Investigating students' insight after attending a planetarium presentation about the apparent motion of the Sun and stars

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We present two studies to investigate the extent to which attending a planetarium presentation increases secondary school students' understanding of the apparent motion of the Sun and stars. In the first study, we used the Apparent Motion of Sun and Stars (AMoSS) test in a pretest/post-test/retention test setting to measure learning gains and improved insight of 404 students (16- to 17-year-olds) after attending a classical planetarium presentation at the Brussels Planetarium. The AMoSS test is a questionnaire on the daily and yearly apparent motion and the observer's position. It consists of six multiple-choice questions about the Sun and six similar multiple-choice questions about the stars. We asked the students to explain their choices. The learning gains are rather small and the scores improve more on the Sun questions than on the star questions. This difference is largest for questions about the yearly apparent motion. We found that this is due to the fact that many students copy their knowledge about the Sun to the stars. Based on the results of this survey, we developed a new planetarium presentation with particular attention to the use of the celestial sphere model. We also developed a learning module that prepares students at school for this planetarium presentation. In a second study, we measured the learning gains after attending this new planetarium presentation among 339 students, also 16- to 17-year-olds. Some school groups had worked through the preparatory learning module at school and others had not. We find that the learning gains on the star questions are significantly higher than in the first study, due to better scores on the yearly apparent motion questions. In this regard, it is notable that we do not see significant differences between those students who prepared the presentation at school and those who did not. In the second study, the number of students who answer all questions correctly after attending the planetarium presentation or working through the learning module increases, but only significantly for those students who worked through the learning module at school.

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I. INTRODUCTION AND PROBLEM STATEMENT

Young children, students, and adults may have difficulty in correctly describing and explaining the apparent motion of the Sun and stars [1–6]. For example, they do not realize that the sunset position changes daily or that stars describe a star trail during the night [4]. Many planetariums consider their planetarium environment the preferred place to teach this topic [7]. However, as far as we know, for the target audience we are aiming at, there is no systematic study that investigates the effectiveness of planetarium interventions in this regard. Therefore, we want to investigate to what extent a research-based planetarium presentation supports fifth year secondary school students (16- to 17-year-olds) to gain a better understanding of the apparent motion of the Sun and stars. It is valuable to verify this for this age group because in Flanders studying the apparent motion of the Sun is part of their curriculum and a lot of schools make a trip to a planetarium in the context of these lessons.

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In the first study, we investigated to what extent the classical presentation in the Brussels planetarium, as it is currently offered to secondary school groups, gives the students insight into the apparent motion of the Sun and stars. Based on the results of this first study and the literature, we developed a new planetarium presentation with a particular focus on the 3D model of the celestial sphere. We also designed a learning module to prepare for the trip to the planetarium at school. In a second study, we measured the effectiveness of the new presentation and learning materials. In this article, we describe the two studies, the development of the new planetarium presentation, and the accompanying learning materials. We compare the results of the two studies. Section II starts with a review of students' difficulties when studying the apparent motion of celestial bodies and refers to research on the role planetariums can play in astronomy education. In Sec. III, we formulate the research questions. In Secs. IV–VI, we describe the first study, the preparation of the new planetarium presentation, and the second study, respectively. We discuss the results in Sec. VII and the limitations in Sec. VIII. We end with conclusions (Sec. IX).

II. BACKGROUND

A. Students' difficulties in studying the apparent motion of the Sun and stars

Several studies have shown that children, adolescents, and adults may have difficulty in correctly describing and explaining the apparent motion of the Sun and stars [1–6]. In this regard, it is notable that the apparent motion of the stars is more difficult to understand than that of the Sun. Although many students learn in school about the Earth's rotation on its axis and the Earth's revolution around the Sun, they do not spontaneously relate those motions to the apparent motion of celestial bodies. For example, Heywood *et al.* [8] asked 26 preservice teachers to explain the Sun's apparent motion. No one attributed this motion to the rotation of the Earth about its axis while they did for the day and night cycle. Several studies [9,10] suggest that special instruction is needed to develop a good understanding of the apparent motion of the Sun and stars. Plummer *et al.* [6,9] argue that it is important to teach students to think in different reference systems and to encourage them to view motions of celestial bodies both from the observer's point of view on Earth (geocentric perspective) and from space (allocentric perspective). Moreover, in order to support student learning, it is essential to consider their alternative ideas during instruction and to realize that transforming those ideas is a slow and difficult process [11]. We list the main alternative ideas related to the apparent motion of the Sun and stars as described in the literature:

1. The apparent motion of celestial bodies is due to the Earth's revolution around the Sun [1,12,13].

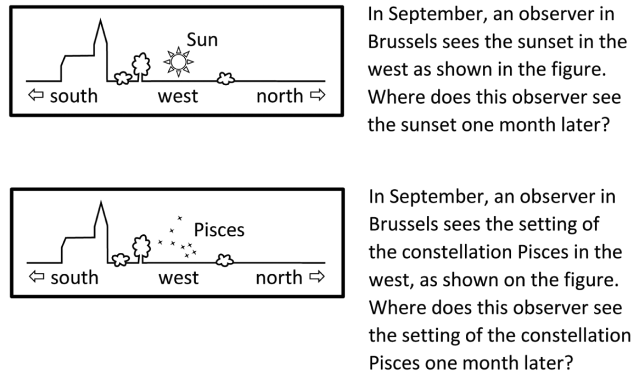

FIG. 1. Shortened version of questions I.C and II.C. For the complete version, see Ref. [18].

2. The Sun always rises exactly in the east and sets exactly in the west [8].
3. Stars do not move in the sky [1,4,14].
4. The Sun is higher in the sky in winter than in summer [14].
5. It is warmer in summer than in winter because in summer the Earth is closer to the Sun [15].

To gain a deeper understanding of these alternative ideas, we developed the Apparent Motion of the Sun and Stars (AMoSS) test in a previous study [16]. In that study, we identified the elements that play a role in the apparent motion of the Sun and stars in relation to the time of the day, time of the year, and the observer's position on Earth. We list these elements in Table VII in Appendix A. A multiple-choice question was designed for each element. Consequently, the AMoSS test contains 12 multiple-choice questions: six questions about the Sun and six similar questions about the stars (for example, see Fig. 1). The systematic design allows us to compare students' ideas of the Sun's apparent motion with that of the stars. We used the test in the first study, where we also asked the students to explain their choices. The results allowed us to identify several mental models which students use when answering the questions of the AMoSS test. For example, some students think that star trails are higher and wider in winter because the nights are longer then. In Sec. IV with the description of study 1, we elaborate on this and we summarize the main mental models that were identified in the first study and reported in a previous manuscript [17].

With our research, we try to find out how we can make these alternative mental models evolve into a correct scientific model and what role a planetarium can play in this. According to Cole *et al.* [19], it is not enough for students to know the cause of certain astronomical phenomena. They must also have the necessary spatial skills to form a correct mental model of these complex phenomena [20].

B. Teaching astronomy in the planetarium

From the very start of the first planetarium at Deutches Museum in 1925, education researchers have been exploring how a planetarium can support astronomy education. With the introduction of digital projectors and mobile planetariums, the possibilities have only increased compared to the very first classical Zeiss projectors. In Belgium, schools have the opportunity to visit a planetarium or invite a mobile planetarium to school. It is thus worthwhile to investigate if a planetarium is a better learning environment than the classroom for teaching astronomy. Research on this topic suggests that there is no single answer [21]: some studies conclude that the classroom has significant advantages over a planetarium [22,23] while other studies show that the planetarium offers opportunities that outperform the classroom [4,10,24].

Reed [25] measured college students' ($N = 159$) understanding of the daily and yearly apparent motions of the Sun and stars and he compared the effectiveness of a planetarium to a classroom as a learning environment. What was unique about his research was that he used celestial spheres in the classroom and in the planetarium that the students could manipulate, thus actively engaging them in the lesson and in the planetarium presentation. Since the scores of participants who took the class at school were higher in both the post-test and the retention test than those who took the planetarium presentation, he suggested that also the planetarium could best be used as a classroom, where best teaching practices were applied in order to make students more active learners.

Edoff [26] explored this idea by also letting fifth and eighth grade students ($N = 542$) individually use manipulatives in the planetarium. He compared two groups of students: a group that attended a classical presentation and a group that used plastic celestial spheres during the presentation to which they could glue celestial objects. The topics of the presentation were (i) the celestial sphere and time, (ii) seasonal changes, and (iii) lunar motion and Moon phases. In the post-test, he found better results in the group using manipulatives than in the group that did not use these.

In addition to the use of these manipulatives during the planetarium presentation, active participation in the planetarium presentation also appears to result in bigger learning gains. Plummer [10] encouraged third grade students in her study to use body gestures (kinesiology) to trace the Sun's path and star trails in the sky. These movements allowed them to better describe the apparent motion of celestial bodies during an interview after the learning activity, compared to students who had taken a learning activity with a different approach on the same topic. Using body gestures also appears to help students fluently switch between the geocentric frame of reference and the allocentric frame of reference [9]. This in turn allows them to develop a better understanding of the apparent motion of the Sun and stars.

Although these studies show that the planetarium can be a good learning environment for teaching astronomy, none of these studies consider the unique capabilities of the projections on the dome. The fact that you can project the night sky on a dome provides a real-life simulation in three dimensions (3D). Educational researchers have recommended the use of 3D models as being crucial for astronomy education [27]. Since the figures in textbooks or the images projected in class are a two-dimensional (2D) representation of a 3D phenomenon, it is difficult for students to build conceptual knowledge about a 3D physical space while being taught using 2D materials [28].

An added benefit of projecting on the dome is that students are completely surrounded by the projected images. Research has shown that visual immersion itself has benefits for learning by reducing cognitive load and increasing attention [29]. With immersive visualizations, users can be inside as well as outside the 3D model. The ability to change frames of reference is an important strength of the digital planetarium. Switching between these different frames of reference, speeding up time, or leaving out the atmosphere with the planetarium software allow users to do things that would be difficult or impossible to observe in real life.

Zimmermann and co-workers [30] compared short- and long-term learning gains among students who attended the 24 min "We Choose Space" planetarium film in a mobile planetarium with students who saw the same presentation on a flat computer screen in a regular classroom. Both groups achieved the same learning gains from pretest to post-test. However, in the retention test after 6 weeks, the students who attended the presentation in the mobile planetarium retained their learning gains, but the other group returned to their scores in the pretest. Zimmermann concluded that passively following a presentation on a flat computer screen does not have the same long-term learning effect as passively following the same presentation in the mobile planetarium.

The above studies show that the planetarium can be an effective learning environment, provided the visual presentation techniques are combined with good teaching practices: using 3D models, stimulating interactivity, … Taking into account these findings and the fact that we have a clear view on students' difficulties as elaborated in Sec. II A, we aim at investigating the effect of a specific, purposefully designed planetarium presentation on students' understanding of the apparent motion of the Sun and stars.

III. RESEARCH QUESTION

In the first phase of the SLOPE (Studying Learning Opportunities in a Planetarium Environment) research project, we investigated to what extent the existing planetarium presentation of the Brussels planetarium supports students' understanding of the apparent motion of the Sun and stars. We limit ourselves to students in the fifth year of secondary education (16- to 17-year-olds) since in Flanders

TABLE I. Topics covered by the Brussels planetarium presentation for school groups.

PART I (80 min)	PART II (50 min)
1 The night sky with well-known star constellations	11 Lunar phases
2 The position of the pole star	12 Solar eclipse
3 Star trails for observers at different latitudes	13 Dance of the planets
4 Circumpolar stars	14 Asteroid belt
5 Different coordinate systems	15 Properties of the Sun
6 The Sun's path for different times throughout the year and for observers at different latitudes	16 Properties of the different planets in the Solar System
7 Earth's revolution around the Sun	17 Properties of Pluto
8 Ecliptic	18 Supernovae
9 Constellations of the horoscope	19 Distances
10 Precession of the Earth's axis	20 Interstellar matter
	21 Observation of planets and galaxies, clusters and superclusters

this topic is taught to these students in the geography course. Based on the results of this first study, we designed a new planetarium presentation. We also developed a learning module that can be implemented at school to prepare the planetarium visit. With a second study, we measured the effectiveness of this new presentation.

The research questions therefore are as follows:

1. To what extent does a classical planetarium presentation improve the insight of secondary school students in the apparent motion of the Sun and stars?
2. To what extent does the revised planetarium presentation improve the insight of secondary school students in the apparent motion of the Sun and stars?

Two subquestions we ask in this regard are as follows:

3. To what extent does preparing for a planetarium visit at school by means of a learning module improve students' insight when attending a planetarium presentation?
4. To what extent does the use of a 3D model improve students' insight when attending a planetarium presentation?

Improved insight is not restricted to increased test scores only. Increasing test scores is what we call learning gain. However, improved insight is broader than learning gain. It implies that students shift to a mental model that is closer to the correct scientific model.

IV. STUDY 1: IMPROVING STUDENTS' INSIGHT WITH A CLASSICAL PLANETARIUM PRESENTATION

A. Methodology

In a first study, we used the AMoSS test to assess the learning gains and improved insight of students (16- to 17-year-olds) who attended the Brussels planetarium presentation as part of a school visit. The Brussels planetarium is one of the oldest and largest in Europe and has 350 seats under the 23 m diameter dome. At its center is a mechanical Zeiss projector, but the dome is also equipped with a digital projection system with eight projectors. The planetarium has a broad educational program for many different audiences. The presentation we examined is the standard presentation for secondary school students. A planetarium employee brings a live presentation in two parts. The first part lasts 80 min and the second part 50 min. There is a 15-min break between the two parts. Table I lists the topics covered in each part.

For school presentations, the number of participants in the dome is limited to a maximum of 150 students. Most of the time during the presentation, the planetarium operator himself is speaking and providing explanations of the images presented. Sometimes, the presentation is interrupted for a short demonstration, e.g., the precession movement of the Earth's axis. The audience is also asked questions, but this is rather limited. The dome remains darkened during the presentation, so asking questions to the audience is not obvious. There is also no use of technology to make interaction easier.

The first study had a pretest/post-test/retention test design. There were 404 participating students from 6 different schools. Only students who participated in all tests and signed an informed consent form were included in this study. All students were in the fifth year of general secondary education, where an introduction to astronomy is part of the geography curriculum, as determined by the Flemish government. In these lessons, the Earth's rotation, Earth's revolution, the Sun's path throughout the year, the ecliptic, … were discussed. For a complete overview of topics covered, please refer to Appendix B. All elements of the AMoSS test were addressed in one way or another, but not all different aspects of the apparent motions of the Sun and stars were discussed explicitly and systematically during the lessons. This topic is also not covered in other courses or other grade levels.

TABLE II. Study 1: mean scores in % on the pretest, post-test, NP test, and retention test for the three groups ($N = 404$). In parentheses, we indicate the learning gains relative to the pretest for groups 1.1 and 1.2 and relative to the NP test (No Planetarium test) for group 1.3.

		Pretest		Post-test		NP test		Retention test	
		Sun	Star	Sun	Star	Sun	Star	Sun	Star
GROUP 1.1	Mean	39	31	51 (+12)	40 (+9)			54 (+15)	39 (+8)
($N = 200$)	Standard deviation	20	19	20	20			21	22
GROUP 1.2	Mean	38	26	48 (+10)	34 (+8)			44 (+6)	28 (+8)
($N = 73$)	Standard deviation	21	17	21	18			21	19
GROUP 1.3	Mean					53	31	58 (+5)	35 (+4)
($N = 131$)	Standard deviation					22	21	21	19

We divided the schools into three groups:

1. Group 1.1: Students who attended the planetarium presentation before the start of the astronomy lessons at school.
2. Group 1.2: Students who attended the planetarium presentation after the astronomy lessons at school.
3. Group 1.3: Students who did not attend the planetarium presentation.

The students of group 1.1 and 1.2 took the AMoSS test as a pretest just before the start of the planetarium presentation. Immediately after the presentation, they took the AMoSS test again as a post-test, each time in the auditorium of the Brussels planetarium. For group 1.1, this happened in September 2019, for group 1.2 in November 2019. Group 1.3 students took the AMoSS test after their astronomy classes at school, also in November 2019. Since this group did not attend a planetarium presentation, we simply call this test "NP test" (No Planetarium test). In December 2019, all these students took exams of the material covered. The retention test followed after the winter break, administered at school by the teacher (January 2020). In each test, students were given the same questions, but in different order. The test lasted 45 min each time. For 6 of the 12 multiple-choice questions, we asked students to write an explanation for the choice they made. Due to time constraints, it was not possible to ask for an explanation for each multiple-choice question. By making different sets of questions in different order and where different questions required an explanation, we ensured that we could collect sufficient written explanations for all questions.

B. Findings

To analyze the multiple-choice answers, a score of 1 was given if the correct alternative was chosen and 0 if no answer was given or if an incorrect alternative was chosen. Table II shows for the three groups the mean scores with the standard deviation of the pretest, post-test, and retention test. Overall, the scores are low: the mean score for the Sun questions varies between 38% and 53%, and for the star questions between 26% and 31%. We see in groups 1.1 and 1.2, which attended the planetarium presentation, in the post-test a learning gain between 8% and 12% on both the Sun questions and the star questions. The score of group 1.1 remained stable in the retention test while that of group 1.2 decreased somewhat. Group 1.3, which did not attend the planetarium presentation, achieves the best mean score on the Sun questions and also outperforms group 1.2 for the star questions both in pretest and retention test. A paired-samples t test was conducted to compare the mean scores of Sun and star questions on the first test (pretest or NP test) and retention test. Groups 1.1 and 1.3 achieve significantly better scores on the retention test than on the pretest or NP test on both the Sun and Star questions ($p < 0.05$).

To compare the scores on the six Sun and the six star questions, a second paired-samples t test was conducted. For all groups, the difference between the mean score on the Sun questions and the star questions for the three tests is significant ($p < 0.001$). To get a better view of these differences, we present a bar graph for each group (see Figs. 2–4), which shows for each question and the three

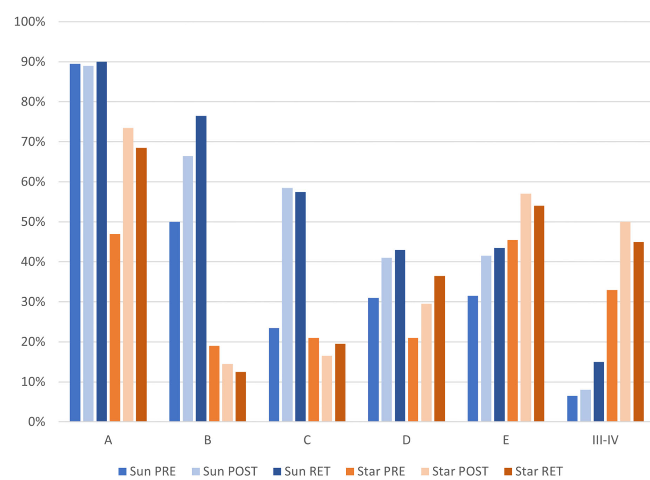

FIG. 2. Group 1.1 (planetarium visit before the astronomy lessons at school): percentage of students with a correct answer per question.

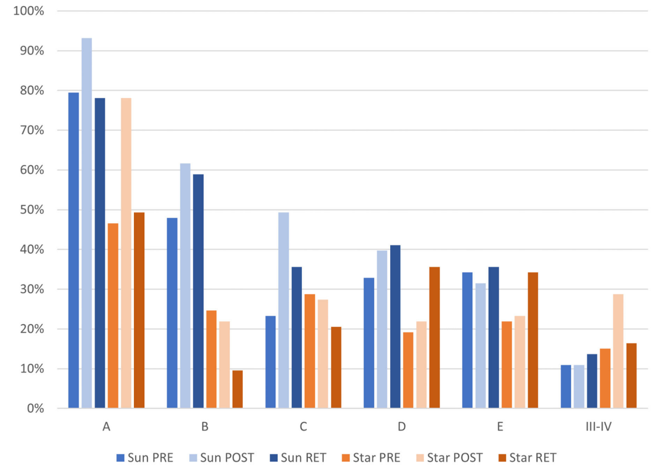

FIG. 3. Group 1.2 (planetarium visit after the astronomy lessons at school): percentage of students with a correct answer per question.

tests the percentage of students who answered the question correctly. On the horizontal axis, we refer to the questions with the letters A, B, C, … that correspond to the rows in Table VII (see Appendix A). Question A is about daily motion, B and C about yearly motion, D and E about observer position, and III and IV about seasons. In these graphs, the difference between the Sun and star questions is most notable in the questions about the yearly motion. We also see that attending a planetarium presentation especially improves the score for the question on the daily motion of the stars (question A) and the change in the position of the sunset throughout the year (question C).

To gain insight in the mental models students use when answering questions of the AMoSS test, we asked them to explain their answers. To analyze these answers, we classified them with a categorization scheme that was developed, validated, and reported by Bekaert *et al.* [17]

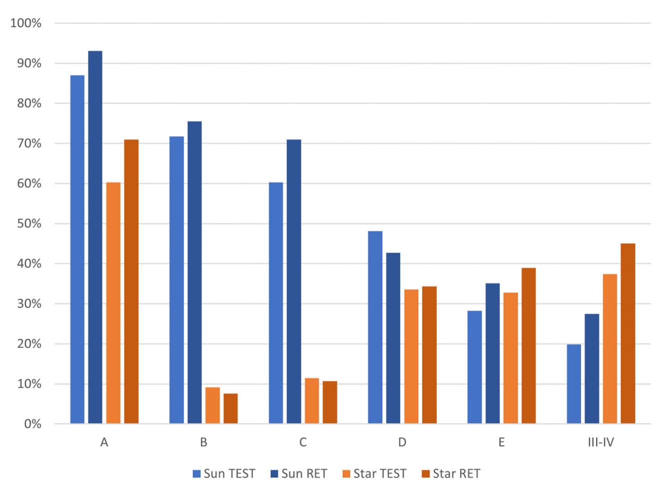

FIG. 4. Group 1.3 (no planetarium visit): percentage of students with a correct answer per question.

by using data from the retention test of study 1. We used the following codes:

1. Statement (S) vs Model (M):
   - S: the explanation is based on an observation from the point of view of an observer on Earth or on something the student remembers;
   - M: the explanation shows at least one element of an allocentric point of view (the view from space);
2. Correct (C) vs false (F):
   - C: the written explanation is correct;
   - F: the written explanation is false;
3. Relevant (R) vs not relevant (NR):
   - R: The written explanation is relevant for the question;
   - NR: The written explanation is not relevant for the question.

Table III shows how the responses to the retention test were classified into different categories. We can summarize that:

1. Most students write a statement (S) based on an observation from the point of view of an observer on Earth or on something the student remembers.
2. When students refer to an allocentric point of view (M), they do this more often for the star questions than for the Sun questions.
3. The majority of written explanations are correct and relevant.

Complementary to the categorization of written explanations, we performed a latent class analysis to detect qualitatively different groups in the population. This allowed us to identify different mental models that students use when answering questions about the apparent motion of the Sun and stars. We reported on this in an earlier manuscript [17]. Here we summarize the main findings:

1. For many students (35%), the apparent motion of stars proceeds identically to that of the Sun. In summer, star trails, like the Sun's path, are higher and wider than in winter. Observers at lower latitudes see the Sun's path and star trails higher and wider than observers at higher latitudes.
2. A small group of students (7%) thinks that star trails are higher and wider in winter than in summer because the nights are longer. For observers

TABLE III. General overview of the classification of the written explanations of the retention test of study 1 [17].

	Sun questions (%)	Star questions (%)
Statement (S)	38	22
Model (M)	18	22
Correct (C)	43	25
False (F)	12	19
Relevant (R)	62	32
Not relevant (NR)	1	5

at a higher latitude, star trails are also higher and wider because during winter there, the nights are longer.
3. A lot of students (19%), when asked questions about how star trails change throughout the year or depend on the latitude of the observer, give a wrong answer or choose the "I don't know" option.
4. A group of students (20%) struggles with the concept of culmination height: they are not sure how to interpret this angle, how it should be indicated on a figure and how it is related to the latitude of the observer and the time of year. Some students think that the culmination height is proportional to the observer's latitude.
5. Many students (19%) do not understand how the position of sunrise or sunset change throughout the year. They are not aware that these points for stars do not change throughout the year. Some students think that the Sun always rises in the east and sets in the west, independent of the time of the year or the observers' latitude.

V. PREPARING AN INTERVENTION

A. Development of a new planetarium presentation

Based on the results of study 1 combined with what we learned from the literature, we developed a new planetarium presentation. We list the underlying design principles and refer to related literature:

1. During the presentation, we explain the similarities and differences between the Sun and the stars systematically [16,17].
2. We encourage students to think in and switch between different reference systems: the geocentric point of view and the allocentric point of view. We use the possibilities of a digital planetarium to display both systems of reference [10].
3. During the presentation, we use a physical 3D model of the celestial sphere, whose different parts are introduced and explained step by step, for example, the observer's horizon, the equator, the ecliptic, etc., [25,26].
4. We encourage interaction by asking questions to stimulate model based thinking during the presentation.
5. We make the presentation efficient and not too long so that students can keep their attention.

Since the planetarium presentation in study 1 took place in the Brussels planetarium, the intention was to develop a new presentation for this planetarium. As a result of the COVID-19 crisis with lockdowns, we had to change this plan. We decided to use the inflatable mobile planetarium of the Brussels planetarium with a central projector and fisheye lens, which could accommodate 25 students. We developed the new presentation with Spacecrafter software. It consists of seven sections:

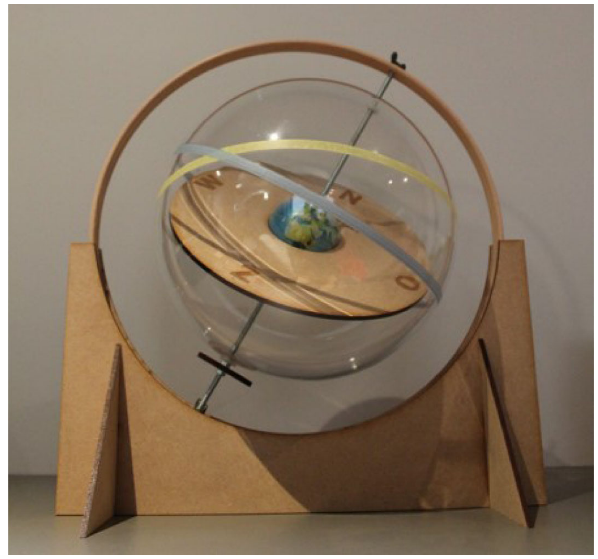

FIG. 5. The 3D model of the celestial sphere used during the planetarium presentation.

1. The daily motion of the stars.
2. The celestial sphere.
3. The daily motion of the Sun.
4. The change of the Sun's path throughout the year.
5. The star trail throughout the year.
6. The star trail for different observers on Earth.
7. The Sun's path for different observers on Earth.

Each time a new section started, the title was projected so that the structure of the presentation was clear to the students. In between, from time to time, the dome was brightly lit so that the planetarium operator could see the students, ask questions, or demonstrate the 3D model of the celestial sphere (see Fig. 5). The presentation lasted about 80 min.

B. Development of the learning module

Since we want to investigate whether preparing at school for a planetarium visit improve students' insight, we developed a learning module that specifically prepares for the newly designed presentation. At the start of this process, we defined the following prerequisites:

1. While working through the learning module, students are introduced to the different elements of the celestial sphere. They are provided with a 3D model that they can manipulate while making the exercises. With this model, we stimulate students to think in and switch between different frames of reference [9].
2. All activities are hands-on. Teacher instruction is kept to a minimum so that students actively engage with the concepts being taught.
3. To discover similarities and differences between the Sun and the stars, for each exercise on the Sun, an analogous exercise on the stars is provided [4,17,31].

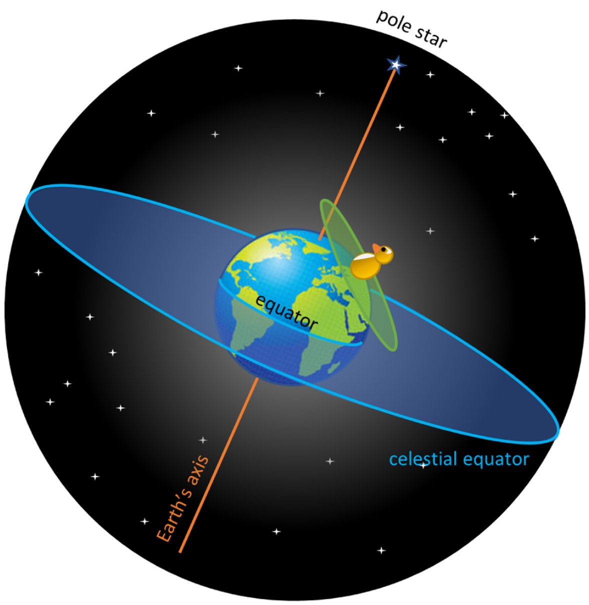

FIG. 6. An example of an image used both in the learning module and the planetarium presentation.

4. The learning module should be completed in two 50-min lessons.

The learning module is structured around two themes:
1. The daily motion of the Sun and the stars;
2. The Sun's path and the star trails throughout the year.

Originally, there was a third theme about the position of the observer on Earth, but due to the time constraints, we had to omit this theme. To increase the link with the planetarium presentation, we used in the learning module the same 3D model of the celestial sphere and the same figures that were used as allocentric 2D presentations in the planetarium presentation. Figure 6 shows an example.

The development of the planetarium presentation and the learning module was an iterative process. Several test runs were organized after which students and teachers could provide feedback. Based on this feedback, the materials were adapted.

VI. STUDY 2: IMPROVING STUDENTS' INSIGHT WITH THE REVISED PLANETARIUM PRESENTATION

A. Methodology

To verify whether the new planetarium presentation we developed based on the results of the first study described above and based on the literature improve students' insight, we have set up a second study. This study also had a pretest/post-test/retention test design. About 339 students from the same target group as the first study (16- to 17-year-olds) participated. The students came from six different schools, one of which had not participated in the first study. We divided the schools into three groups:

1. Group 2.1: These students attended the planetarium presentation after working through the preparatory learning module with their teacher.
2. Group 2.2: These students only worked through the learning module and did not attend the planetarium presentation.
3. Group 2.3: These students only attended the planetarium presentation without taking the preparatory learning module.

We again used the AMoSS test as a measurement instrument. Compared to the first study, question III was transformed into a multiple-choice question with only 1 correct alternative. In the first version of the AMoSS test, this was a question with multiple correct alternatives. The content of the question remained the same, but the alternatives of the multiple-choice question were reformulated. The students of groups 2.1 and 2.2 took the AMoSS test as a pretest just before the start of the learning module, which was scheduled after the astronomy lessons in the geography classes. The students of group 2.1 took the AMoSS test again as a post-test immediately after the presentation in the mobile planetarium at school. The students of group 2.2 did so right after finishing the learning module. Group 2.3 students took the pretest immediately before the planetarium presentation and the post-test immediately after the planetarium presentation. The study took place in October and November 2022. Since every planetarium presentation was given by the same person (the first author of this article) and only 25 students could attend the presentation at a time, the presentation was repeated 15 times. All the students took exams on the material covered in December 2022 and after the winter break they took the retention test, which was administered at school by the teacher (January 2023). In each test, students were given the same questions but in different order. The pretest and post-test took 20 min each. The retention test lasted 45 min. We decided to ask for written explanations only in the retention test, for 10 out of 12 questions. The questions about the seasons (questions III and IV) did not require an explanation because the alternatives of the multiple-choice question already contain explanation.

B. Findings

We calculated the scores the same way as in the first study: 1 point for a correct answer and 0 points for an incorrect or missing answer. Table IV shows the mean scores on the three tests for the three groups, along with the standard deviation. In the pretest, the scores on the Sun questions are somewhat higher than in the first study, but for the star questions, the scores are very similar. On the Sun questions, we see a learning gain from pretest to post-test between 9% and 14% in the three groups, similar to the first study, but for the star questions, we see a stronger increase, between 17% and 23%. All groups maintain or slightly improve their scores on the Sun questions in the

TABLE IV. Study 2: Mean scores in % on the pretest, post-test, and retention test for the three groups ($N = 339$). In parentheses, we indicate the learning gains relative to the pretest.

		Pretest		Post-test		Retention test	
		Sun	Star	Sun	Star	Sun	Star
GROUP 2.1	Mean	63	35	72 (+9)	55 (+20)	72 (+9)	47 (+12)
($N = 85$)	Standard deviation	24	22	22	25	21	24
GROUP 2.2	Mean	54	30	66 (+12)	47 (+17)	70 (+16)	42 (+12)
($N = 90$)	Standard deviation	25	18	22	23	21	27
GROUP 2.3	Mean	57	30	71 (+14)	53 (+23)	71 (+14)	42 (+12)
($N = 164$)	Standard deviation	23	19	21	26	23	25

retention test, but in the star questions, the scores drop between 5% and 9%. A striking observation is that there are few differences between the three groups: working through the learning module in preparation for the planetarium presentation does not lead to better results in the retention test. The group that only worked through the learning module achieved the same results in the retention test as the group that only attended the planetarium presentation. Compared to the first study, we see significantly better learning gains from pretest to retention test only for the star questions ($p < 0.001$). However, the difference between the Sun questions and the star questions remains large. With a paired-samples t test, we found that for all groups, the difference between the mean score on the Sun questions and the star questions for the three tests is significant ($p < 0.001$).

We explore these differences using the bar graphs in Figs. 7–9. We see that working through the learning module and/or attending the planetarium presentation mainly affects the score of the star questions B, C about apparent motion of the stars throughout the year, and IV about the sky map changes throughout the year. Unlike the first study, here we do see a clear progress in the post-test. Also for the question about the daily motion (question A) of the stars, we see in the post-test an improvement of the score in groups 2.1 and 2.3, who attended the planetarium presentation.

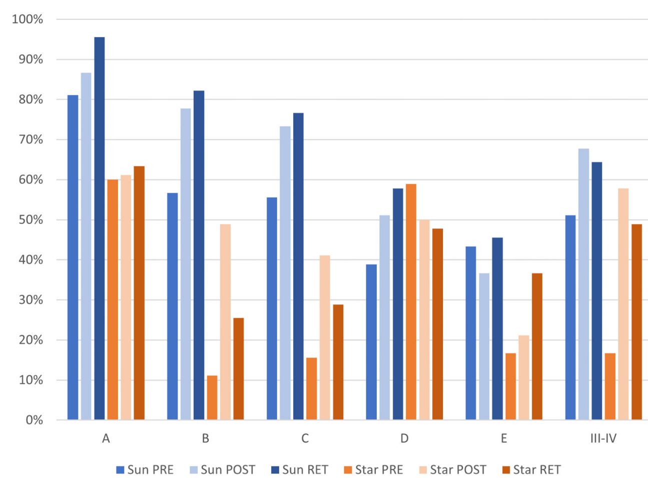

FIG. 8. Group 2.2 (only learning module): Percentage of students with a correct answer per question.

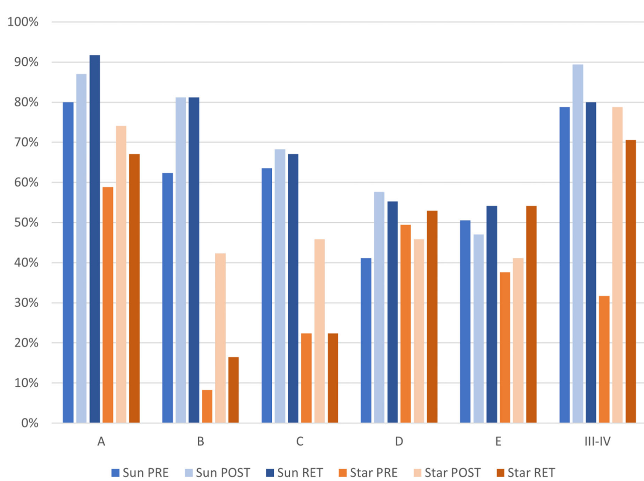

FIG. 7. Group 2.1 (learning module and planetarium presentation): Percentage of students with a correct answer per question.

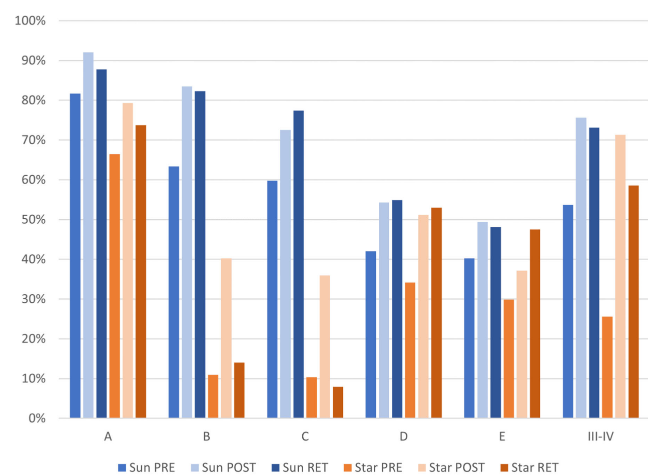

FIG. 9. Group 2.3 (only planetarium presentation): Percentage of students with a correct answer per question.

TABLE V. General overview of the classification of the written explanations of the retention test of study 2.

	Sun questions (%)	Star questions (%)
Statement (S)	48	29
Model (M)	9	15
Correct (C)	48	30
False (F)	9	13
Relevant (R)	60	33
Not relevant (NR)	1	6

We categorized the written explanations of the students when taking the retention test, using the same categorization system as in the first study. Table V shows the percentages of the codes assigned. As in the first study, we find that students usually do not use an allocentric perspective in their answer. They explain their choices by writing a short statement without referring to the Earth's rotation or Earth's revolution. Most answers are correct and relevant.

To detect qualitatively different groups in the population, as in the first study, we conducted a latent class analysis on the multiple-choice answers. To properly compare the two studies, we merged the answers from studies 1 and 2 into one dataset. Since we excluded questions III and IV in the first study, because question III was not a multiple- choice question in the first version of the AMoSS test, questions III and IV are also excluded here. We used the software MPLUS and calculated two fit indices to decide which model suits our data best: the Akaike information criterion (AIC) [32] and the Bayesian information criterion (BIC) [33]. Statistically spoken, the model with the lowest AIC and BIC values corresponds to the one with the best model fit. Since none of these indices reaches a minimum at an interesting number of classes (see Table VI), we determine the number of classes from a theoretical point of view. The classes in the eight-class solution provide an interesting extension of the five-class solution of the first study and fit well with what we learned from the categorization of the written explanations. The eight classes are (we indicate the class color as used in Figs. 10–15) as follows:

TABLE VI. AIC and BIC values for different number of classes.

Number of classes	AIC	BIC
2	53 674	54 312
3	53 397	54 358
4	53 168	54 450
5	53 031	54 635
6	52 930	54 857
7	52 865	55 113
8	52 779	55 350
9	52 736	55 629

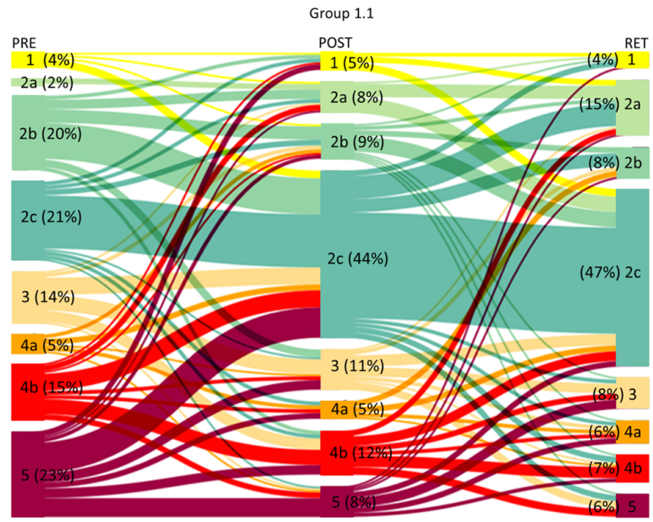

FIG. 10. Evolution of class membership from pretest to posttest to retention test, for students who attended the Brussels planetarium presentation before the astronomy lessons at school. The higher the class is positioned in the figure, the better the student scores on the AMoSS test.

1. Class 1 (yellow): The students in this class answered all questions correctly.
2. Class 2: These students answered all Sun questions correctly but struggle with the star questions throughout the year (questions B and C). This class is divided into three subclasses:
   (a) Class 2a (light green): The star trails are higher and wider in summer than in winter.

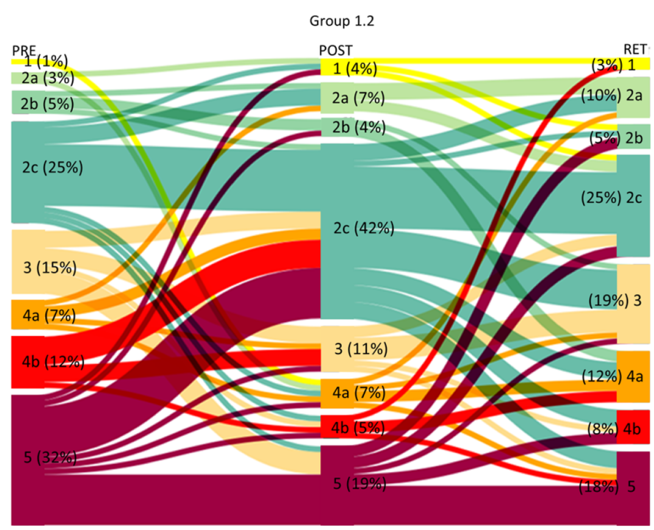

FIG. 11. Evolution of class membership from pretest to posttest to retention test, for students who attended the Brussels planetarium presentation after the astronomy lessons at school. The higher the class is positioned in the figure, the better the student scores on the AMoSS test.

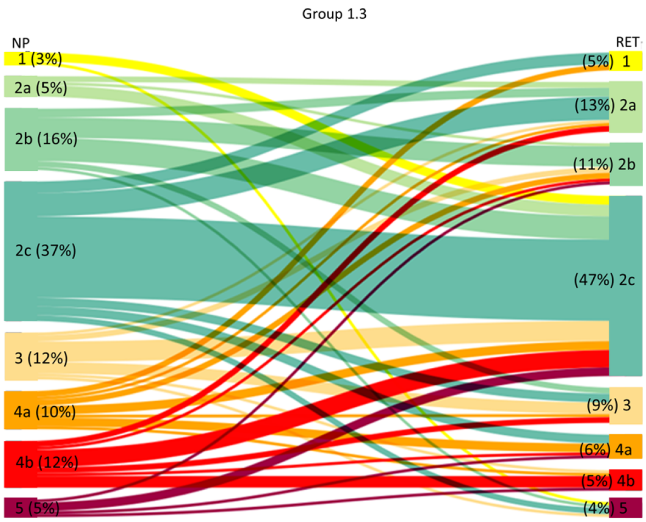

FIG. 12. Evolution of class membership from NP test to retention test, for students who have not attended a planetarium presentation. The higher the class is positioned in the figure, the better the student scores on the AMoSS test.

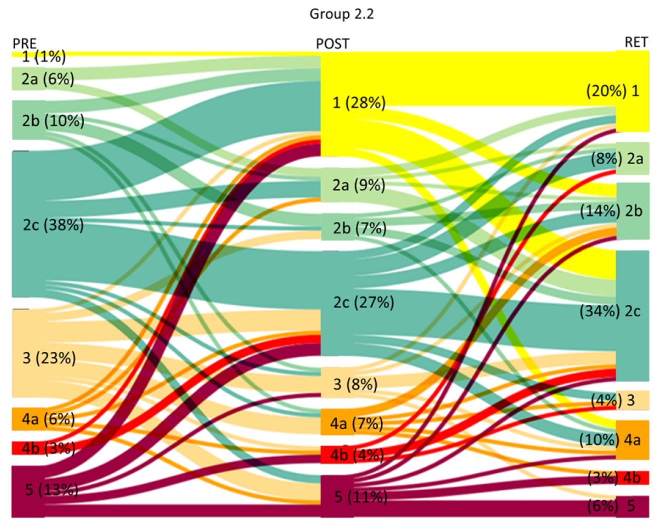

FIG. 14. Evolution of class membership from pretest to posttest to retention test, for students who have not attended the planetarium presentation. They worked through the learning module at school. The higher the class is positioned in the figure, the better the student scores on the AMoSS test.

(b) Class 2b (green): Students answer "I don't know" to these questions.
(c) Class 2c (dark green): The star trails are higher and wider in winter than in summer.

3. Class 3 (light orange): These students answer all the Sun questions correctly, but on the star questions, they often give a wrong answer or choose "I don't know".
4. Class 4: These students do not know how the culmination height depends on the position of the observer. This class is divided into two subclasses:

(a) Class 4a (orange): these students answer incorrectly or "I don't know" to these questions (questions D).
(b) Class 4b (red): these students relate the culmination height to the observer's longitude instead of the observers' latitude.

5. Class 5 (dark red): These students think that the Sun always rises in the east and sets in the west.

Software MPLUS determines the class to which each student belongs. We calculated the size of each class for the

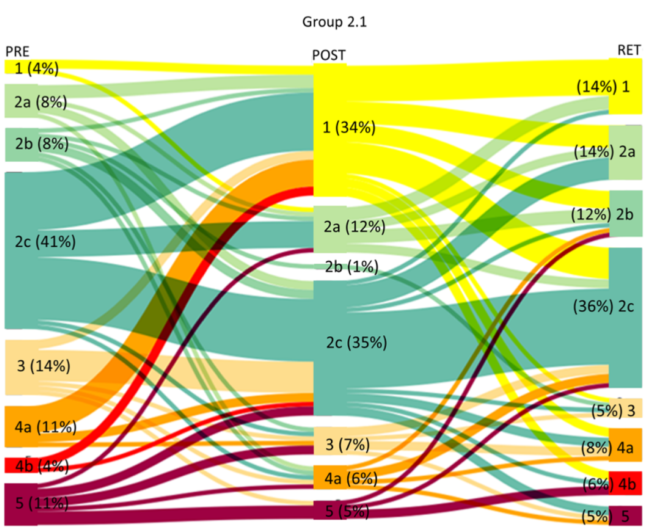

FIG. 13. Evolution of class membership from pretest to posttest to retention test, for students who prepared the planetarium presentation at school. The higher the class is positioned in the figure, the better the student scores on the AMoSS test.

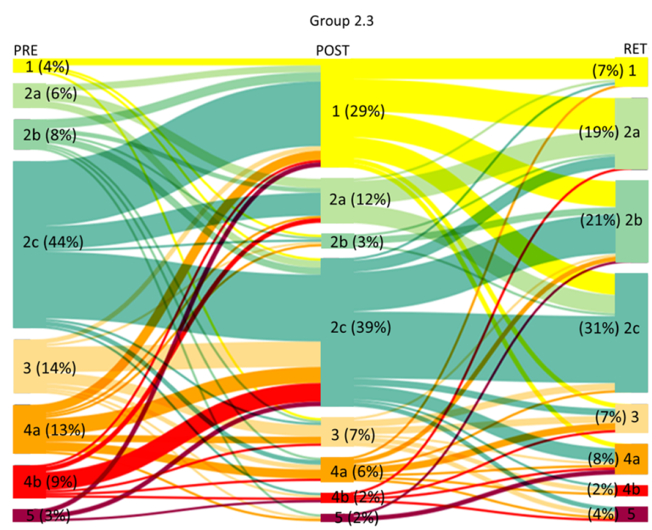

FIG. 15. Evolution of class membership from pretest to posttest to retention test, for students who attended the planetarium presentation without preparing it at school. The higher the class is positioned in the figure, the better the student scores on the AMoSS test.

different groups for the pretest, post-test, and retention test in studies 1 and 2. Using a Sankey diagram, we show the evolution for each group from pretest, to post-test to retention test (see Figs. 10–15). With a two proportions z test, we checked if class sizes changed significantly from pretest to retention test ($p < 0.05$). In the discussion in the next section where we compare the results of the second study with the first study, we elaborate on this evolution and mention for which groups it is significant.

These alluvial diagrams show, for each group, how students evolved between classes through the various tests taken. By displaying the charts in color, it is possible to detect certain trends. Notable in the three groups of study 1 is the dominance of the green color. These are the classes with students who got all the questions about the Sun and stars correct, except the questions about the yearly apparent motion of the stars. Most students in these classes copy their ideas about the Sun to the stars. It seems that these classes get even bigger after having attended a planetarium presentation. In group 1.1 who took astronomy lessons at school after the planetarium presentation, these green classes become even larger in the retention test. So, taking regular astronomy lessons at school did not help these students better understand the yearly apparent motion of the stars. In group 1.2, who did not take any more astronomy lessons at school after attending the planetarium presentation, we notice how the students from the green class swell out again to orange and red classes. So, in the retention test, those classes become dominant again, as in the pretest. Even in group 1.3, who did not take a planetarium presentation, the dominance of the green classes is striking in both tests. In the second study, where all groups took the pretest after school astronomy classes, the green classes are also dominant. Now it is striking how in the post-test the yellow class in all groups increases significantly. This is the class with students who answer all questions correctly. So, for students who move from green to yellow, working through the learning module at school or attending the revised presentation ensures that they do answer the questions on apparent yearly motion correctly for the Sun and stars. In the retention test, we see that quite a few students from the yellow class return back to the green, again reinforcing the dominance of this green class.

VII. DISCUSSION

We have set up two different studies to measure the effectiveness of a planetarium presentation with focus on the apparent motion of the Sun and stars. The target group in each study was students in the fifth year of secondary education in Belgium (16- to 17-year-olds), who get some astronomy lessons during their geography classes. In these classes, students learn about Earth's rotation and Earth's revolution. The Sun's path is discussed but the apparent motion of the stars is not explicitly addressed. In both studies, we used the AMoSS test [16] with 12 multiple-choice questions about the Sun and stars, to measure learning gains from pretest, to post-test to retention test. We also asked students to explain their choices.

In the first study, 404 students from six different schools participated. The planetarium presentation was a classical presentation as offered by the Brussels planetarium to secondary schools. A first group of students attended the presentation before the astronomy lessons at school, a second group after these lessons, and a third group did not attend a planetarium presentation. The pretest was taken in the first two groups just before the planetarium presentation, the post-test just after the presentation. In the third group, the AMoSS test was administered after the astronomy lessons at school. In all groups, the retention test was taken 2 to 3 months after the last test.

In an effort to improve students' insight, we developed a new 80 min planetarium presentation focusing on the apparent motion of the Sun and the stars, using the celestial sphere model as a central concept. By applying this model step by step and learning to use it through examples, we wanted to encourage students to reason based on a correct scientific model. Using this model, we systematically discussed the similarities and differences between the Sun and stars at different times throughout the day, different times throughout the year, and the observer's position. As a result of the COVID-19 crisis, the planetarium presentation was developed for a mobile planetarium, which could accommodate 25 students. We additionally developed a 100 min learning module that teachers could work through with their students, in preparation for the planetarium presentation. This hands-on learning module focused on the celestial sphere model as in the planetarium presentation. Using exercises, students learned about this model step by step could manipulate this model on their desk to discover the similarities and differences between the Sun's path and the star trails. With a second study, we measured the effectiveness of the new planetarium presentation and the learning module.

In these two studies, five of the six groups took their first test after the astronomy lessons at school. Four of these groups achieved scores on the Sun questions between 53% and 63% (see Tables II and IV), which are significantly better than the group that took the pretest before astronomy lessons at school (39%). One of the groups that took the pretest after the lessons at school achieves a similar score of 38%. For the star questions, we see that on the first test, all groups achieve a similar score with an average score between 26% and 35%. On average, the Sun questions are answered better than the star questions. In all pretests, this difference is largest on questions about how the apparent motion of the Sun and stars changes throughout the year. The first conclusion is that taking astronomy classes at school for most groups only has a limited impact on the Sun questions. Thus, studying the Earth's rotation and Earth's revolution at school is not sufficient to understand the apparent motion of the Sun and stars. Special instruction is needed to develop a deeper understanding, especially regarding the stars. This confirms what has already been found in previous studies [4,12,34]. The fact that questions about the Sun are systematically better answered is striking at first glance because the apparent motion of the stars is basically less complex than that of the Sun. On the other hand, the Sun is discussed more at school and we are more familiar with its apparent motion because we can observe it daily. Previous research has also shown that students struggle more with the stars than with the Sun, perhaps because we do not observe the night sky so often [1,4,35]. In our study, we want to explore how a planetarium presentation can help increase this understanding.

Two groups in the first study took the classical presentation in Brussels, while three groups in the second study took a new presentation in a mobile planetarium. For the Sun questions, we see little difference between the two studies: learning gains from pretest to post-test vary between 9% and 14% for all groups. For the star questions, however, there are significant differences. For the two groups attending the regular presentation in Brussels, the learning gains from pretest to post-test are 8% and 9%, respectively. The presentation in the mobile planetarium provides higher learning gains (between 17% and 23%). These are due to the fact that the questions on the apparent motion of the stars throughout the year (questions B and C) and the sky map change throughout the year (question IV) were better answered in the second study. While the regular planetarium presentation in Brussels did not address how star trails depend on the time throughout the year, the revised planetarium presentation systematically demonstrated this while comparing the Sun to the stars. It is worth noting that in the second study, even the group that did not visit the planetarium and only worked through the learning module at school showed similar learning gains on these questions as the groups that did attend the revised planetarium presentation. This is also the case for the overall score. The systematic structure of the presentation, combined with the use of the 3D model of the celestial sphere, and asking questions that encourage model-based reasoning provide better learning gains in the star questions. We attribute the similar learning gains with the group that did not attend the presentation to the fact that we used a similar approach in the learning module. The small differences between the groups are in line with previous research [22,23,25,30] that investigated the added value of a planetarium compared to a regular classroom.

To assess the extent to which the learning gains were sustainable, we administered a retention test several months after the post-test. For all groups, this was after the first semester, i.e., after exams and winter break. In both studies, we see that the results for the Sun questions remain stable, some groups even slightly improve their scores. Taking the exam may have played a role in this. For all groups, we see for the star questions a drop between 1% and 9% compared to the post-test. This is not in line with previous studies that were able to show better retention of acquired knowledge in groups that had attended a planetarium presentation vs a classroom presentation [29,30]. This is especially noticeable in the second study. This is a consequence of the fact that the questions about the star trails throughout the year were answered worse than in the post-test. If we compare the score of the retention test with that of the pretest, we see in the first study for the Sun questions a learning gain of 5%–15%, and for the star questions, a learning gain of 2%–8%. In the second study, for the Sun questions, this ranges between 9% and 16% and for the star questions, it is 12% for all groups. Only for the star questions, we see a significantly better learning gain in the second study compared to the first study ($p < 0.05$).

When we examine learning gains at the question level more in detail, we see that especially the questions that are literally covered in the presentation give the best learning gains. In the first study, this is the Sun question about how the sunset position changes throughout the year (question C) and the star question about how the stars apparently move in the sky during the night (question A). For example, the Brussels planetarium employee literally said, "Many people think that the Sun sets exactly in the west every day, but here I am showing you that this is not the case." How star trails depend on the time throughout the year was not addressed during the presentation. We see that for these questions, the scores do not improve, on the contrary, the scores slightly decrease.

As mentioned above, in the second study, we see the best learning gains with the questions about the star trails throughout the year and the sky map change throughout the year. Immediately after the planetarium presentation or working through the learning module, students answer these questions more correctly than in the pretest, while in the retention test, they make the same mistakes as in the pretest. So it seems that they answer the questions in the post-test correctly only because they have remembered as a fact that the position of the rise, set, and highest point of a star does not change throughout the year. They did not use the underlying model because they may not have fully understood it. This is also evident in the written explanations. We asked students to explain their choice for a number of multiple-choice questions. Using these written explanations, we gained a better understanding of the arguments students used to justify their choices and the alternative ideas they had. In both studies, we found that students rarely write an explanation that refers to the Earth's rotation on its axis, the tilt of the Earth's axis, or the Earth's revolution around the Sun. They usually write something based on an observation or referring to a fact they remembered from class. Despite the fact that in the second study in the planetarium presentation and during the learning module, we focused very much on reasoning based on a correct scientific model, we do not see this reflected in the written explanations. Thus, the limited time provided for the learning module and planetarium presentation proved to be insufficient for most students to develop a deeper understanding of the apparent motion of the Sun and stars. Although the lack of properly written explanations does not prove that students do not have a good understanding of the concepts addressed in the question, there is an additional argument: the limited learning gains in the questions about the position of the observer (questions D and E). Due to time constraints, we did not practice this specifically during the learning module or the presentation in the mobile planetarium. As a result, these questions could only be solved properly if you have a good understanding of the celestial sphere model. Thus, the limited learning gain suggests that only a limited group really understood the model. Perhaps, this has to do with the fact that spatial skills are required to properly understand the celestial sphere model. Research shows that this is very difficult for many students [19].

Using a latent class analysis, we were able to identify qualitatively different groups of students who have specific mental models. In both studies, we see a large group of students who do not distinguish between the Sun and stars in relation to how their track in the sky changes throughout the year. They think that star trails are higher and wider in the summer, just like the Sun. Or conversely, they think that star trails are higher and wider in winter because the nights are longer then. Attending the Brussels planetarium presentation does not help students to adjust this alternative idea. On the contrary, the group of students who think this way grows after attending the planetarium presentation (see Figs. 10 and 11). This explains why we have not seen any learning gain on the questions about the star trails throughout the year in the first study. In the second study, we see that this group gets smaller after attending the presentation in the mobile planetarium or working through the learning module. The group that answers all questions correctly grows, while this is not the case in the first study. This growth is only significant in the school groups who worked through the learning module at school. In the retention test, we see that the group that does not correctly distinguish between the Sun and the stars grows again (see Figs. 13–15). Apparently, for most students attending the revised planetarium presentation or working through the learning module at school was not enough to transform their alternative ideas about the apparent motion of the Sun and stars into a correct scientific model. The fact that this is a slow and difficult process has been described in the literature [36]. The fact that unlike in the first study, in the second study, the group of students who got all answers correct grows significantly, both in the post-test and the retention test, indicates that for that group, the learning module and planetarium presentation helped them to make progression.

VIII. LIMITATIONS

The first study can be seen as a natural experiment: we had the opportunity to investigate an existing situation with our research instrument, as several class groups differed in a meaningful way in whether and how they attended the planetarium session. However, such a natural experiment does not allow to differentiate our central variables, such as planetarium visit or not, time of planetarium visit, from other preexisting differences, such as teaching approaches, teachers' expertise, and student populations. In study 2, similar issues may be at play as schools were allowed to decide in which treatment group they preferred to take part.

Since different schools participated in the studies, students were taught by different teachers, each with their own approach. Therefore, the impact of the school lessons on the results of the AMoSS test may differ from school to school. Although we gave the teachers instructions on what topics should be covered during the lessons, it is possible that this was not always done in the way requested.

As a result of the COVID-19 crisis, we worked with two different planetarium settings in the two studies. In a mobile planetarium, it is much easier to work interactively because the number of participants is much smaller than in the Brussels planetarium. The length of the presentation was also different. This may have affected the results of the second study.

Another limitation is the fact that we used a convenience sample in these studies: the schools participated voluntarily and chose their students on a voluntary basis. This caused the sizes of the groups to be different.

The main limitation of this study was the available time for teachers to work through the learning module, take the pretest, post-test, and retention test, and attend the planetarium presentation. Therefore, we had to make a compromise between what we thought was necessary and what was possible for teachers and students.

IX. CONCLUSIONS AND IMPLICATIONS FOR ASTRONOMY EDUCATION AND FURTHER RESEARCH

After our two studies on the effectiveness of a planetarium presentation with a focus on the apparent motion of the Sun and stars, we conclude that regular school lessons are not sufficient to develop a good understanding of the apparent motion of the Sun and stars. Special instruction is needed.

In answer to the first research question regarding the regular planetarium presentation in Brussels, we can summarize that students make learning gains in terms of the apparent motion of both the Sun and the stars, with the exception of star trails throughout the year. This is due to the fact that a lot of students copy their knowledge about the Sun to the stars, so they answer these questions incorrectly.

Regarding the second research question related to the effectiveness of the revised planetarium presentation for a mobile planetarium, we can summarize that students achieve similar learning gains in terms of the apparent motion of the Sun compared with the regular presentation in Brussels. Immediately after the presentation, for the star questions, the learning gains are on average larger because the questions on the yearly apparent motion of the stars are better answered. The use of a 3D model of the celestial sphere and the systematic approach of the revised presentation allows more students to clearly distinguish between the Sun and the stars with respect to yearly apparent motion.

After attending both the regular planetarium presentation and the revised presentation, students show few elements of a correct scientific model in their written explanations.

Regarding the third research question, we can conclude that when the same teaching techniques, for example, use of a 3D model of the celestial sphere, stimulation of model-based reasoning, systematic approach, etc., are used during a purposefully designed planetarium presentation and learning module at school a planetarium presentation is as effective as the school classes. Unlike previous studies from the literature, we were unable to conclude that attending the planetarium presentation leads to better retention of the knowledge acquired. Moreover, preparing for the presentation did not improve retention either.

Despite the special attention paid to reasoning with a correct scientific model, we see that most students mainly argue using facts when answering questions. In answering the fourth research question, we can not conclude whether the use of a 3D model led to improved insights for most students. More research is needed to determine the extent to which the use of the 3D model contributed to the better learning gains.

A small group of students did make clear progress with the specific approach: they improved their score to the maximum score on the questions asked. In order for a larger group to make a sustainable progression, we believe that the model of the celestial sphere should be addressed regularly during school lessons, in which the apparent motion of the Sun and stars should be covered more systematically in class and should be part of the exam. Using the AMoSS test instrument with 12 multiple-choice questions in these two studies gave us interesting insights into how 16- to 17-year-olds think about the apparent motion of the Sun and stars but also raised new questions. Further research is needed to determine the extent to which students truly understand the model of the celestial sphere. To investigate this deeply, we think an interview study is necessary. It would also be interesting to investigate to what extent the use of a 3D model of the celestial sphere can work in a setting of a larger planetarium, compared to our results in a mobile planetarium.

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APPENDIX A: FRAMEWORK OF THE AMoSS TEST

In Table VII, we present the framework of the AMoSS test.

APPENDIX B: ASTRONOMY TOPICS IN THE FLEMISH SCHOOL CURRICULUM

Content of the astronomy lessons in the fifth year of general secondary education in Flanders:

1. Structure of the universe
   - Composition of the universe.

TABLE VII. 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).

- The galaxy.
- Stars.
- The solar system.
- Structure of the universe.

2. Origin and evolution of the universe
   - Expanding of the universe.
   - Origin of the universe.
   - Evolution of the universe.
3. The rotation of the Earth
   - Apparent motion versus real motion.
   - The consequences of Earth's rotation.
   - Measuring space and time on Earth.
4. Earth's revolution
   - The apparent motion of the Sun.
   - Characteristics of Earth's revolution around the Sun.
   - The seasons.
   - Belts based on the position of the Sun.
   - Coordinate systems to determine the position of stars.
5. Space travel and its applications
   - Types of satellites.
   - Probes discovering space.
   - Remote sensing of the atmosphere.
   - Positioning by means of satellites.
   - Spin-off companies.

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