiple choice questions (a, b, c, ...) of the students on the 12 questions.

3.2 AMoSS test: written explanations

To get insight in the mental models that students use, we also asked them to explain their answers. Because time for test administration was limited to 45 minutes, we limited the number of written explanations to 10 out of 12 questions. Since the alternatives of questions III and IV show possible explanations, we decided not to ask for an explanation for those questions. To analyze these written explanations, we used a validated categorization scheme, designed by the test developers (Bekaert et al. (2022)). This scheme consists of 48 possible student answers and was created during a previous Belgian study, where it was checked for interrater reliability with two independent raters with satisfactory results (overall Cohen's = 0.75).

We organized two training sessions for the team who classified the responses, to make sure that the categorization system was applied reliably and similarly across the four countries. In a first session the categorization scheme was presented to all members of the team and illustrated by examples of real student answers of a Belgian study. As a preparation for the second session, each member of the team was asked to categorize 20 student explanations. During the second session the results of this coding was discussed.

The classification scheme worked as follows: in a first step, the written explanations were classified into five groups:

1. Daily motion (D): the explanation refers to the daily apparent motion of the Sun or star;
2. Yearly motion (Y): the explanation refers to the yearly apparent motion of the Sun or star;
3. Globe (G): the explanation refers to the shape of the Earth;
4. Incomprehensible (Z): it is not clear what the student means;
5. No explanation (X): the student has not written an explanation.

In the second step of the classification process, we distinguished two types of explanations:

1. Statement (S): the explanation is based on an observation from the point of view of an observer on Earth or on something the student knows;
2. Model (M): the explanation shows at least one element of an allocentric point of view (the view from space).

For each written explanation the team also checked whether the written explanation was correct (C) or false (F) and whether the explanation was relevant (R) or not (NR) for the question. Moreover, each explanation was assigned to one of the common answers of a numbered list consisting of a total of 48 possible outcomes. As a result, each answer is characterized by a code of several letters and a number (Example see Table 3). Answers that did not appear in the list were given code O. Although this combined code is not used as such in the further analysis, each element of it makes it possible to compare written explanations in different languages.

Table 3. Example of the classification of students' written explanations of the questions of the AMoSS test about the daily motion (Question I.B and II.B)

Statement (S)	Model (M)
"As summer approaches, the Sun moves higher." (Y.S.4n.C.R).	"The Sun stays at its position, but the Earth moves around the Sun. " (Y.M.3a.C.R)
"In spring days become longer, so Regulus will reach a higher point in the sky." (Y.S.4j.F).	"If the Earth spins on its axis from west to east, the star will move in the opposite direction." (D.M.1a.C.NR)

While classifying the written explanations of the students, we recognized that some students are very consistent in their way of answering the AMoSS test questions. This helped us to interpret the outcomes of the Latent Class Analysis and identify specific mental models students use to explain different aspects of the apparent motion of the Sun and stars.

4 Findings

4.1 Descriptive results of the multiple choice answers

Since the size of the group and the ages of the students are quite different for the four countries, we present the mean test score, the median and the standard deviation for each country separately (See Table 4). We distinguish between the Sun and the star questions.

Table 4. Student scores on the AMoSS test (N = 348). If the difference between the Sun and the stars question is significant ($p < 0.05$), this is marked by an asterisk*.

	Sun questions (6)	Star questions (6)	All questions (12)
BELGIUM (N = 97)			
Mean	45 %*	25 %*	35 %
Median	50 %	17 %	33 %
Standard deviation	26 %	19 %	18 %
GERMANY (N = 47)			
Mean	30 %*	18 %*	24 %
Median	33 %	17 %	25 %
Standard deviation	18 %	27 %	13 %
GREECE (N = 51)			
Mean	29 %*	22 %*	25 %
Median	33 %	17 %	25 %
Standard deviation	20 %	18 %	15 %
ITALY (N = 153)			
Mean	32 %*	21 %*	26 %
Median	33 %	17 %	25 %
Standard deviation	22 %	18 %	16 %

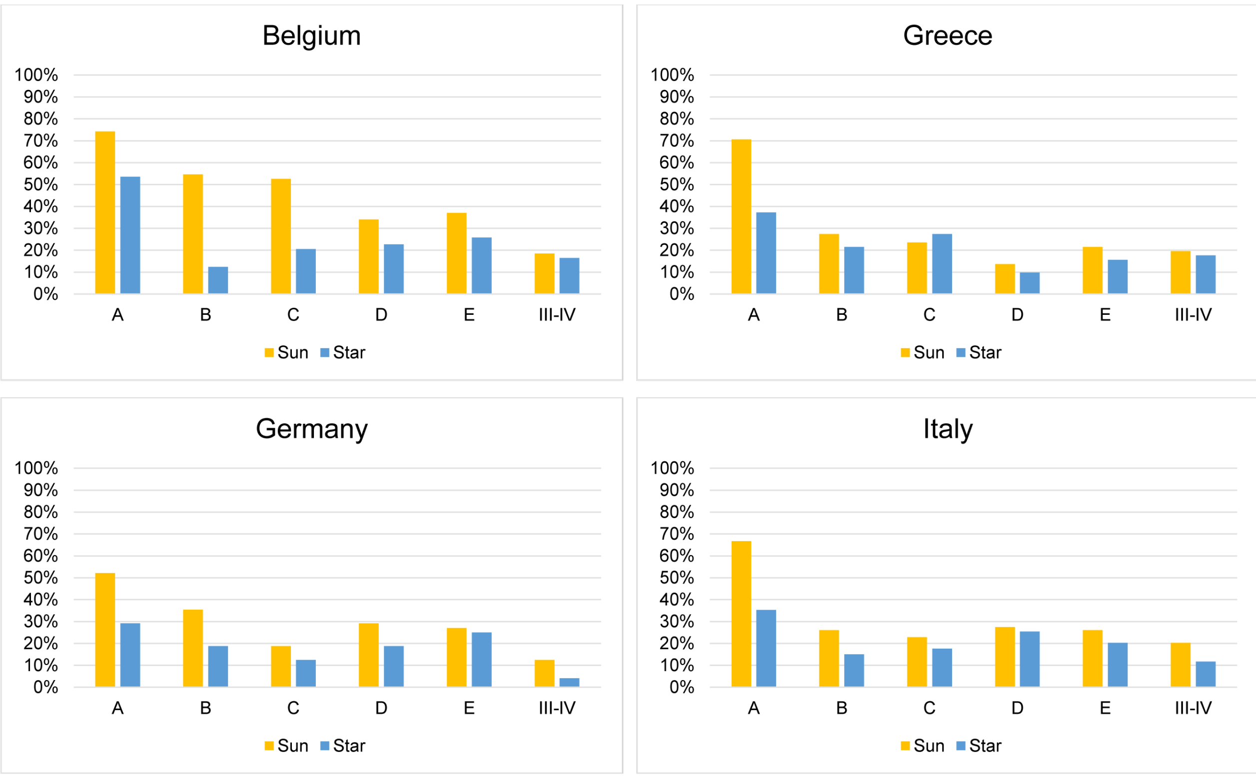

Figure 3. Percentage of students with a correct answer, ordered per question

Table 4 makes clear that overall the score is low and that the Sun-related questions were answered somewhat better than the star-related questions. A paired-samples t-test was conducted to compare the mean score of the six Sun and the six star questions. If this difference is significant ($p < 0.05$), this is marked by an asterisk* in the table. It is interesting to note that the results in the four countries are very similar. To gain a more detailed insight into how well the AMoSS test questions were answered, we present a bar graph showing for each question the percentage of students who answered that question correctly (See Figure 3). Again, we keep the results separated by country. These graphs confirm that the Sun questions were generally answered better than the star questions and that student performance is similar across countries.

4.2 Descriptive results of the written explanations

Table 5 gives a general overview of how the responses were classified in the different categories of the classification system. The table lists per country for each aspect the average number of codes for the Sun and star questions separately. For example for the Belgian student explanations, of the five Sun questions to be explained, an average of 2.3 are coded as statement (S), while for the five star questions, this is only 1.2. A paired-samples t-test was conducted to compare the number of codes between the five Sun and the five star questions. If the difference between the Sun and the star questions is significant ($p < 0.05$), this is marked by an asterisk* in the table.

This categorization reveals that in all countries students tend to use a statement (S) more often for the Sun questions as for the star question. On the other hand, in most countries, most answers for the star questions contain an element that can be linked to an allocentric view (M). Moreover, we see that answers are categorized more often as statements (S) than as models (M). In all countries we also see that the Sun questions are explained more correctly (C) and more relevant (R) than the star questions. While written answers are mostly correct (C) and relevant (R), it is particularly notable that many students leave the explanation box blank (X), even though they were explicitly asked to explain their answer, especially for the star questions.

4.3 Latent class analysis

4.3.1 *Choosing the number of classes*

The first step of a latent class analysis, is to determine the number of classes. First, we calculated two fit indices to decide which model suits our data best: the Akaike Information Criterion (AIC) (Akaike (1974)) and the Bayesian Information Criterion (BIC) (Schwarz (1978)). As a rule, the model with the lowest AIC and BIC values corresponds to the one with the best model fit. Here the model with two classes and the model with six classes (see Table 6), have respectively the lowest BIC and AIC. Second, we searched for the most preferable model from a theoretical interpretation point of view. In the six-class solution, the diversity in students' written responses is better represented than than in the two-class solution. Therefore, we choose the six-class solution.

4.3.2 *Description of the classes*

In the output of the latent class analysis, conducted by the software Mplus, the size of the six classes is indicated by the probability that a respondent belongs to a certain class (See Table 7). These posterior probabilities are calculated based on the respondent answers on the multiple choice questions.

For each question a table is generated with the probabilities that a certain answer is given by a member of a certain class. Table 8 presents an example for question I.B and can be interpreted as follows: there is a 70 % chance of a respondent in latent class 1a answering alternative a to the multiple choice question, a 0 % chance of answering alternative b, a 11 % chance of answering alternative c, …

Table 5. Average number of classification codes assigned to student written explanations. Up to five Sun questions and five star questions were explained. Significant differences are marked by an asterisk*

	Belgium		Germany		Greece		Italy	
	Sun	Stars	Sun	Stars	Sun	Stars	Sun	Stars
Statement (S)	2.3*	1.2*	1.9*	0.7*	1.1*	0.6*	1.8*	0.9*
Model (M)	0.6*	1.1*	0.6	0.8	0.3	0.3	0.6*	0.9*
Correct (C)	2.2*	1.5*	1.5*	0.6*	1*	0.6*	1.4*	0.8*
False (F)	0.7	0.8	0.9	0.9	1.7*	1*	1.3	1.3
Relevant (R)	2.1*	1.2*	1.2*	0.4*	0.6	0.4	1.2*	0.5*
Not Relevant (NR)	0.1*	0.4*	0.4	0.2	0.4*	0.2*	0.2	0.3
Not in list (O)	0.6	0.6	0.4	0.6	1.3*	0.8*	0.4	0.4
Unclear (Z)	0.4	0.4	0.4	0.4	0.3	0.3	0.1	0.1
No explanation (X)	1.1*	1.7*	1.7*	2.5*	2*	3.1*	2.2*	2.8*

Table 6. AIC and BIC values for different number of classes

Number of classes	AIC	BIC
1	13314.121	13568.556
2	13094.922	13607.647
3	12959.795	13730.809
4	12872.293	13901.597
5	12852.181	14139.775
6	12850.382	14692.142
7	12887.968	18908.63

Table 7. Predicted memberships of the latent classes

	Global	Belgium	Germany	Greece	Italy
Class 1a	18%	33 %	4 %	10 %	16 %
Class 1b	13%	7 %	23 %	22 %	11 %
Class 2	32%	20 %	29 %	35 %	41 %
Class 3	13%	19 %	13 %	8 %	10 %
Class 4	21%	19 %	25 %	23 %	20 %
Class 5	3%	2 %	6 %	2 %	2 %

Based on these tables we describe the profiles of the students in the six classes, supplemented with what we learned from the categorisation of the written explanations. Examples of these written explanations illustrate the reasoning of the students in the different latent classes. In the description of the classes we do not take into account the questions about the seasons (question III and IV), because there seems to be no difference between the classes for those two questions. Most students think that the seasons are caused by the varying distance between the observer's position and the Sun throughout the year due to the Earth's tilted axis. For most students, the fact that we see different stars at night in summer than in winter is because the Earth rotates on its axis.

Table 8. Example of the output of software Mplus for question I.B

Class	a	b	c	d	e	f	x
Class 1a	70 %	0 %	11 %	10 %	8 %	2 %	0%
Class 1b	34 %	6 %	0 %	11 %	31 %	17 %	0%
Class 2	27 %	8 %	21%	8 %	28 %	8 %	0 %
Class 3	47 %	3 %	4 %	2 %	4 %	0 %	10 %
Class 4	15 %	6 %	11 %	6 %	25 %	36 %	0 %
Class 5	22 %	0 %	11 %	11 %	0 %	0 %	56 %

Class 1. The students grouped in class 1 answer almost all questions about the Sun correctly. Concerning the stars this class is subdivided in two subclasses.

CLASS 1A: THE STARS ACT LIKE THE SUN. This group knows that the Sun and stars apparently move from east to west during the day and night. The students think that the stars seem to behave exactly the same as the Sun. For both the Sun and the stars, in summer the path of the apparent motion is higher and wider than in winter. When the observer's latitude decreases this path becomes higher and wider both for the Sun and the stars. In Figure 4 the students explain their answers on the question II.B about the culmination height of the stars by using arguments that only apply to the Sun.

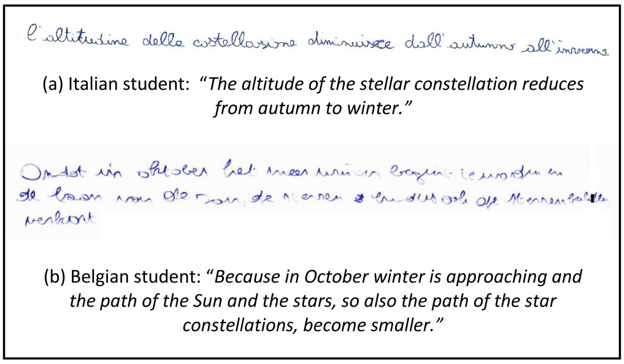

Figure 4. Examples of student answers of class 1a.

CLASS 1B: THE STARS ARE DIFFICULT TO GRASP. This group of students knows that the apparent motion of the Sun is from east to west and that during summer the Sun's path is higher and wider than in winter. Most of the Sun questions are answered correctly. For the time-related questions about the stars these students answer "I don't know!" and for the position-related questions they think that the star trail does not change if the observer's position changes.

Class 2. Concerning the daily apparent motion, the students in class 2 know that the Sun and the stars appear to move from east to west. Concerning the annual motion these students think that the Sun's path and the star trails do not change throughout the year (See Figure 5). They do not know how the observer's position relates to the Sun's path and the star trails: they draw the culmination height incorrectly on a figure for different positions of the observer (See Figure 6) or think that the star trail stay fixed if the observer changes position.

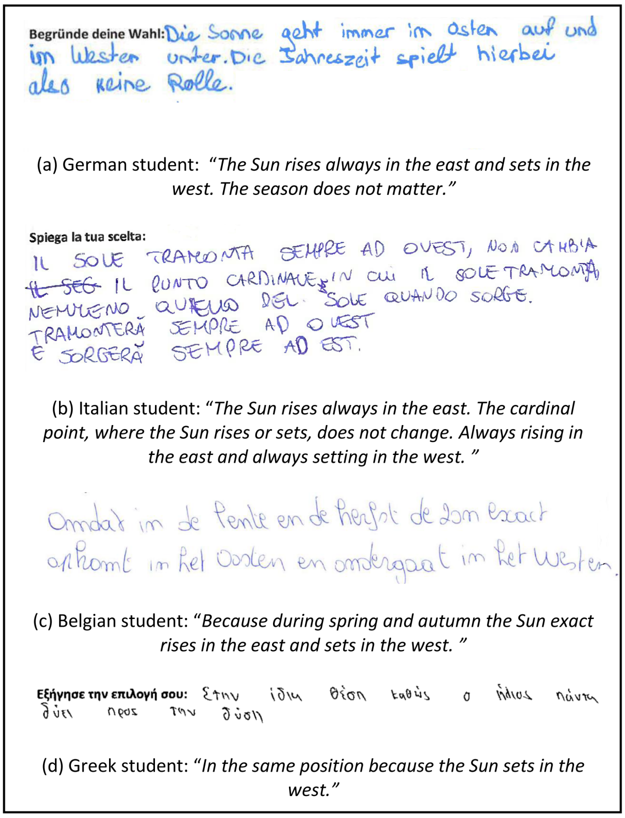

Figure 5. Examples of student answers of class 2.

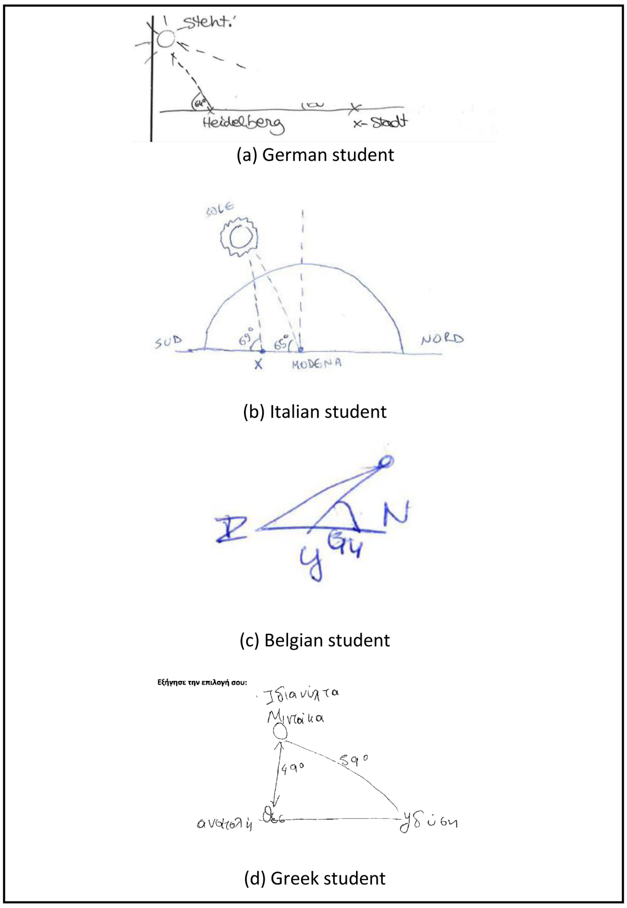

Figure 6. Examples of student answers of class 2.

Class 3. In class 3 we distinguish between the time-related questions and the position-related questions. These students know that the Sun appears to move from east to west during the day, but they think that the stars move from west to east during the night. They also know how the Sun's path changes throughout the year, but they are not aware of the fact that the star trails stay fixed during the year. If the observer changes position, they think that the Sun's path does not change (See Figure 7) and they do not know how the star trail changes.

Class 4. This group is characterized by the fact that students answer almost all other questions with "I don't know", except the first question about the Sun's daily movement and the questions about the seasons.

Class 5. This small group of students prefers not to answer most questions and instead leaves most questions blank.

5 Discussion

In the context of the European Erasmus+ project TASTE we investigated to what extent secondary school students have insight in the apparent motion of the Sun and stars. We have administered the AMoSS test (Bekaert et al. (2020)) with 12 multiple choice questions to 348 students (13-17 years old), coming from four different European countries (Belgium, Germany, Greece and Italy). The systematic design of the AMoSS test, with six Sun-related questions and six parallel star-related questions, allows us to compare students' understanding of the Sun's apparent motion with their understanding of the stars' apparent motion. Thanks to the classification of the written explanations in four different languages, we were also able to analyze and compare student answers. In combination with the Latent Class Analysis technique, we identified six classes with different mental models that students have about the apparent motion of the Sun and stars.

5.1 Students' results on the AMoSS test

As predicted by the teaching experts of the participating countries, the test was perceived as very difficult. This is reflected in the low test scores in each country, with a mean score ranging from 25 % to 35 %. It is remarkable that, despite different ages and different curricula of the participating students, the results are that similar in the four countries. The mean score for the Sun-related questions (29 % to 45 %) is systematically higher than for the star-related questions (18% to 25 %). This confirms previous studies that also found that students usually have a better view on the Sun's apparent motion than the stars' apparent motion (Mant and Summers (1993); Plummer (2009); Vosniadou and Brewer (1994)). This could possibly be explained by the fact that we live much more with the Sun than with the stars. However, since in all participating countries primary school students learn about the day/night cycle, the Earth's spinning and the Earth revolution during the science lessons at school, one could expect the students to apply this knowledge to the stars. Although the Italian and Belgian students who participated in the study, also studied the Sun's apparent motion during a few astronomy

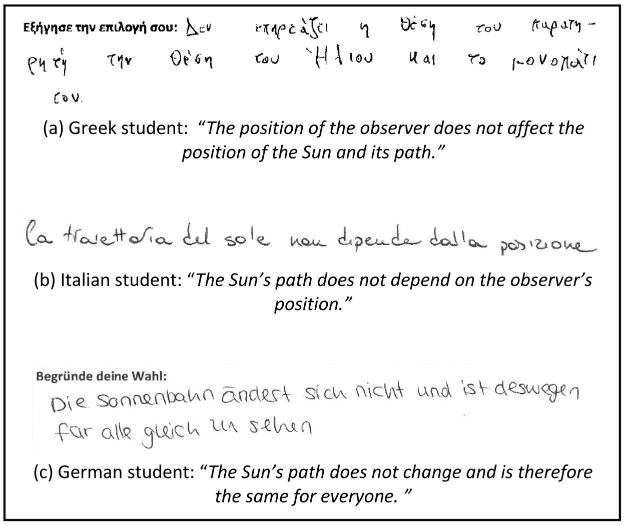

Figure 7. Examples of student answers of class 3.

lessons of their geography course, it seems that this has not helped them to deeply understand celestial apparent motions. We confirm what we found in the literature (Gozzard and Zadnik (2021); Sadler (1987); Vosniadou and Brewer (1994)): following the lessons on astronomy topics has little impact on the test results. It seems that learning about the Earth's spinning and the Earth's revolution around the Sun is not enough to be able to understand the apparent motion of the Sun and stars for different times during the day, different times during the year and different locations of the observer.

This is very clear from the first two questions about the daily motion of the Sun and stars. While in all countries most students know that the apparent motion of the Sun is from east to west, this is less obvious for the stars. This means that a significant portion of the students does not really understand how the Earth's rotation on its axis can be related to apparent motion. We agree with literature (Carey (1986); Plummer (2014); Treagust et al. (2017)) that special instruction is needed for students to fully understand the relativity of motion and to apply this knowledge to the apparent motion of the Sun and stars.

5.2 Students' mental models

Of the six classes into which the surveyed population was divided using a Latent Class Analysis, the class with students (class 2) who believe that neither the path of the Sun nor the star trail, change throughout the year, is the largest (32 %). These students also think that the star trail does not change if the observer changes position. In Germany, Greece and Italy most students belong to this class. Many students write in their explanations that the rising and setting of Sun and stars is always exactly in the east and exactly in the west. It seems that this alternative idea, which has been reported in the literature concerning younger children (Plummer (2009); Plummer et al. (2011); Sharp (1996)), is still present with secondary school students. These students often argue that the Sun and the stars keep their position in the universe, so the observer always sees the apparent motion of these celestial bodies in the same way. Thus, despite instruction they do not relate the Earth's rotational movements to these phenomena at all. This can be due to the way these topics are taught in class: the German team who categorized students' written explanation reports that students often use a rhyme "Im Osten geht die Sonne auf, im Süden nimmt sie ihren Lauf, im Westen wird sie untergehn, im Norden ist sie nie zu sehn" (In the east the sun rises, in the south it travels, in the west it sets and in the north it is never seen).

A second characteristic of this main group (class 2) is their confusion about the culmination height, which is expressed as an angle. When they draw a picture to explain their ideas, they either designate the angle incorrectly on a figure of the Earth, or they do not take into account the spherical shape of the Earth (see Figure 6). As reported in the literature (Panagiotaki et al. (2006); Tao et al. (2012); Vosniadou and Brewer (1990); Özsoy (2017)) a significant group uses the idea of a flat Earth while reasoning about the culmination height for different positions of the observer.

While in Germany, Greece and Italy most students belong to the above described class, in Belgium most students belong to class 1a with students who think that like the Sun's path, the star trails get higher and wider in summer, and lower and shorter in winter. We recognize here the idea of Collins and Gentner (Collins and Gentner (1987)) that mental models are formed through analogical thinking: since students are less familiar with the apparent motion of the stars, they tend to perceive these motions as similar to the Sun's apparent motion. It's interesting to note that the probability of a student belonging to this class varies greatly from country to country: in Belgium this is the biggest group (33 %) while in Germany this is the smallest (4 %).

The fact that 50 % of the students belong to class 1a or class 2 reveal that students do not fully understand how the Earth's revolution influences the apparent celestial motions. How the tilt of the Earth's axis combined with the Earth's revolution affects the apparent motion of the Sun and does not affect that of the stars, seems to be too complex for most students.

For a third group of students (class 3) it is remarkable that they think that stars apparently move opposite to the Sun. Although this concerns a minority of the students (13 %), it is still interesting to note. In each of the four countries a small part of the students belong to this class, but the proportion varies from 19 % (Belgium) to 8 % (Greece).

A final group of students consists of three parts: a group (class 1b) with good scores on the Sun-related questions, but on the questions about the stars they often report not knowing the answer (13 %), a second group (class 4) who knows that the Sun and stars move apparently from east to west but on the other questions they often report not knowing the answer (21 %) and a third group (class 5) who selects almost at all questions the "I really don't know" option (3 %). This means that for these students (making up a total of 37 %) the way they answered the questions and/or the fact that they did not answer, prevented us from deriving their mental model.

On the other hand, based on the fact that the students in the other classes described above use the same type of reasoning in their way of answering different questions of the AMoSS test, we conclude that these alternative ideas can be considered as expressed versions of mental models that students use when answering the questions. Like in the literature (Gilbert and Boulter (1998); Corpuz and Robello (2005)), we prefer to call them expressed versions to emphasize that we can only rely on the student answers we collected by the administration of a limited questionnaire.

Although the six classes are similar to those found by Bekaert et al. (2022) in their study with Belgian 16/17 years old secondary school students, as described in Section 2.2, they are not exactly the same. In the current study also most Belgian students think that star trails change throughout the year like the Sun's path, but this is not so prominent for the German, Greek and Italian students. In these countries, the largest group of students believes that the Sun's path and star trails do not change throughout the year. Thus, these students think that also the culmination height does not change throughout the year, while in the earlier study it was only the position of rise and set of Sun and stars that stayed fixed. Another distinction is the fact that in the current study we did not detect a separate group that believes the star trails are higher and wider during winter because the nights are longer. Based on our data, we cannot explain these differences. Further research is needed to find out if the differences in age and/or curriculum could be a possible cause.

Although we have statistical arguments for the existence of the found mental models by using the Latent Class Analysis technique in combination with the classification of the student's written explanations of the answers on the multiple choice questions, we also have found that most students are not completely coherent in the way they answer the different multiple-choice questions about Sun and stars. While explaining their choices, most students use arguments based on their observations or factual knowledge. This means that they do not rely on elements of an allocentric view while reasoning about the Sun and stars and trying to explain their answers. From the literature (Cole et al. (2018)) we learned that students who are able to think in a geocentric and an allocentric frame of reference, have more chance to develop a better insight in basic astronomical phenomena, like the apparent motion of celestial bodies.

5.3 Implications for astronomy education

It seems to be necessary to stimulate students to learn and think about how the celestial motions in different frames of reference are linked. Since the literature (Chastenay (2015); Plummer and Krajcik (2010); Sneider et al. (2011); Testa et al. (2015); Yu et al. (2015)) indicates that spatial skills have to be trained specifically to be able to switch between different frames of reference, we propose to include this training in the astronomy lessons about these apparent motions at school. In the context of the TASTE project, we also suggest that special attention should be paid to this during planetarium presentations. As indicated in the literature (Uttal and Cohen (2012); Heywood et al. (2013); Plummer (2014); Türk and Kalkan (2017)) we subscribe the idea that making abstract phenomena visible in a concrete way may constitute an important aspect to support thinking. Therefore we suggest to use a 3D model of the celestial sphere to explain the apparent celestial motions and train students to use this model to switch between a geocentric and an allocentric point of view. A systematic comparison of observable and modeled events of Sun and stars should be part of this training to be able to improve students' understanding of the scientific model of the apparent motion of the Sun and stars (Jee and Anggoro (2019)).

6 Limitations

Since the AMoSS test was administered during a science lesson in five schools in four different European countries, we have to take into account that the test may be not taken in the same conditions everywhere, along with the fact that the students' age and their curriculum differed from country to country. Due to the fact that the teams of the different countries categorized their students' responses themselves, many different people were involved in the categorization process. We have not checked the interrater reliability by categorizing the answers independently by different raters. Although we think this is reasonable because the categorization scheme was checked for interrater reliability in a previous study (Bekaert et al. (2022)), this does not account for possible variation in how the raters interpreted the categorization scheme which could influence the results. By organizing an extensive training of the raters including a discussion in cases of disagreement on initial codes, we tried to minimize a variable interpretation of the students' explanations.

A second limitation is the fact that we used a convenience sample in this study: the schools are participating in an Erasmus+ project and have selected their students on a voluntary basis.

A third point of attention when interpreting the conclusions is the fact that in all countries, many students did not write an explanations even though they were asked for. We solved this by combining what we learned from the classification of the written explanations with the statistical technique LCA that uses the multiple choice answers (a, b, c, ...) to look for hidden classes in the sample group.

7 Conclusions

We conclude that students in the four European countries participating in this study experience very similar difficulties in understanding the apparent motion of the Sun and stars. Specific instructions are needed to improve students' understanding of these motions. Policymakers need to provide more time in students' curricula to give teachers the opportunity to pay more attention to these phenomena.

In this study we have identified six student classes with different mental models of the apparent motion of the Sun and stars. In the first class students have a good view on the Sun's apparent motion. Concerning the stars we distinguish between students who think that the star trails change throughout the year in the same way as the Sun's path changes and students who indicate not knowing how the star trails relate to the time of the year or the observer's position. Most typical for the model in the second class is that these students think that the Sun's path and the star trails are fixed: they do not depend on the time of the year. The model in the third class is characterized by the fact that these students think that the stars apparently move opposite to the Sun. In the fourth and the fifth class the students have not expressed their mental model, nor about the Sun, nor about the stars.

We note that the models as described in this European study are very similar to the models found by Bekaert et al. in an earlier Belgian study (Bekaert et al. (2022)). It seems that students' difficulties concerning the deep understanding of the apparent motion of the Sun and stars transcend national boundaries.

The structured analyses and the identification of mental models which are apparent in the student population, helps us in the next step of the TASTE project, namely the development of research based learning materials, both for school and the planetarium, which we hope will lead to a better understanding of all the aspects of the apparent motion of Sun and stars.

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References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19(6):716–723. https://www.doi.org/10.1109/tac.1974.1100705.

Bailey, J. M. and Slater, T. F. (2003). A review of astronomy education research. *Astronomy Education Review*, 2(2):20–45. https://doi.org/10.3847/AER2003015.

Bekaert, H., Van Winckel, H., Van Dooren, W., Steegen, A., and De Cock, M. (2020). Design and validation of an instrument to test students' understanding of the apparent motion of the sun and stars. *Physical Review Physics Education Research*, 16(2):020135. https://www.doi.org/10.1103/physrevphyseducres.16.020135.

Bekaert, H., Winckel, H. V., Dooren, W. V., Steegen, A., and De Cock, M. (2022). Identifying students' mental models of the apparent motion of the sun and stars. *Physical Review Physics Education Research*, 18(1):010130. https://doi.org/10.1103/physrevphyseducres.18.010130.

Brown, D. E. and Hammer, D. (2013). *International Handbook of Research on Conceptual Change*, pages 121–137. Taylor and Francis Inc. https://www.doi.org/10.4324/9780203154472.

Carey, S. (1986). *Conceptual Change in Childhood*. The MITPress, Cambridge, MA.

Chae, D., Han, J., and KIm, E. (2013). Analyzing gifted students' explanations for daily celestial motionbased on the earth-based and heliocentric frames of reference. *J Korea Assoc. Sci. Edu*, 33(3):664–678. https://www.doi.org/10.14697/jkase.2013.33.3.664.

Chastenay, P. (2015). From geocentrism to allocentrism: Teaching the phases of the moon in a digital full-dome planetarium. *Research in Science Education*, 46(1):43–77. https://www.doi.org/10.1007/s11165-015-9460-3.

Cole, M., Cohen, C., Wilhelm, J., and Lindell, R. (2018). Spatial thinking in astronomy education research. *Physical Review Physics Education Research*, 14(1):010139. https://www.doi.org/10.1103/PhysRevPhysEducRes.14.010139.

Collins, A. and Gentner, D. (1987). *How people construct mental models.* Cambridge University Press,Cambridge, UK.

Corpuz, E. and Rebello, N. S. (2011). Investigating students' mental models and knowledge construction of microscopic friction. i. implications for curriculum design and development. *Physical Review Special Topics - Physics Education Research*, 7(2):020102. https://www.doi.org/10.1103/physrevstper.7.020102.

Corpuz, E. and Robello, N. S. (2005). Introductory college physics students' explanations of friction and related phenomena at the microscopic level. In *AIP Conference Proceedings*. AIP. https://www.doi.org/10.1063/1.2084724.

Craik, K. J. W. (1943). *The nature of explanation*. Cambridge University Press, Cambridge, UK.

Eriksson, U. (2019). Disciplinary discernment: Reading the sky in astronomy education. *Physical Review Physics Education Research*, 15(1):010133. https://www.doi.org/10.1103/PhysRevPhysEducRes.15.010133.

Gilbert, J. K. and Boulter, C. (1998). Learning science through models and modelling. *International Handbook of Science Education*, pages 53–56. https://www.semanticscholar.org/paper/Learning-Science-Through-Models-and-Modelling-Gilbert-Boulter/2d72f021bf90ece85585ead7741a2dae11fd92f8.

Gozzard, D. R. and Zadnik, M. G. (2021). Contribution of self-directed, naked-eye observations to students' conceptual understanding and attitudes towards astronomy. *Physical Review Physics Education Research*, 17(1):010134. https://www.doi.org/10.1103/physrevphyseducres.17.010134.

Greca, I. M. and Moreira, M. A. (2001). Mental, physical, and mathematical models in the teaching and learning of physics. *Science Education*, 86(1):106–121. https://doi.org/10.1002/sce.10013.

Heywood, D., Parker, J., and Rowlands, M. (2013). Exploring the visuospatial challenge of learning about day and night and the sun's path. *Science Education*, 97(5):772–796. https://www.doi.org/10.1002/sce.21071.

IAU (2021). Astronomy education around the world. https://astro4edu.org/worldwide/. https://astro4edu.org/worldwide/.

Jee, B. D. and Anggoro, F. K. (2019). Relational scaffolding enhances children's understanding of scientific models. *Psychological Science*, 30(9):1287–1302. https://doi.org/10.1177/0956797619864601.

Johnson-Laird, P. N. (1983). *Mental models : towards a cognitive science of language, inference, and consciousness*. Harvard University Press, Cambridge, Mass.

Lelliott, A. and Rollnick, M. (2009). Big ideas: A review of astronomy education research 1974–2008. *International Journal of Science Education*, 32(13):1771–1799. https://doi.org/10.1080/09500690903214546.

Lopresto, B. M. C. and Murrell, S. R. (2011). An astronomical misconceptions survey. *J. Coll. Sci. Teach.*, 40(14). https://eric.ed.gov/?id=EJ963545.

Mant, J. and Summers, M. (1993). Some primary-school teachers' understanding of the earth's place in the universe. *Research Papers in Education*, 8(1):101–129. https://www.doi.org/10.1080/0267152930080107.

Panagiotaki, G., Nobes, G., and Banerjee, R. (2006). Is the world round or flat? children's understandingof the earth. *European Journal of Developmental Psychology*, 3(2):124–141. https://www.doi.org/10.1080/17405620500397732.

Plummer, J. D. (2009). A cross-age study of children's knowledge of apparent celestial motion. *International Journal of Science Education*, 31(12):1571–1605. https://www.doi.org/10.1080/09500690802126635.

Plummer, J. D. (2014). Spatial thinking as the dimension of progress in an astronomy learning progression. *Studies in Science Education*, 50(1):1–45. https://www.doi.org/10.1080/03057267.2013.869039.

Plummer, J. D. and Krajcik, J. (2010). Building a learning progression for celestial motion: Elementary levels from an earth-based perspective. *Journal of Research in Science Teaching*, 47(7):768–787. https://www.doi.org/10.1002/tea.20355.

Plummer, J. D., Wasko, K. D., and Slagle, C. (2011). Children learning to explain daily celestial motion: Understanding astronomy across moving frames of reference. *International Journal of Science Education*, 33(14):1963–1992. https://www.doi.org/10.1080/09500693.2010.537707.

Rickheit, G. and Sichelschmidt, L. (1999). Mental models: Some answers, some questions, some suggestions. In *Mental Models in Discourse Processing and Reasoning*, pages 9–40. Elsevier. https://www.doi.org/10.1016/s0166-4115(99)80045-4.

Sadler, P. M. (1987). Misconceptions in astronomy. *Proceedings of the Second International Seminar on misconceptions and educational strategies in science and mathematics*, 3:422–425. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=Qx1j90UAAAAJ&citation_for_view=Qx1j90UAAAAJ:kRWSkSYxWN8C.

Schwarz, G. (1978). Estimating the dimension of a model. *The Annals of Statistics*, 6(2):461–464. http://www.jstor.org/stable/2958889.

Sharp, J. G. (1996). Children's astronomical beliefs: a preliminary study of year 6 children in south-west england. *International Journal of Science Education*, 18(6):685–712. https://www.doi.org/10.1080/0950069960180604.

Sneider, C., Bar, V., and Kavanagh, C. (2011). Learning about seasons: A guide for teachers and curriculum developers. *Astronomy Education Review*, 10(1):010103–010103–22. https://www.doi.org/10.3847/aer2010035.

Tao, Y., Oliver, M., and Venville, G. (2012). Chinese and australian children's understandings of the earth: a cross cultural study of conceptual development. *Cultural Studies of Science Education*, 8(2):253–283. https://www.doi.org/10.1007/s11422-012-9415-1.

Testa, I., Galano, S., Leccia, S., and Puddu, E. (2015). Development and validation of a learning progression for change of seasons, solar and lunar eclipses, and moon phases. *Physical Review Special Topics - Physics Education Research*, 11(2):020102. https://www.doi.org/10.1103/PhysRevSTPER.11.020102.

Treagust, D. F., Won, M., and McLure, F. (2017). *Converging Perspectives on Conceptual Change*. Routledge, London.

Trumper, R. (2000). University students' conceptions of basic astronomy concepts. *Physics Education*, 35(1):9–15. https://doi.org/10.1088/0031-9120/35/1/301.

Trumper, R. (2006). Teaching future teachers basic astronomy concepts—seasonal changes—at a time of reform in science education. *Journal of Research in Science Teaching*, 43(9):879–906.

Türk, C. and Kalkan, H. (2017). Teaching seasons with hands-on models: model transformation. *Research in Science & Technological Education*, 36(3):324–352. https://www.doi.org/10.1080/02635143.2017.1401532.

Ubben, M. S., Hartmann, J., and Pusch, A. (2022). "holes in the atmosphere of the universe": An empirical qualitative study on mental models of students regarding black holes. *Astronomy Education Journal*, 02(1). https://astroedjournal.org/index.php/ijae/article/view/29.

Uttal, D. H. and Cohen, C. A. (2012). Spatial thinking and STEM education. In *The Psychology of Learning and Motivation*, pages 147–181. Elsevier. https://doi.org/10.1016/b978-0-12-394293-7.00004-2.

Vosniadou, S. and Brewer, W. F. (1990). A cross cultural investigation of children's conceptions about the earth, the sun, and the moon: Greek and american data. https://www.semanticscholar.org/paper/A-cross-cultural-investigation-of-children's-about-Vosniadou-Brewer/43a75368f09e209c6542fc5813ec4de3f1273202.

Vosniadou, S. and Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science*, 18(1):123–183. https://www.doi.org/10.1207/s15516709cog1801_4.

Wagner, F. and Ros, R. M. (2003). The EAAE: Promoting astronomy education in europe. In *Astronomy Communication*, pages 177–188. Springer Netherlands. https://www.doi.org/10.1007/978-94-017-0801-2_10.

Weller, B. E., Bowen, N. K., and Faubert, S. J. (2020). Latent class analysis: A guide to best practice. *Journal of Black Psychology*, 46(4):287–311. https://www.doi.org/10.1177/0095798420930932.

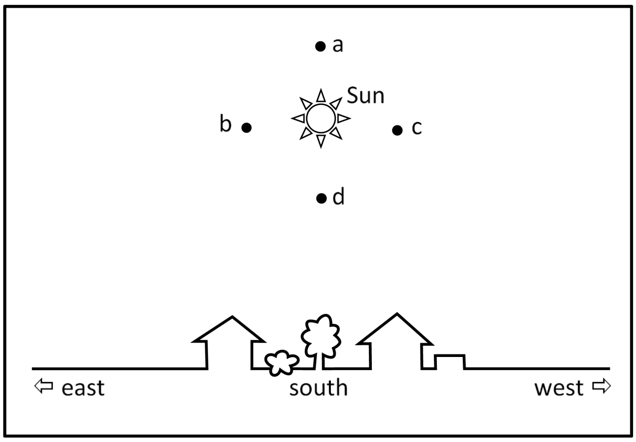
Yu, K. C., Sahami, K., Sahami, V., and Sessions, L. C. (2015). Using a digital planetarium for teaching seasons to undergraduates. *Journal of Astronomy & Earth Sciences Education (JAESE)*, 2(1):33. https://www.doi.org/10.19030/jaese.v2i1.9276.

Özsoy, S. (2017). Is the earth flat or round? primary school children's understandings of the planet earth: The case of turkish children. *International Electronic Journal of Elementary Education*, 4(2):407–415. https://www.iejee.com/index.php/IEJEE/article/view/207.

9 Appendix: AMoSS Questionnaire (version 2.0)

9.0.1 Question I.A

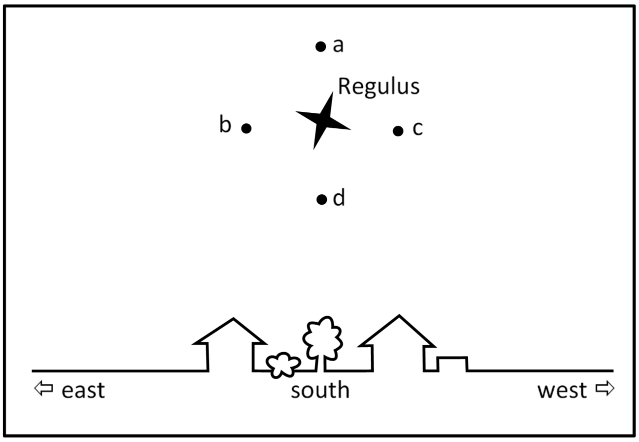
On March 21st, an observer in Brussels sees the Sun in the south high above the horizon as shown in the figure. Where does this observer see the Sun one hour later?



(*a*) Near point a
(*b*) Near point b
(*c*) Near point c
(*d*) Near point d
(*e*) In the same point: the Sun's position in the sky doesn't change.
(*f*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

9.0.2 Question II.A



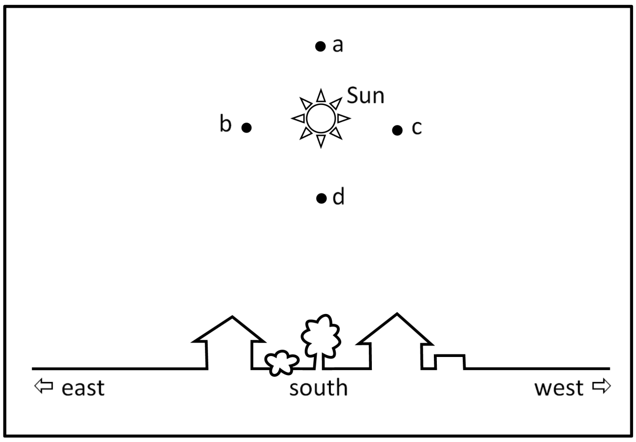
On March 21st, an observer in Brussels sees the star Regulus in the south high above the horizon as shown in the figure. Where will this observer see Regulus one hour later?

(*a*) Near point a
(*b*) Near point b
(*c*) Near point c
(*d*) Near point d
(*e*) In the same point: Regulus' position in the sky doesn't change.
(*f*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

9.0.3 Question I.B

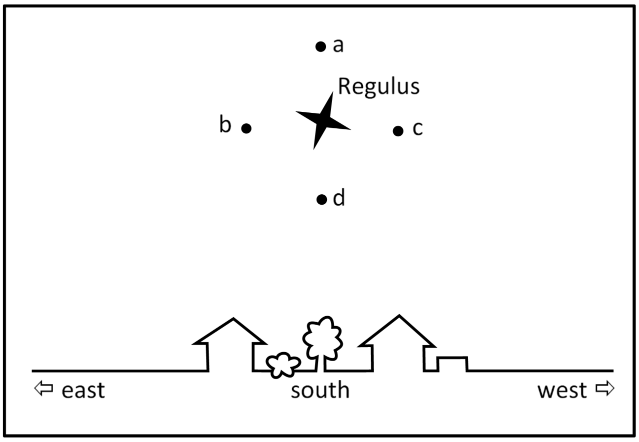
On March 21st, an observer in Brussels sees the Sun at its highest point, as shown in the figure. Where does this observer see the Sun one month later at its highest point?



(*a*) Near point a
(*b*) Near point b
(*c*) Near point c
(*d*) Near point d
(*e*) In the same point as on March 21st
(*f*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

9.0.4 Question II.B



On March 21st, an observer in Brussels sees the star Regulus at its highest point, as shown in the figure. Where does this observer see Regulus at its highest point one month later?

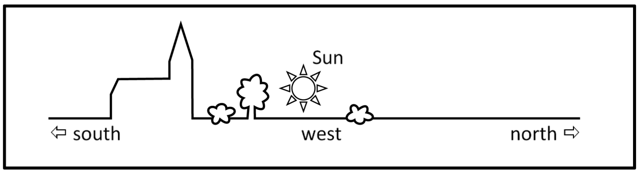
(*a*) Near point a
(*b*) Near point b
(*c*) Near point c
(*d*) Near point d
(*e*) In the same point as on March 21st
(*f*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

9.0.5 Question I.C

In September, an observer in Brussels sees the sunset in the west as shown in the figure. Where does this observer see the sunset one month later?

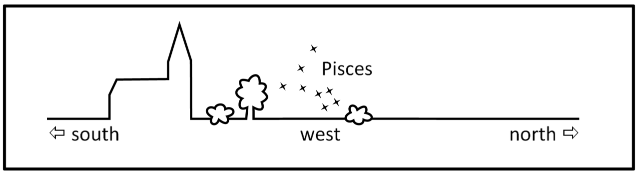
(*a*) More to the south
(*b*) At the same position



(*c*) More to the north
(*d*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

9.0.6 Question II.C



In September, an observer in Brussels sees the setting of the constellation Pisces in the west, as shown on the figure. Where does this observer see the setting of the constellation Pisces one month later?

(*a*) More to the south
(*b*) At the same position
(*c*) More to the north
(*d*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

9.0.7 Question I.D

On the first day of summer, the Sun rises to a maximum altitude of 62 degrees in Brussels. In another European city X, the maximum altitude of the Sun on the same day is 58 degrees. What can you conclude from this?

(*a*) Brussels is situated 4 degrees south of city X.
(*b*) Brussels is situated 4 degrees north of city X.
(*c*) Brussels is situated 4 degrees west of city X.
(*d*) Brussels is situated 4 degrees east of city X.
(*e*) From the position of the Sun, you can't make decisions about the location of city X.
(*f*) I really don't know.

Explain your choice: [Blank box occupying half a page provided for response]

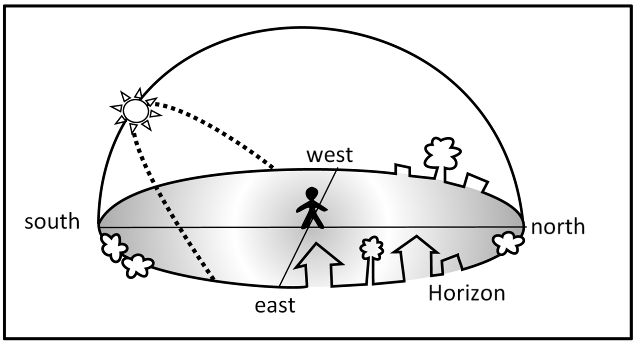
9.0.8 Question II.D

On the first night of winter, the star Mintaka reaches a maximum altitude of 39 degrees in Brussels. In another European city Y, the maximum altitude of Mintaka during the same night is 44 degrees. What can you conclude from this?

(*a*) Brussels is situated 5 degrees south of city Y.
(*b*) Brussels is situated 5 degrees north of city Y.
(*c*) Brussels is situated 5 degrees west of city Y.
(*d*) Brussels is situated 5 degrees east of city Y.
(*e*) From the position of Mintaka, you can't make decisions about the location of city Y.
(*f*) I really don't know.

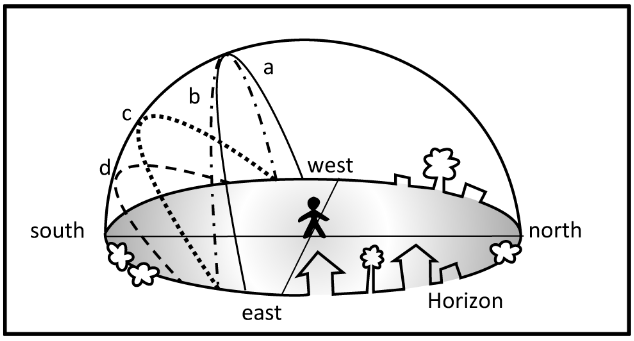
Explain your choice: [Blank box occupying half a page provided for response]

9.0.9 *Question I.E*



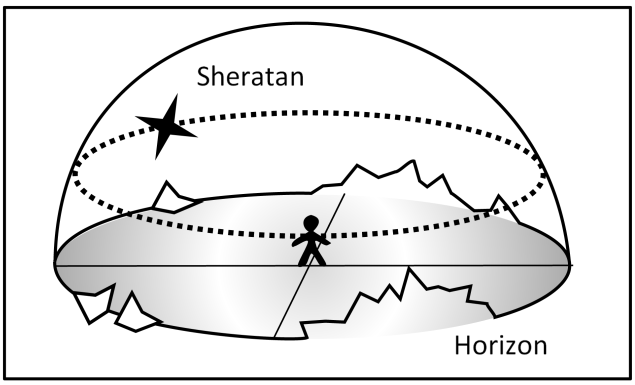
The dotted line describes the motion of the Sun on November 1st for an observer in Brussels. This line is called the Sun's path. How does an observer see the Sun's path on the same day, at 2000 km south of Brussels?

(*a*) According to the full line a
(*b*) According to the dashed line b
(*c*) According to dotted line c: same Sun's path as in Brussels.
(*d*) According to the dashed line d
(*e*) None of these lines represents the Sun's path.
(*f*) I really don't know.



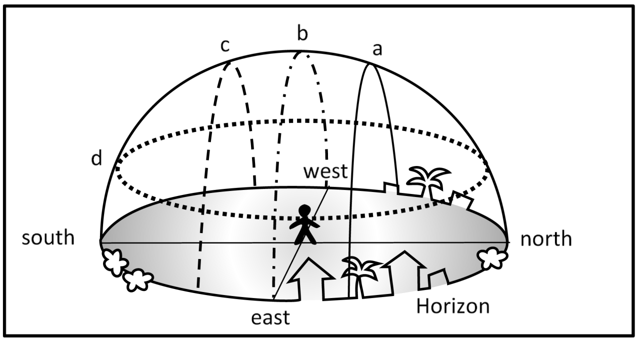
Explain your choice: [Blank box occupying half a page provided for response]

9.0.10 *Question II.E*



The dotted line describes the motion of the star Sheratan on November 1st for an observer at the North Pole. This line is called Sheratan's star trail. How does an observer at the equator see Sheratan's star trail in the same night?

(*a*) According to the full line a
(*b*) According to the dashed line b
(*c*) According to dashed line c
(*d*) According to the dotted line d: the same star trail as at the North Pole
(*e*) None of these lines represents the star trail there.
(*f*) I really don't know.



Explain your choice: [Blank box occupying half a page provided for response]

9.0.11 *Question III*

In Belgium we experience different seasons throughout the year. What is the main cause of this?

(*a*) The distance between the Earth and the Sun changes throughout the year.
(*b*) The speed of the Earth on its orbit around the Sun changes throughout the year.
(*c*) Due to the tilt of the Earth's axis, Belgium is sometimes closer to and sometimes further away from the Sun throughout the year.
(*d*) Due to the tilt of the Earth's axis, the maximum height the Sun reaches during a day changes throughout the year.
(*e*) I really don't know.

9.0.12 *Question IV*

The constellation Gemini is visible in Brussels in February during the night, but not in July. Why is this?

(*a*) In July, the constellation Gemini doesn't rise above the horizon for an observer in Brussels.
(*b*) When the constellation Gemini is above the horizon in July for an observer in Brussels, the Sun is also above the horizon.
(*c*) In July, the constellation Gemini is only visible in the southern hemisphere of the Earth.
(*d*) Because the Earth rotates around its axis, you see different stars in the sky in July than in February.
(*e*) I really don't know.