MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(11), em2723
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/17285

Exploring effects of embodied learning on students' perception on astronomy and science

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Received 17 December 2024 ▪ Accepted 17 September 2025

Abstract

Embodiment has recently become of interest for educational environments in general and science education in particular. The present study conducted in several classrooms across Europe set out to explore what effects this approach can have on the self-reports on science interest, engagement in activities, social appreciation and knowledge gains. Change in self-report regarding these areas were evaluated in a pre-post design. The learning sequence was found to positively impact students' perceptions of scientific knowledge gained and increased the self-reported interest during the lessons across all participating countries. The results show that embodied learning has the potential to positively impact science lessons.

Keywords: embodied learning, astronomy, interest, engagement, self-reporting

INTRODUCTION

Astronomy has been found to be interesting for both boys and girls alike (Bergstrom et al., 2016). Therefore, in the pursuit of fostering a profound understanding of the cosmos, educational approaches to astronomy play a pivotal role. The emerging field of embodied learning, which integrates physical movement and sensory experiences into educational methodologies, stands as a promising frontier in enhancing comprehension and engagement in science education (Glenberg& Gallese, 2012) and beyond (Glengerg, 2015).

Several findings support the hypothesis of using movements and enaction to ground learning on a deeper cognitive level (Abrahamson & Sanchez-Garcia, 2016; Glenberg, 2010, 2015) and thus make more abstract concepts intuitively accessible to people of diverse backgrounds. In the context of astronomy learning, one deals with distant objects; projected movements where size and distance are merged in one piece of information; and referential change. Studies that are related to embodied astronomy learning investigate the use of gestures (Dove, 2022; Nathan, 2021; Reinboth & Farkaš, 2022) or the movements of students (Asher et al., 2007; Rollinde, 2019; Rollinde et al., 2021) to improve the ability of spatial thinking (Dove, 2022; Kendon, 2000; Rollinde et al., 2021) or the understanding of physical laws (Asher et al., 2007; Nathan, 2021; Rollinde, 2019).

This study investigates the use of a specific tool to enable high enactive involvement in astronomy educational environments, the so called human orrery (HO)–a map on which students can walk and trace the trajectories of selected planets and comets (Asher et al., 2007). Implementation of this tool has taken place in the context of the European ARISTARCHUS-project starting in March 2021 and ending in February 2025.

In the course of the ARISTARCHUS project there have been a total of 6 learning sequences created (available at the website of the project, http://aristarchusproject.eu). Each of them deals with one concrete concept related to astronomy, physics or math education. The main goal was to see if embodied learning brings merits into the astronomy education lessons. As such, we conducted the exploratory present study to assess changes in self-perception of the students in pre-post design with regards to affective aspects such as interest in science, engagement in activities and perceived science learning. We will show that it increases both in self-reported interest in science and in perceived engagement, knowledge gains and social appreciation could on average be statistically significantly facilitated in most classrooms.

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Contribution to the literature

- To our knowledge this is the first study done in field that collects empirical information of a multi-lesson embodied teaching unit.
- The study presents cross-cultural results.
- It highlights commonalities and differences between several countries of the European Union (France [FR], Greece [GR], and Cyprus [CY]).

CONTEXTS AND METHODS

Theoretical Background

The question of the body from the point of view of learning is the subject of a field of research initiated in the 2000s first in mathematics education (Abrahamson et al., 2020) and then science education (see, e.g., Kita et al., 2017), based on the paradigm of "embodied cognition" (Varela et al., 1991). According to this paradigm, the individual's interactions with his or her environment are constitutive of cognition; abstract concepts are based on these sensory-motor experiences in their fundamental cores.

There have been several first attempts to research embodied aspects of physics before, such as in the area of electric fields (Glenberg & Gallese, 2012) or in the area of atomic physics (Johnson-Glenberg & Megowan-Romanowicz, 2017). However, the exact impact on learning of embodied sequences is not yet clear (Davis et al., 2023; Ke et al., 2005). Embodied cognition highlights the crucial role of sensorimotor engagement in learning, emphasizing that the process of abstraction and knowledge emerge not only from abstract reasoning but also from bodily interaction with the environment (Dove, 2022; Nathan, 2021; Reinboth & Farkaš, 2022). Gestures, movement, and proprioception play a key role in conceptual understanding (Kendon, 2000), particularly in physics and mathematics, where learners instinctively use gestures to represent forces, trajectories, and spatial relationships. These gestures play a role in maintaining or recalling visual imagery, simulating action (Hostetter & Alibali, 2008), or describing abstract causal concepts (Cooperrider et al., 2016). Not only do our thoughts and words shape our actions or gestures, but our actions or gestures also shape and assist our thoughts and words (Goldin-Meadow, 1999; Kersting et al., 2023). These gestures underlie conceptualisation. Another approach consists of collectively simulating the phenomenon being studied. For example, in the theatre of energy studied by Scherr et al. (2012), pupils represent physical manifestations of energy, moving between places in a room to stage its transformations. Such simulations have also been observed in the context of astronomy learning (Euler et al., 2019). The study provides an example of pupils producing qualitative descriptions of orbital motion that are similar to Kepler's laws by enacting them in a dance for two; this 'enacted analogy' of the phenomenon studied then becomes a resource for grasping certain characteristics of the situation and helps to make it intelligible. As these authors point out, 'by involving the students' bodies as representations of physical entities, embodied learning activities can help students draw and explore metaphorical parallels between characteristics of their bodies and the entities they represent in phenomena' (Euler et al., 2019). In astronomy education, this approach is particularly relevant because celestial phenomena occur on scales that are difficult to grasp through direct observation or conventional classroom activities. The HO exemplifies this approach by providing a blended learning space where students navigate a mapped representation of planetary orbits, simultaneously engaging with physical, social, and conceptual dimensions of learning. By stepping into the role of celestial bodies and experiencing orbital motion firsthand, learners develop an intuitive grasp of astronomical concepts, reinforcing their understanding through multisensory engagement. This embodied enactment fosters deeper conceptual stability, enhances spatial reasoning, and bridges the gap between abstract models and lived experience, making it a powerful tool for science education. As embodiment is linked to more subconscious, intuitive learning (Asher et al., 2007), the present paper aims to mainly explore affective aspects of its influence.

Additionally, to our knowledge, extended applications in the field–during science lessons at school conducted by regular teachers–have not yet been thoroughly examined. Therefore, we conducted the present exploratory study to give first results of self-perceptions of students as influenced by an embodied learning sequence in schools. To evaluate these affective facets, we evaluated mainly self-reported interest (which has been shown to be connected to job choices [Bergstrom et al., 2016]), and perceived knowledge gains to assess whether the students had changed their self-assessment of their abilities to explain and know astronomical concepts. We evaluated mainly self-reported interest and perceived knowledge gains to assess whether the students had changed their self-assessment of their abilities to explain and know astronomical concepts. Though the latter is not a necessarily valid assessment of real conceptual enhancement, changes in self-perceived knowledge and skills are still an effect on self-perception, which in turn has been shown to be linked to academic success in the

Table 1. Questions of the test and correspondence with SDG targets

No	Question
SDG target 4.6 interest for science	
Q1	Rate how much you liked the science lessons
Q2	Rate how comfortable you felt in the science lessons
Q3	Rate how much you have mentioned your interest in your science lessons
SDG target 4.6 novelty for science	
Q6	I discovered new science in the science lessons
Q11	I feel like I have learned new ways of discovering the world in the science lessons
SDG target 4.7 active citizenship	
Q3	Rate how important you felt your actions in the science lesson were
Q10	I understood what to do in the science lessons
SDG target 4.7 appreciation of other	
Q4	Rate how much you helped others in your science lessons
Q5	Rate how much working with others helped you to better understand science lessons
Q7	Rate your degree of connection with your peers in science lessons
Q8	I took help from other in the science lessons
SDG target 4.6 universal literacy (knowledge)	
Q12	I can explain why earth is a special place in the universe
Q13	I can explain why there is day and night
Q14	I can explain what a year in the solar system is
Q15	I know many different objects in the solar system

long run (for a more recent review on that matter, see Mathew, 2017). As such, the research question (RQ) was:

RQ. How does an embodied astronomy learning sequence in the science classroom effect self- perceptions of students, regarding science interest, engagement in activities, social appreciation and knowledge gains?

To answer this question, a pre-post design was implemented in the field and self-reported affective facets were collected in several classes across multiple countries (FR, GR, and CY). In the next section, we will document the research methodology used in more detail.

Methodology

The learning sequence with the HO was composed of three sessions (HO1, HO2, and HO3). The implementation strategy that was given to the teachers followed three phases. Firstly, just before session HO1, learners anonymously answered a questionnaire. They were asked to answer with respect to their feeling/impression about traditional science lessons they had taken the same year. Secondly, they attended the learning sequence on the HO. Thirdly, just after the session HO3, learners answered the same questionnaire as before, but with respect to their feeling/impression about the HO learning sessions only. We first describe the group of classes that were engaged in this study and afterwards the items of the questionnaire. Lastly, the HO and the sessions HO1-2-3 are described in relation to the items of the questionnaire.

Samples and implementation of the learning sequences

In FR, a total of 58 students took part in the study. They came from mainly two primary schools with average to low socio-economic backgrounds. The age of the students was 9-13 years. In GR, four primary schools with a total of 60 students participated in the study with the ages of the students ranging from 7-11 years old. The socio-economic background of the students was diverse and ranged from high to low. In CY, a total of 79 students ranging from ages 7-12 participated from 3 schools with one school having a high socio-economic background, one having a low socio-economic background and the third having a mixed background, though about 30% had moved to CY from more Eastern countries. The study was also conducted in Germany, though due to technical issues the data cannot be reported.

Description of the questionnaire

The questionnaire was based on the European sustainable development goal 4 (SDG 4) about quality education for all[1]. The questions are meant to cover two specific targets about quality education for all (**Table 1**):

(1) The target 4.6 universal literacy and numeracy, and more specifically "knowledge and interest for science" is accounted for in three series of questions. Q1-2-9 investigate the interest of learners in science with words "like", "comfortable" and "interest". Q6-11 investigate their feeling about learning and "discover science/ the world". Q12-12-14-15 are directly related to science literacy through their ability to explain different phenomena (day and night, the

[1] https://international-partnerships.ec.europa.eu/policies/sustainable-development-goals_en

year as a unit of time), to list objects of the solar system, to describe earth as a "special place in the universe".

(2) The target 4.7 education for sustainable development and global citizenship and the "promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development" is related to two series of questions: learner feels that they were engaged in its learning which we relate to the training for active citizenship (Q3-Q10), and that they connect as a group during the teaching lessons which we relate to "appreciation of others" (Q4-5-7-8).

Having two to four questions for each of the five blocks of the SDG target gives a greater signification to the answer. If a learner is unsure about their feeling on one target, the answers to the different questions for the same block will compensate. Additionally, if they are sure about their feeling, the series of positive (or negative) answers will get a larger statistical level of significance. Except for the series about science literacy, questions are not ordered by series of the target so that learners will not be influenced by the similarity of the questions. The questions used were of generally rough resolution and for example regarding interest, better instruments to assess that facet do exist in the literature (e.g., Kleespies et al., 2021; Luo et al., 2019). However, after consulting with a consortium of 11 primary school teachers, we did decide against using more common scales for measuring the constructs for two main reasons:

1. From a standpoint of time-economy, the questions had to be posed to the students within approximately 10-15 minutes as teachers deemed more time-consuming testing phases for unsuitable especially in the primary school classes examined. As the present study was always planned to get a rough exploratory idea about various affective facets, this was prioritised above gaining more detailed insights into the constructs.
2. Difficulties can be encountered when constructing instruments to measure interest for very young children, though some successful attempts have been made (for example see Post & van der Molen, 2019). Some of these difficulties are for example that statements are phrased in a too complex manner for children from grade 3 and grade 4 or that the scales used are too complicated to understand. We did try to mitigate the latter criticism by using smiley faces as scales, which were deemed acceptable by the teachers.

The primary school teachers we consulted to ensure an assessment that fit to the level of the participants were all teachers that took part in the ARISTARCHUS project and all teachers that taught the sequences we evaluated were part of this consortium as well. With this, we tried to ensure that the evaluation had a high fit to the participants we aimed to assess the affective variables of.

Answers to each question are rated from "I disagree with the statement" (1) to "I agree with the statement" (4) represented for younger children by smiles. The questionnaire was answered online via a gamified tool. The number (1) to number (4) were indicated by unhappiest to happiest emoticons. For youngest learners, the teacher explained for each single question the meaning of the emoticon. The ranking is quite subjective: Some individuals may be reluctant to choose extreme 1 and extreme 4 while others favour clear and extreme answers. Therefore, in the analysis, only two answers are considered: (1-2) and (3-4) as being "negative" and "positive", respectively. Though this is a rougher analysis than what the 4-point scales could potentially enable, mapping of ordinal scales (smiles) to metric scales (numbers) does pose a principal difficulty in itself and we chose to circumvent this by having a binary evaluation of the answers. With this, we could both roughly ensure that especially the students from primary school could evaluate their feelings more easily using smileys and ensure that statements about agreements and disagreements could still be compared by analyses via binomial distributions.

Description of the learning sequences

General description of the HO: The HO is a flat material representation, a space-time map, of the movements of some of a few selected bodies in the solar system around the sun (**Figure 1**). Movements of planets and comets are represented through discs located at their positions at different times within a single static image (a chrono photography). Quite always drawn in the heliocentric frame, they accurately feature elliptical orbits consistent with Kepler's laws. Students move along the planetary orbit at a rhythm determined by another person (usually the teacher) who claps his hands regularly. Between two claps, all planets move, simultaneously, from one point to the next, while the sun stays at rest (in the heliocentric frame).

A detailed description of this walk is given on the website of the HO (http://planetaire.over-blog.com/en). Hence, students are directly involved in the experience. Their own actions are central to the demonstration, as they physically enact the movements of the planets. The HO thus allows an embodied (Abrahamson et al., 2020) and interdisciplinary approach combining knowledge of astronomy, kinematics and geometry (Abboud et al., 2021; Asher et al., 2007; Rollinde, 2019; Rollinde et al., 2021). Embodied learning is still somewhat of a rarity in most schools, which, depending on the age of the students, can cause hesitation at first, making it important to ease the students into it. We assume that this strategy of "learning by moving in new ways" (Abrahamson et al.,

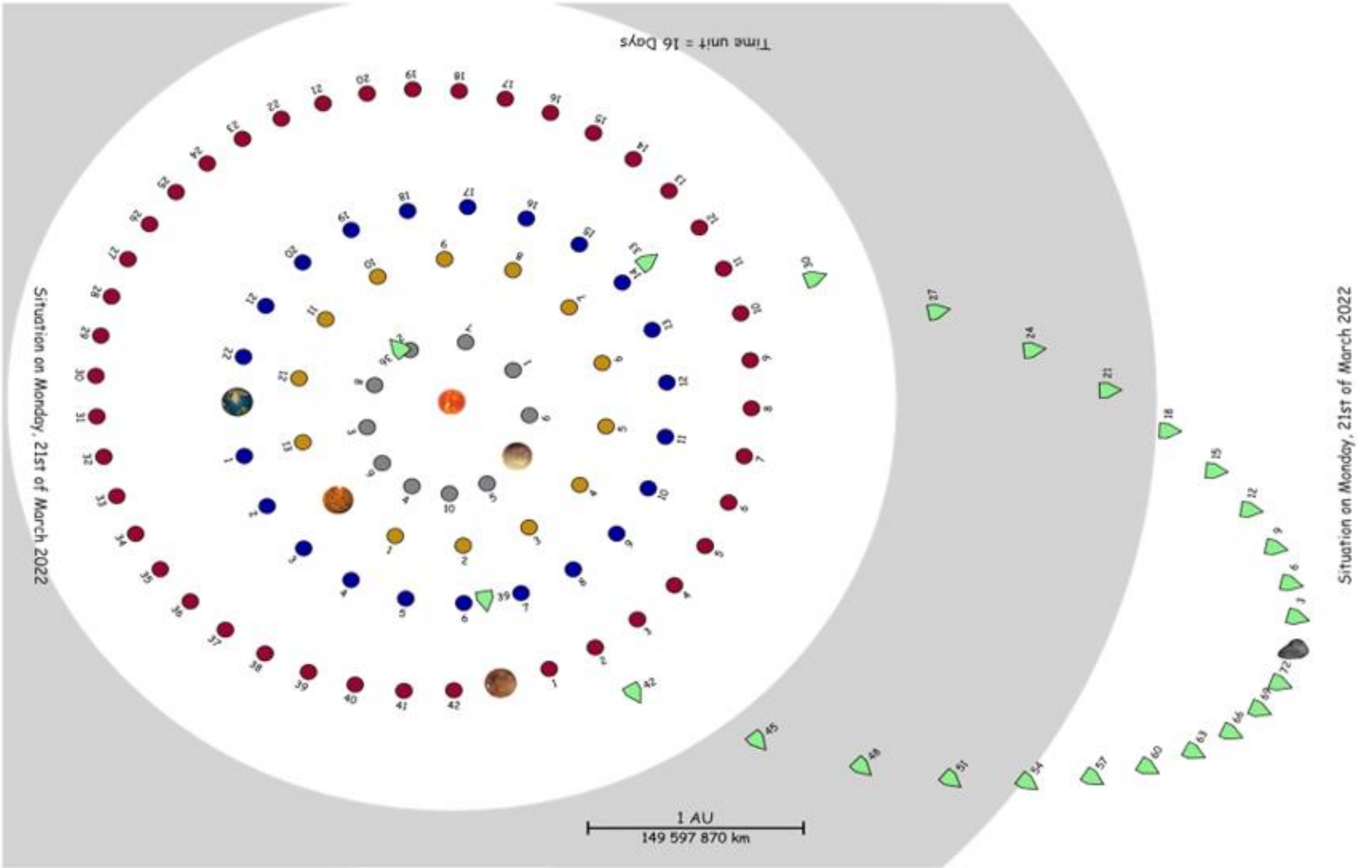

Figure 1. The 3.4 × 6.4 m HO that is being used during the sessions described in the article (different versions with the countries' languages exist & this version is in English and without logos for the article's sake) (Source: Authors' own elaboration)

2020) helps to get students more involved and active (questions Q3-Q13-Q9-Q10) and feel that they learn in a new way (question Q11). The link between action and cognition helps to maintain interest (Q1-Q9), understand the tasks to do (Q2-Q10) and feel a connection with peers (Q3-4-5-7-8).

Description of the learning sequence: In the course of the ARISTARCHUS project there have been a total of 6 learning sequences created thus far (available at the website of the project, http://aristarchusproject.eu). In this paper we lay a focus on the first 3 of these learning sequences that have been used as a "common ground" for the schools that have been part of the presented study. Meaning, that each class that took part in this research was taught at least these 3 sessions. The tests were then given before and after those 3 sequences: exploration of the HO, duration of a year for the individual planets, and the concept of day and night on earth. Those concepts also serve as a common ground in the curricula at the age of the classes involved in the four countries. Those pieces of knowledge are linked to the Questions Q12-13-14-15. We assume that astronomy is not often taught in such details in the classes which is related to question Q6. We note that the novelty of embodied learning with the HO may also lead to a feeling of uneasiness with this "new way of learning" which would lead to a negative global impression. Hence, the results of the comparison of pre- and post-test will be informative about the impact of this strategy on all SDG targets described in **Table 1**. In the following, the 3 sequences will be roughly outlined:

Exploration sequence: While most of the later sequences are somewhat independent from each other and the order of teaching can vary, the exploration sequence acts as a baseline introduction to the use of the HO. Through this sequence the students learn the concepts of the HO and about its "rules". We will provide a brief description to give the reader an understanding of the main aspects of this learning session. A detailed analysis is the subject of a paper that has been submitted in 2024 during the ESMEA project (http://ldar.website/esmea). While true for all the sequences, an open and non-judgemental environment is key to a successful work with the HO especially in this sequence. Here we wanted the students to reflect on what they see and feel when they first encounter the HO. The usual start of this sequence began with a walk on the HO. It was mostly a simple free walk, but depending on the students hesitation it proved to be beneficial to give them a gentle "nudge" to engage them more. For such a task it was easily possible to have about 20-30 students on the HO at a time and thus to include all of them. After a few minutes of free walking, more or less depending on the students, the teacher would guide into a sharing-phase, so that the students could share what they had discovered. In this phase it was mandatory that there was no judgement on "wrong" answers as the students were not being graded but instead presented with a collection of novel information. If a students gave a "wrong" answer, the teacher was encouraged to ask why the student believed that they had the correct answer. This could bring forth interesting responses that were taken as the base for further discussions. For example, often times, mercury or even the comet was mistaken for our moon, as they both share a lot of similarities in their appearance. A student then was asked for the reason why they thought mercury is the moon. Other students were asked for their opinion as well to instigate a learning process together. The difficulty in this task was often that students easily took things for a fact. Them pointing out "this is the earth!", when pointing at the image of the earth on the HO, was interpretation-wise on the same level as "this is the moon!", when they point at mercury, because the more descriptive observation would have been "there is a blue sphere!" in the case of earth or "there is a brown sphere with dents!" in the case of mercury. It was important that students played out or actively pointed out the things they have discovered and describe them. For this objective, they were supposed to walk a path they discovered, show the size of the scale or go and stand on, or touch, a planet to show its discovery instead of simply pointing at it from afar. If not everything was discovered, they were told that "there is more ...", which drove them to continue searching without influencing them too much. The key elements or words that are needed in this sequence are the names of the planets, the types of celestial objects (star, gaseous-, terrestrial planet, etc.) in relation with question Q15 and Q12, the orbits, the scale of the HO and the starting date as well as the time scale mentioned on the HO. After all things on the HO have been pointed out and discussed, a first guided walk on the HO was started. Depending on the size of the class it proved helpful to divide the class: while one group walks on the HO, the remaining part of the class would be given specific observation tasks on the movement of their colleagues. During these first walks the teacher could gently introduce the rules of the HO, teaching the students how to use it. The teacher would introduce the students to the two rules:

1. On each clapping of the hands the lifted foot needs to be set down on a dot.
2. On each clapping the distance between two dots on the same orbit has to be traversed.

The initial walk usually started on the orbit of the earth which is most familiar with the students as one cycle around the sun is one year and the duration of the path between three dots (so two steps) is roughly one month. Once the students succeeded, it was time to discuss the other half's observations and to switch, or to move on to other planets after another brief practice on earth. The different planets were then discussed and walked on, until every planet has been walked on and a collective performance with all celestial objects was realised.

A year on each planet: The second sequence focused specifically on the definition of a year. Depending on the size of the class this was either done by groups on small printed orreries or by walking together on the large HO. The reason for this is that each student would play the role of one child being born on one planet on the Orrery and celebrate their birthday with each turn around the sun. Given there are 4 planets on a HO, the suggested group sizes were 4-12 students, with some of them having observational tasks. The students were already used to walking on the HO from the previous sequence and therefore could start with exploring the different duration's that the planets need to finish one revolution around the sun. The students quickly grasped that they were moving in different "speeds". At this point it was important to talk about the definition of "speed" as the students might claim to walk faster or slower without understanding angular and linear velocity. For example, mars only have a difference of approx. 14% linear velocity while the angular velocity is only half of earth's as mars takes almost twice the time to orbit around the sun. However, at the age considered in this study, details about speed were left out and focus was on the concept of duration only. The learning objective was to understand that a single duration may be counted with different units–the units being the year for each planet, like year on earth, year on mars, etc. This would be deepened by a game about the birthdays where each student pretends to being born on one of the inner 4 planets and their friends would send them a birthday cake for each year that they have finished on their individual planet. This allowed them to relate birthdays on one planet, to its being a complete revolution for this planet and the unit of year associated to this planet. For 9-12-year-old students, it was enough to compare prediction and count the number of revolutions. The knowledge about the definition of one year (astronomy, question Q14) and about the description of one single duration with different units (mathematics) was targeted to be facilitated with this exercise. For older students, teachers additionally moved on and asked for a prediction when the child on earth would be 40 years old–which requires the use of a mathematical relation of proportionality.

Day and night: This sequence started with a short dialogue with students about alternation of day and night. Young students usually provided many hypotheses on day/night alternation related to their own everyday experience and perception of what they experienced during the day and the night. In particular, the moon is often present in students' hypotheses as a sign of the night. The goal of this session was to show that day and night may be explained by the movements of earth and sun only. To do this, several students were asked to stand on dots on the earth's orbit on the HO and then to position themselves emulating noon and then midnight. This sometimes caused some confusion at first and it helped to either have a student standing on the sun, or have a light source positioned there. Afterwards, the students performed a simulation: They were asked to move so that the sun appears to wander across the sky or in the orrery from the left side of the students to their right. This could be achieved by spinning, hence modelling the rotation of the earth in the correct direction. These observations and experiences were then collected, noted down and in the end applied to other planets where the different durations of night and day were finally discussed.

The potential influence of the learning sequences on the research items: After the description of each of the sequences that the classes faced with the teachers, we now want to consider the potential influence that these sequences, in our opinion, might have on the items listed in **Table 1**, providing expectations for the RQ at hand. We emphasize that the influence on each individual session cannot be observed since we consider a post-test only after the three sessions. We hypothesized that the fact that students are actively taking part in the science lesson by using their own body would greatly increase their interest in science lessons (items Q1, Q2, and Q9) and impression of novelty (Q6 and Q11). Although all sessions may increase the interest in science and feeling of novelty, the exploration session was expected to have the largest influence on those set of items. Still, the exploration session is quite guided and mostly relies on the teacher-student interaction more than on a student-student interaction. This is different in the session about the definition of a year and day-night, where the student-student relationship has a much larger potential significance. Thus, we expected an influence of those sessions not only on the items of active citizenship (Q3 and Q10), but especially on the items of appreciation for others (Q4, Q5, Q7, and Q8). Influences on the social aspect of "belonging" were also expected as each student is part of a whole system in all sessions (Q3 and Q10 again) and group discussion are involved in all sessions (Q4 and Q8). Beyond that we expected the biggest influences on the items about science literacy (Q12 till Q15). The place of earth (Q12) and objects of the solar system (Q15) were the subjects of all sessions, with an emphasis during the exploration sessions. Day and night (Q13) and the year (Q14) were the specific topics of the two last sessions. Therefore, we expected an increase in self-perceived knowledge on these topics.

All concepts in the three sessions also serve as a common ground in the curricula at the age of the classes involved in the four countries. Those pieces of knowledge are linked to the questions Q12-13-14-15. We assume that astronomy is not often taught in such details in the classes which is related to question Q6 and hence expect a high level of improvement for those questions.

We assume that this general strategy of "learning by moving in new ways" (Abrahamson, 2021) helps to get students more involved and active (questions Q3-Q13-Q9-Q10) and feel that they learn in a new way (question Q11). The link between action and cognition helps to maintain interest (Q1-Q9), to understand the tasks to do (Q2-Q10) and to feel a connection with peers (Q3-4-5-7-8). We note that the novelty of embodied learning with the HO may also lead to a feeling of uneasiness with this "new way of learning" which would lead to a negative global impression. Hence, the results of the comparison of pre- and post- test will be informative about the impact of this strategy on all SDG targets described in **Table 1**.

RESULTS

The answers from the student for each country and each question are provided in **Table 2** for the pre- and the post-test. In each case, results consist in a pair of numbers: students who answered negatively and then positively (1-2 and 3-4, respectively). To evaluate the evolution of perception before and after the session, a variation of McNemar's test was used.

Table 2. Answers for the pre- and post-test to each set of questions (see **Table 1**)

	Question	FR	GR	CY	All
Interest for science	Q1-like	9/49-5/53	9/56-3/52	19/60-12/67	37/165-20/172
	Q2-confortable	9/49-8/50	13/40-3/50	13/66-5/73	35/155-16/173
	Q9-interest	22/36-21/37	12/43-3/52	22/57-7/72	56/136-31/161
	Q1+Q2+Q9	40/134-34/140	34/139-9/154	54/183-24/213	128/456-67/507
Novelty of science	Q6-new science	6/52-4/54	7/49-2/54	15/63-7/70	28/164-13/178
	Q11-new ways	7/51-6/52	16/39-3/52	15/64-21/58	38/154-30/162
	Q6+Q11	13/103-10/106	23/88-5/106	29/127-28/128	65/318-43/340
Active citizenship	Q3-importance of action	10/48-14/44	11/44-9/45	18/61-8/71	39/153-31/160
	Q10-understand my action	14/44-12/46	13/43-4/52	16/64-3/77	43/151-19/175
	Q3+Q19	24/92-26/90	24/86-13/97	34/125-11/148	82/303-50/335
Appreciation of others	Q4-help other	15/43-27/31	20/36-21/35	38/41-25/54	73/120-73/120
	Q5-work with other	11/47-11/47	12/43-4/51	22/57-14/65	45/147-29/163
	Q7-connection with peers	21/37-25/33	18/38-6/50	19/58-16/61	58/133-47/144
	Q8-took help	41/17-47/11	41/15-30/26	55/25-53/27	137/57-130/64

Table 2 (Continued). Answers for the pre- and post-test to each set of questions (see **Table 1**)

	Question	FR	GR	CY	All
Science literacy	Q12-earth	19/39-12/46	5/50-5/50	22/56-10/68	46/145-27/164
	Q13-day and night	11/47-10/48	18/36-2/55	24/54-9/69	53/137-21/169
	Q14-a year	27/30-15/42	28/26-11/43	41/37-18/60	96/93-44/145
	Q15-objects	24/33-16/41	16/37-3/50	36/41-8/69	76/111-27/160
	Q12+Q13+Q14+Q15	81/149-53/177	67/149-21/195	123/188-45/266	271/486-119/638

Note. For each country four numbers are provided & the pair of numbers of negative positive answers at the pre-test followed by the same pair for the post-test

Table 3. Evolution of answers to questions related to the interest in science lessons (see **Table 1**)

	Question	FR	GR	CY	All
	Total (**Table 2**)	58	60	79	200
Interest for science	Q1-like	6/2	8/2*	14/7**	28/11**
	Q2-confortable	5/4	12/2**	10/2**	27/8**
	Q9-interest	9/8	10/1**	18/3**	37/11**
	All	20/14	30/5**	42/12**	92/31**
Novelty of science	Q6-new science	5/3	5/0*	11/4*	21/7**
	Q11-new ways	4/3	15/2**	**7/13**	26/18
	All	9/6	20/2**	18/17	47/25**
Active citizenship	Q3-importance of action	**4/8**	5/3	15/5*	24/16
	Q10-understand my action	8/6	13/4*	15/2**	36/12**
	All	**12/14**	18/7*	30/7**	60/28**
Appreciation of others	Q4-help other	**3/15****	7/8	24/11*	34/34
	Q5-work with other	4/4	9/1**	13/5*	26/10**
	Q7-connection with peers	**6/10**	12/0**	13/10	31/20*
	Q8-took help	**6/10**	17/6*	15/13	38/29
	All	**17/39****	45/15**	65/39**	127/93**
Science literacy	Q12-earth	13/6	4/4	18/6**	35/16**
	Q13-day and night	5/4	16/0**	20/5**	41/9**
	Q14-a year	18/6**	19/2**	29/6**	66/14**
	Q15-objects	16/8*	15/2**	32/4**	63/14**
	All	52/24**	54/8**	99/21**	205/53**

Note. For each country, two numbers are provided; The first is the number of students who answer negatively and then positively and thus improve their ratings positively; The second is the number of students who answer positively and then negatively and thus improve their ratings negatively; Those set of pairs are compared to a binomial distribution; The evolution is considered significant (*) or very significant (**) if the p-value of a binomial distribution is lower than 0.05 or 0.01; & The first line indicates the total number of answers for each country (due to problem in the data collection, there may be some variation among each question for the same country)

Following the McNemar procedure (**Table 3**), the number of students who answer negatively and then positively (improving their ratings positively) is compared to the number of students who answer positively and then negatively (improving their ratings negatively). Under the null hypothesis, these two numbers should be the same. The classical McNemar test is a chi-square test of homogeneity. We modified the procedure by replacing the chi-square test with a binomial test, as very few students changed their response. The following five areas have been addressed with our questions (see **Table 1**): "interest for science", "feelings of novelty", "participation", "social appreciation for others", and "astronomical literacy". Through all five areas, the positive improvements of the self-reports outweighed the negative improvements. Still, most students did in fact not change their minds.

The pre-test (**Table 2**) gives us an indication as to how the participants already felt about science and about their knowledge of the solar system. Self-reports about facets of interest (Q1, Q2, and Q9) were in general already rather positive in the beginning, with only about a quarter of the participants from all groups and countries self-reporting negative regarding liking the science lessons before or feeling comfortable and about a third of the students self-reporting negatively on interest itself. Compared to this, every group in general (**Table 2**) shifted towards a more positive self-reporting from before to after the embodied learning sequences. Looking at the more fine-grained picture of the individual students (**Table 3**), it shows that for all changes save for the French groups self-reporting on Q9, the shifts were mainly only from negative to positive, whereas in said Q9, in the French groups the changes were in both directions. Also, for both CY and GR, the reported change was almost everywhere significant or highly significant. Self-reports about experiencing novelty of science (Q6 and Q11) were in general already positive in the beginning, though some negative ones also appeared especially in Q11, with about a fifth of the participants from all groups and countries self-reporting negative regarding feeling to have discovered new science and new ways of discovering things about the world. Compared to this, every group in general shifted towards a more positive self-reporting from before to after the embodied learning sequences. Looking again at the more fine-grained picture of the individual students (**Table 3**), it shows that for all changes save for the GR groups, the shifts were both from negative to positive and vice versa. In said GR groups, the changes were generally only towards more positive self-reporting with Q11 being significant. Conversely, in Q11 of CY, the changes did mainly go toward a more negative self-reporting. In general, self-reports about feelings of engagement and active citizenship (Q3 and Q10) were also already mostly positive in the beginning, with only about a quarter to a sixth of the participants from all groups and countries self-reporting negatively regarding active citizenship. Looking again at the more fine-grained picture of the individual students (**Table 3**), it shows that the changes were mainly positive for the groups from GR and CY, though more negative for the FR groups regarding Q3 and mixed for Q10.

With respect to self-reporting on appreciation for others (Q4, Q5, Q7, and Q8), the self-reports were on the outset all pretty diverse, with some starting off in part with very negative self-reporting (e.g., Q8 in FR and CY), some starting off in part with mixed self-reporting (e.g., Q4 in CY) but also mainly were more positive than negative. Looking at the more fine-grained picture of the individual students once more (**Table 3**), all countries differed in the nature of changes: For FR, changes were more towards a more negative self-reporting with the changes in Q4 being significant. In GR, these changes were more positive and in the case of Q5 also became significant and for Q7 highly significant.

Lastly, self-reports on scientific literacy (Q12-Q15) were overall mixed to positive. Looking at the more fine-grained picture of the individual students however (**Table 3**), indicated an overwhelmingly positive change towards a better scientific literacy indicated by the self-reports. Especially in GR and CY these changes were significant and highly significant save for Q12 in GR. In FR, only one of the questions improved significantly (Q14), but still the positive trend showed up here as well. Taking together all the items from the five areas, the influence of the embodied sessions is highly significant for the perception about science literacy, with an increasing influence on “place of the earth”, “day and night”, “objects in the solar system” and “year”. The order of increased influence is identical to the order of decreased initial positive perception of knowledge (the less students felt confidence about a subject, the larger is the evolution of their perception). The influence on the interest in science is also significant for all related items and all countries. However, even if we measure a general positive influence on perception of citizenship and on novelty, this is less significant and differs from one country to another.

DISCUSSION

With respect to the RQ and what effects the embodied learning sequence had on self- perceptions regarding such factors as interest in science or the lessons, perceived knowledge gains or perceived engagement, several observations can be made. All in all, the data collected from the self-reports showed a lot of stability between the pre- and post-reporting. Most students did not change their minds and the perception of science lessons with regards to the affective facets we addressed in the self-reports stayed roughly the same. This can be seen as an indicator of the stability and confidence on the answers and to some of the constructs addressed in the evaluations such as general interest tend to be stable over longer periods of time (Xu & Stacey, 2016). Also, in general, shifts between the pre-post reporting are consistent across countries with some outliers in FR for the appreciation of others and active citizenship as well as novelty of science for CY. Again, from this we conclude that the trends observed are in general indicators for consistency of the exploratory results. There were, however, the mentioned differences especially in the appreciation for others between the FR and GR groups. It is unclear as to why these were so divergent and how much cultural differences played into this. In general, the differences in FR and GR are striking, as in the FR groups, self-reported perceptions did change both from positive to negative and in the GR and CY groups, the differences were mainly positive. Furthermore, it is worth to mention that the teachers who agreed to partake in this project are likely more open to experimentation with their teaching methods and new or alternative ways of teaching different to the average methods.

To investigate this discrepancy further, we conducted interviews with FR and CY teachers. All interviews confirmed that, according to teachers, the HO transforms science education by making abstract concepts more accessible through interaction and movement. It promotes collaborative, fun and interdisciplinary learning, while posing logistical and pedagogical challenges that require careful preparation. Teachers are seeing a shift in their role from transmitters of knowledge to facilitators, which enriches their teaching practices in a lasting way. French teachers emphasised the greater self-confidence of pupils who are less at ease in theory, and the overcoming of preconceived ideas. CY teachers stressed the increased engagement of pupils, especially those who are usually unmotivated, as well as the playful and collaborative setting that reduces anxiety and facilitates inclusion. French teachers emphasise individual progress in complex concepts, while CY teachers focus more on the overall effect on class dynamics and inclusion. Is that related to personal or cultural differences? This requires further studies to be concluded.

In the future, the sample size is planned to be expanded to see whether the exploratory results hold true for a more general sample. In general, however, interest in science and science literacy as expressed by perceived knowledge about the topics addressed in the learning sequences has indeed positively changed throughout all groups and countries. We therefore conclude that the sequences have indeed a potential to facilitate positive affective developments towards science and science learning. However, one has to be careful of course as self-reports do not necessarily match with more objective measures of, e.g., conceptual understanding and tend to have low validity (see, e.g., Davis et al., 2023; Prince et al., 2008). The impact of the teaching sequences on the perceived knowledge of the participants is of significance even with strict p values applied, and we conclude that at least the perception of astronomy knowledge can be improved by the sequences. As the nature of this study was exploratory, we however have to warn against jumping to the conclusion that the sequences did in fact facilitate a real significant understanding of the concepts at hand themselves.

CONCLUSIONS AND OUTLOOK

Though there have been several positive results found for the implementation of the sequences and their effects on self-reported affective variables, due to the exploratory nature and other factors, several limits must be kept in mind when looking at the results and conclusions drawn from this study:

- The sequences were only roughly evaluated by the methods used, i.e., the pre- and–were done only before and after all the sequences together. A more fine-grained look on what exactly caused the mainly positive effects and how much of it can indeed be attributed to which factor is yet to be seen. For example, did the collaborative nature of the activities mainly foster greater interest and more positive social experiences or was the embodiment mainly responsible.
- The sequences were only three small units and therefore took only a comparatively small-time scale of the science lessons. This means that novelty effects have for sure had influences on positive change in affective variables (compare for example recent findings on this in the context of gamified learning [Rodrigues et al., 2022]). In the future, more long-term evaluations are planned to see how big this effect indeed is.
- Though self-reports of knowledge gains are a positive result, more in depth-tests for, e.g., conceptual understanding and its changes during the sequences have not been undertaken. It is therefore not yet clear how big the influence of embodiment on these more sophisticated levels is. Other research has shown in other areas that deeper conceptual understanding can indeed be facilitated by embodied learning (Glenberg, 2010), but it has yet to show how much these sequences did. An evaluation of the mental models of the solar system through drawing is underway and already indicates positive results (see the poster by Loch et al., 2023).
- Not only was the sequence novel for the students but also for the teachers. The data collected was thus from classes where these teaching methods have not been implemented smoothly and do not completely compare to a more everyday teaching session.
- No control group was examined that underwent the same lessons without the HO or other instructional forms. It is therefore unclear how exactly the embodied sequence fares against more traditional instructional practices.
- It was noted by the GR/CY–researchers of the team that the classes usually are educated in a more traditional way, also because of safety concerns, making the use of the HO a big difference to the usual teaching methods, which might bias the results.

The results turned out to point into mainly positive directions regarding developments of the affective variables linked to the embodied sequences. However, conclusions as to whether they facilitate conceptual understanding cannot be made at this point and will be evaluated elsewhere. Additionally, the reported findings should be further pursued and the results more closely examined: The questions we used to evaluate changes in for example interest were very rough and better scales do exist to assess interest in more detail and might net more fine-grained descriptions of the constructs at hand: While the present study provides promising insights into the potential of embodied learning, future research should more systematically address the current limitations. To move beyond the reliance on self-reports, future studies could incorporate more detailed explication interviews with students to gain deeper insights into their engagement and subjective learning experiences. Additionally, detailed classroom observations and systematic analyses of students' drawings and representations could help to more objectively assess conceptual understanding and track its development over time. In fact, this is already being prepared. To account for potential teacher bias and cultural influences, studies should include diverse educational settings and ideally involve multiple instructors to enhance generalizability.

By triangulating data sources and incorporating more robust designs, future research can provide a stronger foundation for both theoretical advancements and practical recommendations in science education. Of note is that the increase in engagement did not only occur in a single lesson but across multiple lessons. Indeed, in the corresponding literature it is argued that a catch-effect is needed first for long-term interest and then a hold-effect over a longer period. Based on our results, we conclude that at least the catch effect was successfully achieved in the present study, while trends towards a hold effect were also there (as the increase was across several lessons). As such, we see the approach as a new potential way to facilitate the catch-hold-effects. Still, more investigations on long-term effects are advised. The findings suggest that embodied learning holds promise for enhancing student engagement and understanding. To translate these insights into everyday teaching practice, future research should develop and evaluate scalable classroom interventions that integrate movement-based or spatially grounded activities. For example, teachers might use floor maps, role-play, or manipulatives to support abstract concepts in science or mathematics. The degree of enaction (full body vs. just movement of hands) is to our knowledge not yet investigated and pursuing this further seems highly advisable. Additionally, as not all changes were positive and in the FR setting indeed turned more negative, the exact causes for the changes must be further assessed in further studies. We were unable to reconstruct what exactly caused the negative outlier by interviewing the corresponding teachers. It must be investigated if this was an outlier or if there is a potentially detrimental effect on engagement in using embodied learning. First trends across countries were found to be mostly positive: In the end, the results as collected in the self-reports indicated that on average students react positively with regards to affective variables to embodied learning sequences and they might indeed prove useful for further facilitating effective teaching environments in astronomy education and beyond. As such, this study provides a mostly positive case of implementation of embodied learning in the field/in schools.

Author contributions: All authors contributed equally to this article. All authors have agreed with the results and conclusions.

Funding: This study was funded by the European project ARISTARCHUS from European Commission with project number 2021-1-FR01-KA220-SCH-000032478 and supported by the Open Access Publishing Fund of Leipzig University.

Ethical statement: The authors stated that no ethical approval was needed for the study. All data was collected annonymously. Written informed consents were obtained from the participants.

AI statement: The authors stated that no generative AI was used in the writing of this article.

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

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

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