ASTRONOMY EDUCATION JOURNAL

Astronomy Education Journal, 2026, Vol. 06, No. 1

doi: 10.32374/2026.6.1.152bp
ISSN: 2004-2981 Published in Sweden

RESEARCH ARTICLE

An embodied encounter with the Solar System

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Abstract

Background: A Human Orrery (HO) is a two-dimensional map of the Solar System drawn on the ground or printed on a tarp, which uses a scale of one meter for the Astronomical Unit. The HO functions as a dynamic model of the Solar System where participants play the role of celestial bodies. Learners physically engage with their peers, symbolically re-enact the orbits of planets and comets, and depend upon the group to "run the HO". As they move, stop and go again, observing the configurations formed and reflecting upon their own motions and positions, they engage in collaborative forms of thinking and reasoning. In this article, we investigate the emergence of a model of the Solar System as 9-10 year old learners explore the Human Orrery for the first time and perform during a one-hour "discovery session". **Results**: We analyze the joint actions of both learners and teachers as they engage with the HO. We look at ways in which the HO space functions as a blended learning space, integrating physical, social and conceptual dimensions. Learners carry out a structured inquiry process through their interactions and observations: they come face to face with an unusual situation, reflect upon their perceptions, put forward interpretations, and eventually reach a conclusion. The teacher nurtures their curiosity, guides the activities and inquiry process, and ultimately helps learners formalize ("institutionalize") their findings and understandings. The emergence of scientific concepts and the adoption of valid methods of inquiry through the HO is a gradual process that spreads over six one-hour sessions. **Conclusions**: A single, introductory, one-hour workshop is enough for the HO space to be transformed into a virtual Solar System that feels real, through the symbolic re-enactment of the planets and comets orbiting the Sun. The learners do not behave as passive observers : they become moving celestial objects and must accordingly act as reflective movers who perceptually and kinetically engage in reflection. They enact motions, orbits, and revolutions with an accurate relative speed. This dramatically reduces the epistemic distance between the observer and the objects and phenomena observed. It makes scientific reasoning more appealing and accessible, while fostering a more intimate connection to astronomical phenomena. From the alternation of day and night to the retrogradation of Mars, the HO offers a rare and exciting opportunity to enact and measure mathematical relations in the context of astronomy (such as Kepler laws).

Keywords: Solar System; Human Orrery; Inquiry Based Science Education; Metaphorical gestures

1 Introduction

Astronomy is usually a popular subject among students and is often included in school curricula (Salimpour et al., 2021). However, many learners still ignore key astronomical facts. Despite the instruction they receive in school and their exposure to scientific information, their knowledge of the Solar System has not improved over the years. "Alternative" conceptions (Simon and

Bailey, 2025, and references therein) are surprisingly common in all age groups. Many learners lack rational explanations for basic phenomena such as the alternation of night and day, the Sun's movement across the sky, the Earth's seasons and the Moon's phases. When primary school pupils describe the Solar System (e.g. Lelliott and Rollnick, 2010), they tend to focus on the Sun-Earth-Moon system. Jupiter is the most frequently mentioned planet (if planets are mentioned at all). The Moon, which is rarely construed as a specific object, is often confused with the planets (e.g., Sharp and Kuerbis, 2006; Calderón-Canales et al., 2013). As school children grow up, their knowledge of the Solar System evolves. The visuals used in textbooks or displayed in the classroom influence and reshape their early conceptions (Pena and Gil Quilez, 2001). Although students are likely to know the names and order of the planets by junior high, some visual representations prove misleading. For example, displaying the planets as a line can be confusing. One of the authors conducted a survey among 100 learners aged 11 to 13 which confirmed the prevalence of the Earth-centered model among younger learners and a clear shift towards Sun-centered conceptions with aligned planets among older learners (publication under preparation). As in many other areas of science, learning about the Solar System requires acts of personal and social cognition rather than acts of direct transmission (Sharp and Kuerbis, 2006). This paper examines how a dynamic teaching tool the Human Orrery (HO) may be used by learners to construe the Solar System in terms of object-types, distances, durations and movements. We specifically investigate how learners collectively construct meaning and progressively build a model of the Solar System through bodily engagement and inquiry during the introductory session presented below. A Human Orrery (HO) is a flat, two-dimensional map of the Solar System which is drawn on the ground or printed on a tarp (Fig. 1). It uses a scale of one meter for the astronomical unit. The HO functions as a dynamic model of the Solar System. Learners play the role of celestial bodies and symbolically re-enact the motions of planets and comets. As the activities unfold, participants engage in collective reasoning, using their senses, their motions, and their minds. Designing and setting up a HO obviously requires compression and simplification, which we discuss in Section 2 where the model of the Solar System represented in the HO is compared to the scientific model used in astronomical research. School users of the HO must first get acquainted with the general setup of the tool and discover the strategies that they will be using later for exploring the Solar System. This requires a structured introductory session that sets the stage for the embodied, performative and reflective actions to come. The introductory session is a pivotal moment because it determines what will happen next. We call this opening session a *first encounter with the Human Orrery*, or *discovery session*. In this article, we investigate how learners collectively make sense of the HO during this first encounter. More specifically, we examine how the signs and spatial organization of the HO progressively become meaningful through bodily engagement, observation, movement, and interaction. We also explore how the teacher guides this collective inquiry process. Finally, we examine how a more accurate model of the Solar System progressively emerges from the activities and interactions prompted by the HO. The theoretical framework introduced in Section 4 allows the research questions to be formulated more precisely.

The verbal-kinetic script that we have established for that "first encounter" is the product of an intense collaboration between co-designers and teaching partners in French schools. It uses inquiry as a teaching strategy (Section 3) and embodied learning as a theoretical background (Section 4). The way knowledge emerges as the group engages with the HO is analyzed using the Joint Action Theory in Didactics (JATD), which is described in Section 5. A specific instance of the general discovery session is analyzed in Section 6. The findings are then placed in a broader context, with particular attention paid to learner engagement and learning processes, not just in astronomy education but also in science and mathematics.

2 Background to the Human Orrery

Planetariums use dome-shaped projections of the sky to display the movements of the planets around the Sun (Brazell and Espinoza, 2009; Plummer et al., 2015). They are usually quite large and spectacular. Viewers are likely to be impressed by the sense of cosmic grandeur they convey, which appeals to the senses and emotions, not just the mind. Orreries offer a more modest but valid alternative to planetariums. They are smaller mechanical models of the Solar System that come with their own technical features and material constraints: the planets are represented as three-dimensional spheres and their movements reproduced mechanically. The focus placed on motion and miniaturization makes orreries attractive and impressive too, but also creates a kind of distance between the human observer and the clever mechanical object observed. As its name suggests, the Human Orrery (HO) integrates the human component. It turns the human observer of the Solar System into an active participant, both as a "doer" ("mover", "player") and a reflective "viewer". The HO displays a flat, space-time map of the motions of selected bodies in the Solar System around the Sun. The successive phases of motion are evoked through a series of discrete discs (dots), located at their respective positions at different times. The single, overall static image forms a kind of schematic chronophotography of the orbiting planets (Fig. 1). The HO is always drawn in the heliocentric frame, with the Sun at rest. The discs (dots) accurately figure elliptical orbits consistent with Keplers laws. The distance between Earth and the Sun is of one meter, which allows participants to act as planets or comets moving around the Sun. The material configuration of the HO encourages an embodied and interdisciplinary approach to astronomy, combining knowledge of the universe, kinematics, geometry and analysis. The first orreries to be designed on a human scale were conceived in Japan (Dynic Astropark) and in Northern Ireland at the Armagh Observatory (Asher et al., 2007). The Japanese orrery uses circular orbits, while the Armagh Orrery is a very accurate representation of the elliptical orbits that includes planets up to Saturn and two comets. Since 2015, F-HOU [1] (Rollinde et al., 2016) has been promoting the educational use of Human Orreries in France and in Europe. Different teaching sequences have been tested and analyzed to help and incentivize teachers, with field reports and studies published in different journals by the ESMEA team[2] (Rollinde, 2017; Abboud et al., 2019; Rollinde and Decamp, 2019; Rollinde et al., 2022; Rollinde and Maisch, 2023).

2.1 The design of the Human Orrery

This section presents the system of signs used to model the solar system on the Human Orrery, and typically identified during the discovery session. .

The length scale is set at one meter per Astronomical Unit (AU) to simplify conversions. Different kinds of objects in the Solar System may be represented in Human Orreries:

- **Planets**. When a Human Orrery is permanently set up in a large space, almost all the planets can be displayed. The largest French HO is located in a junior high school. It includes

1 handsonuniverse.org/france
2 http://ldar.website/esmea

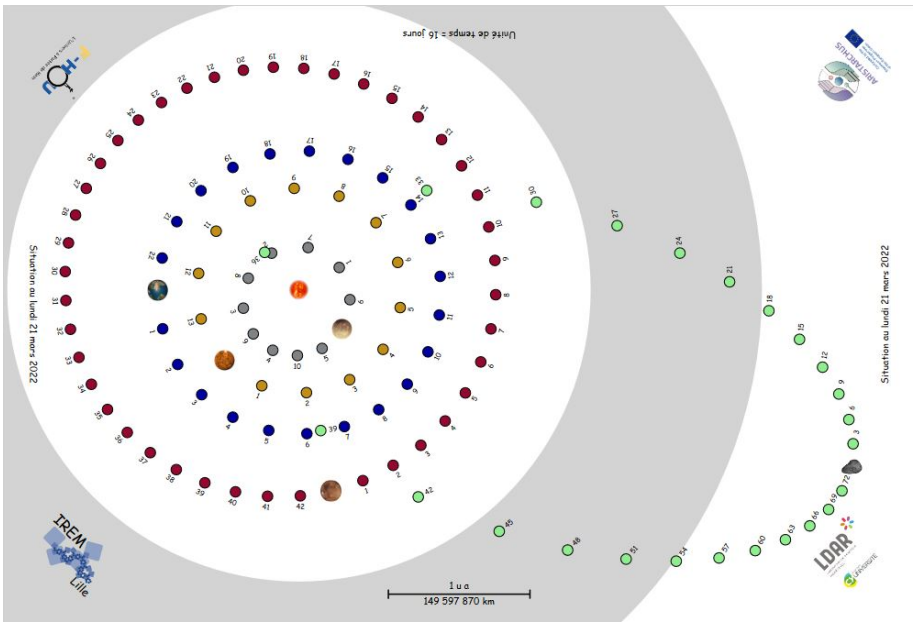


Figure 1. The 3,4*6 m^2 Human Orrery which was used during the session described in this article. Labels are in French. See text for details.

planets up to Saturn. The orbit of Uranus will soon be added, at about 10 AU from the Sun. Printed orreries are usually smaller. They offer a more limited display, which is restricted to the orbits of inner planets: Mercury, Venus, Earth and Mars (up to 1,6 AU from the Sun).

- **Comets**. The orbits of one or two comets are usually represented: typically Comet 2P/Encke, whose orbit extends up to 4 AU at its aphelion (the position furthest away from the Sun), and Comet 67P/ Churyumov-Gerasimenko, which reaches the orbit of Jupiter (at 5,7 AU from the Sun).
- **Asteroid and dwarf planets**. The main asteroid belt is a torus shaped region (2-3 AU radius from the Sun) between Mars and Jupiter, which contains a multitude of solid, irregularly shaped bodies called asteroids or minor planets. These are much smaller than planets. On the HO, they are represented as a 2D grey ring, together with the orbit of the dwarf planet Ceres (if the tarp is large enough).

Each orbit is dotted with painted discs and their corresponding numbers. The duration from the position numbered *i* to the position numbered *i+1* is constant for all orbits. It is called the time step (Δt). In a few cases, the numerical series goes from three to three (Encke) or alternates over two periods (Mercury). We discuss these exceptions in the next section. Positions in the heliocentric frame, at a constant time interval (Δt), are shown through a succession of discs (dots). Planets and their dotted orbits are assigned a particular color. The fact that all the discs are the same size clearly shows that they are not drawn to scale. The discs which represent the position of objects at some "initial date" are slightly larger, and in the case of a printed tarp - represent the image of the planets or the comet. The disc associated with the Sun is also slightly larger. Details about the model used to create the Orrery are discussed below.

When doing (or running) the HO, participants are assigned a specific planet (or comet) that they must *stand for* and *move by*. They travel along the corresponding orbit at a pace that is set by the instructor (or a peer). The instructor's hands clap rhythmically, and a kind of choreography of the orbiting planets develops as result. Between two claps, the participants move in unison: they step forward from one disc to the next, following the marks and their numbers, while the Sun stands at rest (in the heliocentric frame).

2.2 A precursor scholar model of the Solar System

The HO is a teaching and learning tool. Its accuracy does not preclude discrepancies with the scholarly models used in astronomical science. However, teachers and learners are informed about the most obvious differences, so it is unlikely that the departures from higher-order models will generate misconceptions. The model we use in the HO should be viewed as a "precursor model" of the Solar System (Weil-Barais, 2022). We refer to it as the "Orrery model." It is tied to astronomical research, but some practical choices had to be made to handle the reality and complexity of physical situations. When considering only the Newtonian dynamics of the Solar System, objects interact through the gravitational forces of an N-body system, where N is greater than three. Consequently, it is impossible to compute their exact trajectories analytically. The Orrery map is created using a program developed by F. Recher (IREM de Lille)[3] that retrieves the positions of objects at any given time from the IMCCE website.

1. It is important to realize that the system of signs used to encode the positions and motions of the planets in the HO may adversely affect performance. The colored discs appear to viewers as discrete units spaced along the orbits. This may encourage participants to hop or walk robotically from dot to dot in staccato fashion. This is why users of the HO should keep their legs moving between the claps, because orbiting planets are in continuous motion.
2. Various options are available for the determination of time steps (Δt).

    - Δt =1/24th the terrestrial year. This allows the Earth to come back exactly at point 0 after one revolution. The time step will not be written on the HO since it may be derived thanks to the movement of Earth along its orbit. Note that the duration of the last step that reaches dist 0 is not equal to Δt for other planets since their period is not an exact multiple of Δt. Yet the duration of this last step is not so different, which makes it possible to walk smoothly all along the orbit.

3 You may create your own orrery here: https://orreries.univ-lille.fr/en/

- Δt =16 terrestrial days (this is the option chosen for the Human Orrery that is used in this paper). In this configuration, there are 23 discs (dots) along the orbit of Earth, and the time step is indicated on the HO. The duration that corresponds to one orbital period along the orbit of Earth on the HO would now be 368 days. So, all orbits are similar in that the duration of the last step is not equal to Δt (but close enough).
- Mercury presents a special case. Its orbital period is approximately 88 days. With a value of Δt = 16 days, one orbital period corresponds to 5.5 steps. Therefore a second series of discs is added to complete 11 steps before reaching position 0. The two series alternate along the orbit (Figure 1, grey discs). With the choice of Δt =1/24th a year, 88 days correspond to 5,78 steps, so the last step is not so different from others, and only one orbital period is drawn.
- As comets move away from the Sun to their most distant point (or aphelion), they lose velocity. As they approach the Sun again (perihelion), they regain speed. Drawing only one disc over three prevents the discs from getting too close to each other at aphelion (Figure 1, green discs). Three steps are consequently required to travel from one disc to the next.

3. Last but not least, orbits in the Solar System are not stable and change over a large period of time: about 10.000 years for Mercury's orbit, and 400.000 years for the Earth's orbit. It follows that the trajectory of each object on the Orrery may be viewed as relatively stable over the period of time considered in an educational context, typically a dozen orbital periods.

3 Teaching and learning with the HO

Mathematics and science education researchers jointly designed a set of teaching and learning sequences with input and feedback from teachers who regularly use the HO in their classrooms. The sequences they devised are intended for groups of learners aged 813. The scripts can be freely downloaded from the European project website ARISTARCHUS[4] (Karampelas et al., 2024). Each session follows the Investigative Science Learning Environment approach (Etkina, 2023) with an emphasis on the observation phase. This approach allows teachers to design progressive STEAM instruction. The first session introduces the HO. Its main goal is to understand what the printed signs and symbols represent and discover the basic choreographic principles of the HO. The goal of the second session is to set up a Human Orrery in the school courtyard. This HO will be used during the five following sessions to investigate various STEAM concepts related to space, duration, and scales (units of time and distance, geometry, and kinematics). The closing session contains a set of brief exercises designed to optimize the physical and intellectual performance of learners as they "do" the HO. As its title suggests, the present article is primarily focused on the discovery session "An Encounter with the Solar System" where learners find out about the HO: its symbols and structural components, as well as its embodied nature and the rules of verbal-kinetic engagement.

3.1 Inquiry and observation

According to the theory of inquiry (Dewey, 1938; Barrow, 2006), "Human beings develop and grow by re-establishing transactions with their environment in order to maintain continuity. When disruption occurs and the balance of activity is disturbed, the subject engages in intelligent behavior aimed at restoring continuity in the course of his or her activity." The learners are expected to move onto the tarp and take on the role of planets, which is unchartered territory for them. They must decipher what the signs stand for, such as the colored discs (dots) and the scales, and adjust their motor actions accordingly, with "new forms of knowledge produced in the process." Users of the HO are normally expected to follow a phased pattern of inquiry : 1) Facing an indeterminate situation and experiencing doubt; 2) Framing the problem or issue at stake; 3) Finding (and possibly agreeing on) a solution ; 4) Reasoning; 5) Understanding the operational nature of facts and their interpretation. The process of inquiry has been theorized in the context of science education under the name of Inquiry Based Science Education (IBSE) or Investigative Science Learning Environment (ISLE). Following the classification introduced by Strat et al. (2024), this section focuses on the procedural domain, where "explicit instructions are given on how to perform [during this specific learning session] the various practices involved in an inquiry process".

According to Zask (2017), who stresses the importance of observation at every stage of the inquiry (as defined by Dewey), it is essential to distinguish between different types of observation:

- spontaneous observation: identifying the cause of the problem - material or cognitive - in order to overcome it.
- reflective observation: looking for ways to transform the existing situation by creating new tools.
- observation guided by hypotheses, with a view to collecting data,
- observation to the power of 2, which involves looking at the consequences of initial observations in terms of concrete effects, situated practices, or existentially felt results.

Discovering the Human Orrery is largely a matter of observing and interpreting the signs through actions and perceptions. Observation "involves training all the senses and coming into direct contact with things" (Zask, 2017). Observation is used not only to collect data that will impact further reasoning, but also to integrate perception, motor action, and reflection.

3.2 Design

As already stated, the primary goal of the discovery session is to introduce learners to the HO, particularly by identifying the patterns and relationships that are visually displayed. Learners engage in authentic astronomical inquiry, beginning with their common-sense interpretations of the HO. As they observe, act, and discuss things together, their initial interpretations evolve into more accurate conceptions. This progression is made possible by the continuous coordination of action, perception, and reasoning. Learners adjust their perceptions, compare their perceptions with their understanding, adjust their hypotheses, and collectively refine the meaning of the signs displayed on the HO.

The introductory session described below is designed for learners aged seven and older. The only prerequisite is that participants be able to walk rhythmically and know their numbers up to 40. It is easier if learners also know their three times table, though it is not required. This first interdisciplinary STEAM session connects different topics and academic subjects.

- Astronomy: identifying Solar System objects and their orbits.
- Art: reproducing the choreographed movements of Solar System objects around the Sun.
- Science: introducing the concepts of distance and duration and their units without addressing the concept of speed. We consider speed to be a complex notion that requires a specific

4 https://elearning.aristarchusproject.eu/ - access requires to create a free account

session. Therefore, the teacher was asked not to dwell on this concept.
- Mathematics: discussing the notions of distance and duration scale; adapting the choreography to the different numerical series.

To initiate the inquiry process, the teacher instructs the children to move around the entire Orrery space and observe what they see. Then, the teacher randomly asks pupils to express what they have noticed, i.e. *to verbalize patterns*. This corresponds to a **spontaneous observation** of a sign that needs to be interpreted.

Next, the teacher asks the children to point to and move around the object or pattern in focus, while the rest of the group gathers around them.

The group is invited to seek an interpretation (i.e. *form different hypotheses, think of likely explanations*). Throughout the process, the teacher guides the group towards finer, more articulate perceptions, using questions such as "How do you know that?", "What makes you believe this?", "Can you show us...?." **Reflective observation** then begins to determine how the signs on the tarp interconnect. Throughout this process, the teacher may guide the group in various ways. For example, he or she may set one student or a small group in motion, have the group collect data on the tarp, or else provide extra scientific information that is not available on the tarp. Once the class has reached a consensus, the teacher summarizes the discussion and asks : "Are there other things you see or think that you wish to share with us ? [**spontaneous observations**]"

Compared to the IBSE models and to the model proposed by Etkina (2023), the identification process used in this opening session emphasizes direct observation and observational experiments. Correctly interpreting the signs for the planets, the comet, and the Sun, making sense of the discs (dots) along the orbits, and understanding how the distance and duration scales are marked, require focused observation. Through the Investigation or Inquiry process, the HO tarp becomes a performance space where young learners can move as if they were planets orbiting the Sun. The discovery phase is essential for subsequent learning sessions because it enables the whole class to interpret the signs used in the Human Orrery and learn the basic motions required to "do" the planets. In the following sessions, the focus will gradually shift from identification and interpretation to prediction.

In a subsequent section, we will provide a detailed description of the identification process that occurred in a specific teaching environment. We will explain how all the participants worked together to overcome obstacles and find solutions.

4 Theory

This section provides the theoretical background for analyzing the learning session presented in Section 3. We consider two interrelated dimensions. First, the process of inquiry is made possible by embodied behavior: it is the learners' bodily participation that allows the Orrery model to function. Second, embodiment itself arises from the articulation of three spaces: the physical space where the activities take place, the social space of the classroom, and the conceptual space of astronomy. These three spaces integrate and create a stimulating environment conducive to inquiry. It is important to note that all humans, in all cultures, have an innate capacity to use space, marks, and bodily motions symbolically. This is why converting a tarp into a miniature Solar System, human bodies into celestial bodies, and physical movements into planetary orbits can be done so easily and almost effortlessly.

4.1 Embodied learning

The HO setup allows learners to immerse themselves in the Solar System, to physically experience and understand relatively distant and abstract phenomena such as the kinematics of the planets, through bodily reenactments and performative reflexivity. It is a particular instantiation of embodied learning in STEM education. Embodied cognition refers to the emergence of cognitive abilities from our sensorimotor apparatus, as we interact with the environment. (Varela et al., 1991; Lakoff et al., 1999; Gallagher, 2005; Shapiro, 2011). Numerous studies have underscored the importance of gesture, motion, and proprioception in learning, particularly in the process of abstraction. (e.g. Nathan, 2021; Dove, 2022; Reinboth and Farkaš, 2022).

4.2 Using embodied learning in physics

Early research on embodied STEM learning focused on the role of gestures. When learners talk about abstract concepts in physics or mathematics, they use words and gestures co-expressively (Kendon, 2000). Most of the time, the gestures they make are congruent with the action, movement, trajectory, shape, or location of the phenomenon being discussed. These gestures play a crucial role in maintaining or recalling visual imagery, simulating action (Hostetter and Alibali, 2008), and describing abstract causal concepts (Cooperrider et al., 2016). Thoughts and words are shapers of human action and gesticulation. Conversely, physical actions and gestures fuel cognitive processes and verbal expression (Goldin-Meadow, 1999; Kita et al., 2017). Physical action and gesticulation are thus inseparable parts of human expression and conceptualization. Many concepts in physics teaching require performing actions and interacting with objects or substances. As trite as it may seem, physics is an inherently "physical" subject. Yet the physicality of understanding in physics education is not given all the attention it deserves. As emphasized by Goldstone et al. (2008), perceptualmotor activity is constitutive of knowledge construction: *"knowledge is not simply in the extracted verbal or formal description of a situation, but rather in the perceptual interpretations and motoric interactions"*. Several studies within the embodied learning paradigm focus on the design of physical learning environments for STEM education (cf. Lindgren et al., 2016; Abrahamson et al., 2020). The approach we propose promotes physical engagement in physics education. This means placing the student's "learning body" in an environment conducive to bodily interactions with concrete or abstract objects and promoting performative modes of thinking and reasoning. In such environments, the learning body interacts with other learning bodies and performs "acts of understanding that integrate perception, movement and knowledge" (Lapaire, 2022, p. 283). One way of doing this consists in eliciting perceptualmotor activities that align with the concepts being studied. This is likely to create multimodal memory traces that contribute to the formation of more stable knowledge. For instance, teachers may suggest working on the mathematical representation of centripetal forces by having learners rotate objects of different kinds in an augmented reality environment (Johnson-Glenberg et al., 2016). They may find that full bodily engagement can lead to improved understanding. As they engage in sensorimotor activity, learners develop a kinesthetic perception of the effects produced by rotating objects. They adjust their posture or actions accordingly. The authors compare different learning settings and identify three main criteria that contribute to the stabilization of knowledge: (i) motor engagement; (ii) gestural congruence (the extent to which the enacted gesture is related to the content to be learned); (iii) the perception of immersion.

This approach has subsequently been extended to other

learning environments, and may be classified along two dimensions (Skulmowski and Rey, 2018): (1) bodily engagement (how much bodily activity is involved) and (2) task integration (whether bodily activities are related to a learning task in a meaningful way or not). Another approach is for a group to elicit and simulate the phenomenon under scrutiny. For example, in the "theater of energy" examined by Scherr et al. (2012), students represent physical manifestations of energy by moving between different areas of 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 students producing qualitative descriptions of orbital motion resembling Keplers laws by enacting them through a paired dance. This "enacted analogy" of the studied phenomenon becomes a resource for understanding certain characteristics of the situation, making it more intelligible. As the 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, p. 010134-5). The enactment is constitutive of the semiosis at work in the situation, namely the process by which learners produce, manipulate, and transform systems of signs to construct meaning and engage with disciplinary knowledge.

Much like the theater of energy, the HO provides a simulation of the studied phenomenon based on bodily engagement and the congruence of the learners' movements with the motion properties being investigated.

4.3 Enacting planetary motion laws - the HO space as a stage

The HO aims to elicit an enactment of the motions of planets and comets around the Sun. The HO space functions as a "blended space" (Fauconnier and Turner, 2008) that integrates at least three spaces : the *physical place* chosen to set up and carry out the activities (e.g. a hall, a playground, a classroom); the *social space* of the classroom (where learning is institutionally organized) and the conceptual, *cosmic-semiotic space referring to the Solar System* (which is materialized by the model traced on the ground or printed on a tarp). The latter includes cultural elements. It is important to note that learners experience those three spaces jointly and simultaneously as they "do" the planets and comets.

Participants stand, step and move through their immediate surroundings which they clearly acknowledge as the proximal physical space. As they do this, they enact distant celestial objects, positions and movements that normally belong to Outer Space. That second space is both *factive* it exists as fact - and *fictive*: its kinetic realization is a form of symbolic action (bodily movements are not actual planetary motions but everyone acts as if they were). The participants are also seen responding to prompts and instructions. They engage in guided activities, thus acknowledging the HO as a social and educational space.

All three spaces physical, social-educational, cosmic-semiotic merge into one single experiential space: the blended HO space, with its own rules of "make-believe" (simulation), kinetic properties, and cognitive functioning. What holds for space holds for the body as well. Participants are seen responding physically and socially to the co-presence of fellow human bodies. They are also seen symbolically enacting celestial bodies, as part of the *kinetic fiction* of the HO. By complying with the physical guidance issued by the instructor, performing and engaging in reasoning tasks, the sensing, moving and cognizing bodies genuinely behave as learning bodies (Lapaire, 2022). So, just as we have three integrated spaces, we have three integrated bodies, blending into one "HO learning body," with its own behavioral codes, movement patterns and reflective activity (Lapaire, 2022).

4.4 Research Questions

As the collective inquiry unfolds under the teacher's guidance, how does the model on the ground become meaningful to learners? In what ways does bodily engagement contribute to semiosis? Under what conditions does the inquiry lead to a more accurate understanding of the Solar System and the emergence of a model?

Other studies on embodied learning in physics analyze the activity of a single learner or a small group of peers. The present study focuses on analyzing how participants engage collectively during a single introductory session. The situation is viewed as characteristic of the interactions and cognitive-semiotic processes that we have so often witnessed in French schools. During this type of opening session, participants must interpret numerous signs to identify the properties of celestial objects in the Solar System. The present study examines the joint physical actions of teachers and students and identifies the processes that occur during the investigation.

5 Methodology

5.1 Research setting, participants, and data

The one-hour session described in Section 3 was conducted with fifteen nine- to ten-year-old children at a French primary school. The learners will be referred to as "pupils" from this section onward. We used a 3.4 mš Orrery (Fig. 1), with the following orbits and color codes: Mercury (grey), Venus (orange), Earth (blue), Mars (red) and Encke (green). The time step was 16 terrestrial days. The initial date was March 21, 2022 (spring equinox). The length scale was one meter per astronomical unit. An experienced teacher who had attended a training workshop organized under the auspices of the ARISTARCHUS project facilitated the session. He was completely in charge for the first time. The "Discovery session" that he facilitated was based on the scenario presented in section 3.2, which had been previously tested during the teacher training course. The "encounter" between the pupils and the HO was filmed by our team. The audio was automatically transcribed using Adobe Pro. The transcription was checked and revised (see Appendix, Table 13). Each line was numbered and labeled with the speaker's pseudonym.

5.2 The "triple genesis" as an analytical framework

The analysis focuses on the meaning-making process as learners engage collectively during the discovery session. We consider the spatial and temporal circulation of knowledge and use the "triple genesis" framework (Sensevy et al., 2005) which analyzes the joint action of learners and their teacher within a classroom setting (Joint Action Theory in Didactics, JATD). The three geneses are defined as follows:

- *Topogenesis* (the genesis of positions) describes the process of dividing the activity between the teacher and the pupils, according to their potentialities.
- *Mesogenesis* (the genesis of the milieu) describes the process by which the teacher organizes a milieu (here, the Human Orrery) with which the pupils are expected to interact in order to learn.
- *Chronogenesis* (the genesis of didactic time) describes the evolution of the knowledge proposed by the teacher and

id	3	5	6-9	10 -21	23 -26	27 - 28	29-31	32-35
notion	Number	Earth	Moon	Discs	Planets - Moon	Sun	Moon-Planets	Comet
category	U	P	U	U→O	P	O	O	P→O
id	36	38-39	41	42-45	45-47	48 - 50	51-55	56-59
notion	Sun	Discs	Date	Spatial scale	Temporal scale	Numbers (Earth)	Numbers (Mercury)	Numbers (Encke)
category	O	O	O	U→O	P→O	O	P→O	O

Table 1. Summary of the chronogenesis (Table 6) with the time of emergence of different notions and their categories (Unconnected, Precursor, Overlap).

studied by the pupils as it unfolds through joint action. As clarified in Sensevy (2010), responsibility for the advancement of knowledge in the classroom is shared between the learners and the teacher.

These dimensions cannot be separated, as each aspect of the teachinglearning process simultaneously involves the evolution of knowledge, the distribution of roles, and the transformation of the milieu.

The triple genesis method used in the present study is based on three types of complementary data: (1) verbal interactions, as recorded in the session transcript, including teacher-student and peer discussions; (2) bodily interactions, such as pupil movement across the tarp, spatial positioning, and metaphorical or representational gestures produced while interpreting signs; (3) elements of the HO (the tarp, images, and numbered discs) and pupil engagement with these elements. For analytical clarity, we identify traces that are characteristic of each genesis, even though they co-occur in practice.

The session was divided into episodes based on the recordings and transcripts. Each episode was defined by a sign that became the focus of the group's attention over a continuous time interval (chronogenesis).

We then examined each episode from three complementary perspectives, each of which sheds light on a different aspect of the triple genesis process. We undertook:

- An analysis of the roles assumed by the teacher and pupils (topogenesis);
- An examination of how meanings are constructed from what acts as a sign, through a study of the interactions between the teacher and his pupils (mesogenesis and chronogenesis);
- A definition of the degree to which the pupils emerging conceptions align with the Orrery model as defined in Section 2.2.

We annotated the data using three analytical categories O, P, and U.

O. overlap (sufficient similarity between the Orrery and students knowledge elements); P. precursor (a students knowledge element differs from the Orrery, although there is potential for overlap); U. unconnected (no apparent connection between the knowledge elements of the student and the Orrery).

Our analysis of embodiment was entirely based on the video footage that we recorded, with a focus on motions and gestures (Alibali and Nathan, 2012). The gestures were annotated and inserted into the transcriptions (Mondada, 2018). The transcriptions were then used to analyze how the signs on the tarp, the motions, the gestures, and the uses of speech contribute to the "triple genesis" and integrate. As the analysis progresses, we will consider how bodily engagement may be implicated, to varying degrees, in the triple genesis.

6 Analyses

Table 1 summarizes the chronogenesis of the different pieces of knowledge during the session. Throughout the analysis, we use the chronological order (id) described in the first column of Table 6) rather than the timing (second column) or the id of the full transcription (Table 13). Similarly, from the observation of the localization of the pupils and the teacher (Annexe 2, Table 10), we generated a map of displacement (Figure 2).

The group follows a structured path, starting from the center (number 1) and gradually moving outward while making back-and-forth movements between the near and distant zones of the Solar System. The center of the Solar System is not the center of the map, but it acts as an attractive pole for the group.

6.1 A collective inquiry within space

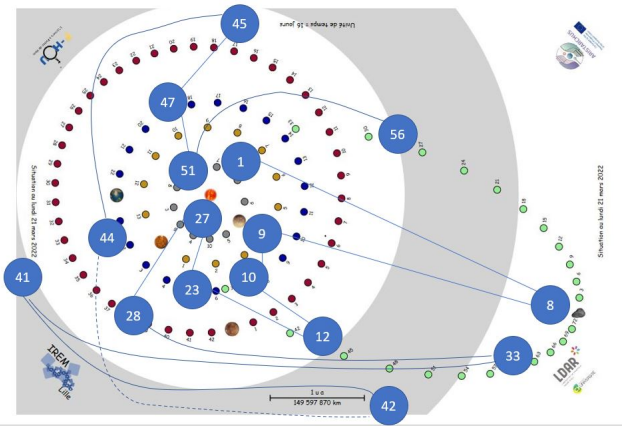


Figure 2. Circulation of the group as a whole along the tarp. Numbers are related to the timeline of the session (Tables 6-10, Annexe 1).

The session begins with observing or looking for familiar objects, such as the Earth, the Moon, numbers, and colored disks along the orbits (id 3-9). These initial observations often remain in category U, as pupils project their personal interpretations (for example the Moon may be confused with a comet, or the color of the disks may be interpreted as a symbol of heat). Planets are identified progressively (id 5-31), and hesitations are dealt with as they arise (section 6.2). The Sun is also identified and confirmed early on (id 27-28). The comet (id 29-35, section 6.2) requires a longer identification process: the initial propositions are precursors (P), which often arise from naive associations (e.g., likening a comet to a rock or the Moon). The guesses eventually converge towards a correct interpretation (O). Then, the pupils discover more abstract elements, such as the numbering of the orbits (id 48-59) and, most importantly, the spatial and temporal scales (id 41-47). These signs require more effort to read and interpret. Since they are not directly linked to the model (categories U or P), their comprehension requires multiple attempts.

After several tries, the pupils correctly relate the numbers on the orbits to their positions and understand the correspondence between the discs (dots) and the passage of time (category O, ID 21, 55, and 59). Thus, the discovery of the Orrery generally follows a chronogenesis that moves from concrete, immediately recognizable objects (e.g., the planets and the Sun) toward more symbolic signs (e.g., scales and numbers), which require stronger mediation.

We would like to revisit a few specific moments of convergence. Position 27 corresponds to the pupils gathering around the Sun. The teacher can look at the image and ask students questions to assess their prior knowledge and justify the hypothesis that the Sun is at the center. The pupils do not use any information from the Orrery. Position 51 corresponds to a gathering near Mercury's orbit. This allows for reflective observation aimed at understanding the necessary actions to move along Mercurys orbit (see Section 6.3). When the group moves away to reach positions distant from the center, it does so by following a pupil who has spotted an interesting element (spontaneous observation), such as the comet (8) or the distance scale (42, see Section 6.4). When a pupil spots the time scale (at the top of the map, number 45), the teacher asks her to read the label. This time, the group does not follow her but remains at the center of the Orrery. Then, the whole group discusses the timescale through an observation of disks along the orbits of the inner planets (47, see Section 6.4).

This path of exploration is progressive and structured. It is undertaken by the group as a whole or by individual pupils who spontaneously take on leadership roles. Spontaneous observations lead to movements between zones near and far from the Sun, where reflective observations are made. The roles are not distributed among participants according to some preexisting pedagogical scenario but on the basis of the spontaneous observations they make. This collaborative inquiry is carried out in the moment. It engages both teachers and pupils in joint action and involves semiosis, as a multimodal process based on observation and bodily engagement. After analyzing the topogenesis (or the organization of activity between the teacher and pupils) as the planets and comet are observed, we will return to the chronogenesis.

6.2 Spatial structure of the celestial objects

The distribution of roles in the construction of knowledge is not stable throughout the session. Different modes of topogenesis emerge. Some initiatives come from individual students, while others arise from the group as a whole. The teacher modulates their responses by guiding, postponing, or sometimes avoiding an immediate answer. This section illustrates the diversity of situations by analyzing episodes associated with the objects on the Orrery.

Planets

First, we note that the pupils identify the planets themselves. One pupil spots the image of Earth early in the session (5). The group does not identify it, and the teacher only confirms that "there is a planet," likely assuming that the group can recognize the image of Earth. As the group discusses an orbit composed of blue dots (1319), one pupils uses the word "Earth" (18). This is the first time the word has been spoken during the session. The teacher asks, "Why did you say it's Earth?" The pupil simply points to the image again. Identifying the image of Earth does not raise any serious issues for the group or the teacher. In other settings, when teachers ask why pupils named the image "Earth," the pupils point out the blue color of the ocean and the continents. This has never been a problem in sessions from the primary school level onward. Here, it is simply a matter of assigning the image of Earth an institutionally approved name.

Shortly after, other images of planets are observed. One pupil spots Venus and mistakenly identifies it as Mars (23). The group hesitates, suggests Jupiter, and then rejects the idea since Jupiter is too far away. Another pupil points to the image of Mars with his foot (24). He suggests that it is Mars and, at the teachers request, justifies his claim by pointing out the presence of clouds on Mars, which are visible on the image. Another pupil points out that Venus's image also shows clouds. The teacher confirms the names of Mars and Earth.

After a short discussion about the Sun, one student spots the image of Mercury (29). The proposition of this image being the Moon is discussed (30, see below). As the teacher explains that this is another planet, two pupils suggest Mars and then Mercury. The teacher asks for a justification for the choice of Mercury, and one pupil states that Mercury is the planet closest to the Sun (31). This argument does not come from the observation of the Orrery but from an external source of knowledge. This statement seems to convince the group, and the teacher then returns to the name of the image of Venus. The group proposes several names until the teacher asks a pupil who knows the Solar System well, and she gives the name Venus.

The presence of the images allows the group to focus on the visible objects during the first ten minutes of the session before addressing more complex symbols (Table 1). The group suggests different names, and when the correct one is proposed, the teacher asks for a justification (this allows the teacher not to be caught off guard by an argument that could not be contradicted and to manage time, according to the teachers own words in a post-session discussion). A pupil then contributes personal knowledge that is not present on the Orrery to support their proposal. The teacher progressively establishes (institutionalizes) the different planet names as the session unfolds. We insist that, from a mesogenetic perspective, the spatial structure of the artifact emerges through the pupils movements well before it is named and stabilized by the teacher.

Comet

The case of the comets is different because such objects are unfamiliar to most pupils at this age (Sharp and Kuerbis, 2006). The image of the comet does not resemble any familiar object. The attraction to this unusual object is reinforced by the green color of the dots (discs) along the comets orbit. Thus, from the very first minutes of the session (6), a pupil draws the groups attention to the image of the comet and the green dots (discs). The teacher invites the group to gather around the image. As the group observes closely (9), the same pupil notices craters and a gray color which they mistake for the Moon. One pupil objects, saying no, not at all, but the teacher prefers to postpone the discussion: Well see later that its not the Moon, but for now well keep the idea. About seven minutes later, after all the planets have been named, the teacher reminds the group that "something remains to be recognized" (32). A student recalls that "it is over there, the green dots, the thing"... A group discussion follows, prompted by the teachers request to propose something (32-33). Again, pupils bring in elements of knowledge that do not come directly from the observation of the Orrery. The oval shape of the green orbit is associated with the shape of Plutos orbit; the non-circular shape of the image of the comet contradicts the familiar round shape of the planets. The Orrery thus provides clues that complement the initial knowledge of the pupils, leading to the realization that the represented object is not a planet. The pupils then propose meteorites and asteroids, which are probably the only names they know besides the planets. The teacher then adds information that cannot be inferred from observing the Orrery: "Meteorites have fallen on the ground of the Earth," whereas the object here is "in space." The teacher concludes by introducing the term "comet," which the

students had not mentioned. A student unexpectedly interrupts the teacher and the general discussion ends abruptly.
The topogenesis of the objects associated with the images on the Orrerythat is, the organization of the activityis multifaceted. The pupils themselves initiate the identification of the planets, which becomes the subject of group discussion based on visual clues and prior knowledge. During the discussion, the teacher's role shifts between prompting, validating, and rejecting the pupils' proposals. During this session, the teacher rarely asks the group for validation to save time and keep the momentum. However, when the group does not reach the expected level of knowledge which only occurs with lexical elements, such as the name of the comet or the astronomical unit (see below) the teacher supplies the missing information. Overall, the class makes sense of the spatial distribution of objects drawn on the tarp (mesogenesis) through collective, embodied exploration (Section 6.1). The time of emergence (chronogenesis) of each object is also determined by the group's walk through space.

6.3 Visual and spatial observations

In this section, we examine more closely how different elements of the artifact begin to take on meaning through pupils visual and spatial observations. The mesogenesis is particularly visible here, as the images and symbols on the tarp are progressively interpreted, compared, and related to one another. These observations are not purely perceptual: they are supported by pointing gestures, spatial orientations, and small bodily adjustments that help pupils articulate and refine the relations they perceive.

From spontaneous to reflective observations

The Moon presents an interesting case in terms of observations. Pupils feel that they need to locate the Moon in this model of the Solar System. The moon is deeply embedded in our imagination and closely associated with observing the sky (Lelliott and Rollnick, 2010). Pupils therefore expect to see the Moon on a map representing the Solar System. However, the Moon is not represented because of the scale of distance. The Earth-Moon distance (384,840 km) is about 1/400 of the Earth-Sun distance (AU). 1 AU corresponds to 1 meter on the Orrery, so the center of the Moon would be 0.25 cm from the center of the Earth - right under Earth's disk. For a primary school class, such a comparison of distances would require an additional session. One option would be to use the Stellarium software to demonstrate visual changes of scale. Many pupils (and teachers) think the Moon is missing because it is too small. However, all the objects on the Orrery are represented by discs (dots) of equal size. The disc representing the Sun is the same size as those representing the Earth and the comet. It follows that, disc sizes are not to scale. This subtlety often causes difficulties, especially among primary school teachers. We now describe how these concepts emerge through various activities during the session.

It starts with spontaneous observations. Looking at the signs in the Orrery, pupils propose different objects that "look like" the Moon, such as the comet Encke (8) and Mercury (11; 26; 29-30) where one may observe craters and a dark color. In the case of Encke, the teacher directly rejects the proposition of Encke being the Moon (9).

The case of Mercury is discussed further, with different hypotheses proposed to interpret the image. Some pupils think that "the Moon is near the Sun" so the image of Mercury may well be the Moon, but the group is not sure (29, "yes, no, yes, I don't know"). They focus on the image itself ("well, it is close there"). Since the teacher tells the pupils that "this is not the Moon", a reflective observation that connects Moon and Earth (30) emerges: the Moon is orbiting Earth. The teacher then points towards the orbits of Mercury and Earth to indicate "that is simply not possible" and concludes that this [Mercury] is not the Moon but another planet. We note that this discussion may have also been used to dismiss the idea that Encke is the Moon.

The pupils do not mention the Moon again during the session. They do not need to explain its absence. However, the topic of the Moon will be raised again during the choreography of the orbiting planets in a subsequent session, following an amusing comment made by the teacher (see an extract of the transcriptions, Table 2). This occurs approximately 20 minutes after the episode concerning the Moon and Mercury, and lasts only 30 seconds. The teacher returns to the fact that the Moon is absent from the scene. The previous reflective observation was based on the Moon's movement around Earth. Now, the class focuses on the object itself. The teacher rejects the proposition "(it's not there because) it is hyper small" without further explanation, saying, "That could be it, but it's not the case." Then someone suggests "it is too far from Earth." The teacher does not repeat the statement but directly explains that the Moon is too close to Earth to be represented. This confirms that a discussion about the absence of the Moon from the Orrery may be too complex for primary school children to handle. Discussions about the presence or absence of the Moon should best be avoided unless the pupils insist to have one.

The chronogenesis of the Moon shows how initial spontaneous observations evolve into reflective ones that relate multiple signs on the Human Orrery (mesogenesis), rather than focusing on any image in isolation.

From observation to a semiosis based on sensorial modalities

In order to understand the concept of an orbit on the HO, students must interpret the sequence of colored discs and their corresponding numbers. The semiosis comprises several stages. First, a child notices one number (3). Then, another child draws the teacher's and the class's attention to the blue circles by pointing to three successive blue discs (dots) with her foot (10). The class moves aside to talk about those discs (12 to 22). Then, the same pupil walks along the orbit and points to a longer sequence of discs (see Table 3, upper left). When the teacher asks her what the blue dots represent, she directs the class's attention to three dots in a row (representing the orbits of Mercury, Earth, and Mars) by pointing to them in a line (see Table 3, upper center) which she interprets as a heat gradient, the red being understood as a symbol of high temperature. The teacher redirects her attention to the blue dots when a pupil suggests moving along them (see Table 3, upper right). In the discussion that follows, the teacher addresses the pupils who were observing (18-22, see transcription in Table 4).

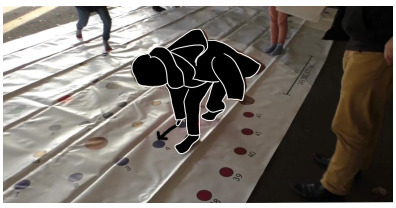
They describe this circular movement as "the earth turning" (Table 3, lower left), and then a pupil makes a generalization by associating this movement with the path of the planets. She simultaneously represents this path with circular finger movements in the transversal and frontal planes (see Table 3, lower right). The circular movement made by the pupil on the tarp is re-enacted manually in the form of an iconic gesture. The finger movement symbolizes the planets' continuous circular motion, which is initially represented by a series of dots on the tarp. At the end of the activity, the teacher introduces the term "orbit" and sums up the pupils' remarks by explaining that the blue dots (discs) actually represent the Earth's orbit (22).

Once pupils have made sense of the image of Earth and the sequences of blue discs, they will have no difficulty extending those findings to other sequences of colored discs. This correspondence does not need to be validated by the teacher and occurs gradually as pupils encounter different sequences of discs, such as those for the comet (38), Mars (39), and Mercury (51).

In this particular session, the pupils first make observations, then engage their bodies by moving along the orbit they have observed, and finally produce metaphorical gestures that enable

Table 2. Extract of the transcription when the Moon was discussed again

370	25:21	"G7" is the Earth. We are on Earth.
371	25:22	- Do you agree? - (pupils) yes... - A certain number of you have your heads in the clouds - (pupils laugh - the english "heads in the clouds" corresponds to "you are in the Moon" in French)
372	25:28	By the way, we didn't talk about the Moon earlier.
373	25:31	- Why do you think we can t see the Moon? - [B3] because it s extremely small.
374	25:34	- because it's very small. - [B3] yes.
375	25:36	- (Pupil) yes, it s so small that it... - No, that could be it, but it's not... "G3"?
376	25:41	- [G3] because it s very far away - because it s very far away from what - [G3] from the Earth
377	25:45	- not very, very far. - (Pupils) Oh! Oh! - That's it!
378	25:49	- So the Moon is too close to the Earth for us to be able to depict it.
379	25:52	We can t. We can t depict it.
380	25:54	It would be too close to the Earth. It s the Moon, it must be going around "G7".
381	25:58	If we depicted the Moon, it would be underneath. It would be under the Earth, so we can t see it.
382	26:03	OK, so we've done that.

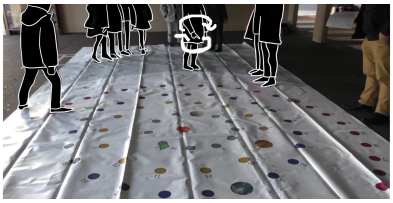


35 - 1:59
G2: "blue dots"

45 - 2:09
G2: "it's hotter and hotter"

53 - 2:43
Teacher: "walk on the blue dots"

65 - 3:10
B3: "that's planet Earth there"



68 - 3:22
G3: "that's what I think what it looked like"

Table 3. Encounter of the orbit of Earth in different phases (see text for details)

them to shift from a discontinuous to a continuous representation of the orbit.

6.4 Congruency

In this section, we focus on how bodily actions become congruent with the astronomical meanings under construction. This congruencyunderstood as a match between the structure of the movement and the structure of the conceptplays a central role in supporting abstraction. As noted by Skulmowski and Rey (2018) and discussed in Section 4, embodied learning is most effective when bodily actions are meaningfully aligned with the conceptual relations to be understood.

Distance scale

The notion of spatial scale relies on the proportional relationship between the distance measured on a map and the corresponding real-world distance between the objects it represents. On the HO, this relationship is materialized by a one-meter segment drawn on the tarp, labeled as 1 A.U. underneath. The segment thus acts as a reference for scale: one meter on the map corresponds to the average EarthSun distance, defined as one Astronomical Unit (1 AU $\simeq 1.5 \times 10^8$ km).

Although the pupils already know that a map requires a spatial scale in order to be interpretedi.e., to relate distances in the representation to distances in the real worldthey had never previously encountered the Astronomical Unit as such. The meaning of the letters A and U is explored lexically (42-43). Units is immediately proposed, while the search for A, although guided by the astronomical context, proves more hesitant and varied.

The teacher then invites the pupils to "try to figure out the length of the Astronomical Unit on the tarp between two objects." This triggers a brief but revealing episode (44), in which several pupils use their arms and legs as measuring tools to determine where the reference segment is on the tarp (see Figure 3). One pupil, presumably familiar with the concept, confirms that the Earth-Sun distance corresponds to one Astronomical Unit, matching the length of the segment. Other pupils then start to move back and forth between the distance scale and the Sun/Earth, keeping the space between their hands or feet constant. Interestingly, while the pupils all move together to-

Table 4. Extract of the transcription as observers comment on the movement along the blue dots - orbit of the Earth

53	02:41	Walk on the blue dots. Then watch what "G2" does
54	02:46	What does that remind you of?
55	02:46	"G1"? -[G1] The Earth is rotating - Ah!
56	02:50	It might make you think about the fact that the earth rotates. All right.
59	02:56	Right, that s enough, "G2", thank you very much.
60	03:00	And how? Do you know? You said the Earth? But why the Earth?
62	03:04	- Why do you say it s the Earth? -[B3] Because there s the Earth there
63	03:07	"B3", can you show us? - [B3] Right there.
65	03:10	All right, so that s planet Earth there.
66	03:12	So you think that the circles, the blue discs, are the Earth. OK.
68	03:22	[G3] That's what I think, in fact what it looked like. I think it s the path of the... [G3 and other pupils] Planets.
69	03:31	It s the path of the planets. Do you know a word that corresponds to a path for planets?
70	03:39	- "G4" - [G4] The Solar System.
71	03:43	So, the Solar System. That's more like the whole of it, isn't it? Instead of... But you said the path of the planets.
73	03:50	Is there a word for talking about the path of the planets? No, you don't know the word? No...
76	04:01	Well, the path of the planets. You don't know the word
77	04:03	It s called the orbit.
78	04:06	[B3] Ah! Yes, the orbit.
79	04:07	It s called an orbit.
80	04:10	The blue lines, the blue dots there are the Earth's orbit.

wards other signs (45 and onwards), many persist in comparing the scale segment with the Earth-Sun distance through bodily gestures (stepping, stretching their arms).

Figure 3. First phase of the session. One pupils uses its legs to reproduce the distance scale

This activity reveals a didactic congruence between the abstract notion of spatial scale and bodily motion. Children use their feet and arms to embody the length of one astronomical unit. This physical exploration helps children understand the concept of an astronomical unit by linking it to physical action.

Temporal scale

After about thirteen minutes (45), the class discovers the timescale, which is labeled "16 days." The teacher refers to it as a "unit of time." The pupils begin walking across the tarp seemingly at random, while the teacher redirects them toward the orbits and numbered discs (14). One child talks about a "length of time" (46), showing that he is shifting from the concept of "time" to "duration." Soon afterwards, another student moves her foot from one disc to the next along Mars's orbit (47). Since the orbital period of Mars is unknown, the teacher redirects the class to the Earth's orbit (48). Through a simple computation, pupils are able to verify the value of the time scale using Earth's period (49-51). The teacher concludes with a duration of 368 days (23 $\times$ 16), which he considers about right, without emphasizing that the final step back to disc 0 does not correspond to the same duration. For a primary school children, confirming the duration of a step in relation to planetary periods is difficult. Such verification would be more appropriate as follow-up work in the classroom after the discovery session. During the discussion, some pupils continue walking from disc to disc along different orbits. The reflective observation of movement first on Mars and then on Earth helps establish a connection between the timescale and the duration of a step between two discs.

Immediately after this observation, supported by calculation, a pupil makes a spontaneous observation about Mercurys orbit (51), which creates a new perturbation and reopens the question of the relationship between signs and their meanings. Mercurys period is a multiple of 8 days, not 16. On the tarp, ten positions of Mercury are represented over two periods (0-5 and 6-10). Thus, two interlaced sequences unfold along the same trajectory (0, 6, 1, 7, etc.), producing apparent inconsistencies ("there is something that is not quite right here") that pupils detect and have to negotiate (51-55). They scrutinize the numbered discs, searching for "1" near "0" ("that is not right, there is no 1"). The teacher then asks one pupil to walk the orbit, stepping from one number to the next. The pupil manages to complete the path by following the first sequence of discs. The coherence of the

walk from one disk to another is thus restored by walking "one disc out of two"a rule institutionalized by the teacher. A second spontaneous observation comes from another pupil, this time about Encke's orbit (56). Near aphelion, the comet moves very slowly, so positions every 16 days would be too close together. As a result, only one position out of three is represented ("there is a 3 here, but there isn't a 1 or a 2"). Again, the teacher invites a pupil to walk along the orbit. Following the sequence of disks, a pupil confirms: "from 3 to 3." The teacher then institutionalizes: "between each point on the comet, it isn't sixteen days, its three times "as much () otherwise" the points would be too close together there."

By physically moving from one disk to the next, stopping, hesitating, or correcting their path, the pupils gradually uncover the existence of these different embedded rules. The body thus becomes the medium through which temporal abstraction (regular 16-day intervals) and numerical structure (dual sequences or multiples of 3) are confronted, coordinated, and ultimately understood. This process allows pupils to construct duration as both iterative and structurally organized.

This episode once again highlights a didactical congruence between abstraction (here, the temporal scale) and embodied movement: pupils make sense of the numbers on the discs and then physically walk along different orbits, each step consistently representing 16 days. This bodily enactment supports their understanding of orbital time by linking numerical order, spatial positioning, and temporal progression.

6.5 Summary of the analysis

Overall, the different episodes discussed in the analysis show how pupils gestures, orientations, and coordinated movements come to mirror the spatial and relational properties of the signs on the Human Orrery. Through these embodied actions, the artifact is progressively transformed into a meaningful system (mesogenesis), while interpretations evolve and stabilize over time (chronogenesis). The distribution of initiatives between pupils and teacher further shapes how these embodied resources are utilized within shared collective activities. The congruency analyzed in the last subsection highlights how bodily engagement contributes to weaving together the different dimensions of joint action, supporting the emergence of more abstract and coherent meanings.

7 Discussion

The "Discovery" session introduces a wide range of scientific notions. Various astronomical and STEM-related topics are covered. The names and order of the inner planets are retrieved, and gaseous planets are discussed even though they are not represented. All types of objects in the Solar System are listed: one star, planets, comets, asteroids, and moons. The Moon's specific characteristics lead to a discussion of the different sizes and scales in the Solar System. The notions of orbits and revolution are understood through walks and other movements.

Mathematical knowledge is also present: numerical series; the shapes of orbits; the position of the Sun as the center; and the notion of scales (distance and duration) with their associated units (days, years, and the Astronomical Unit). It should be noted that knowledge related to science, such as speed, referential frames, and force, is not present in this discovery session but will be the subject of subsequent sessions.

In the discussion that follows, we interpret how bodily engagement contributes to the progressive schematization of astronomical notions. We consider how learners actions and perceptions reshape the milieu (mesogenesis) and how meanings evolve during the collective activity (chronogenesis). Taken together, these interpretive lenses help us understand how the Human Orrery becomes a space in which movements, interpretations of the sign system, and scientific models gradually converge.

7.1 Making the Orrery meaningful

At the beginning of the session, pupils face an unfamiliar spatial layout whose meaning is not immediately available. This lack of continuity in their activity leads them to observe, compare, and question the signs displayed on the tarp. Such moments of indeterminacy are precisely what Zask (2017) identifies as the triggers of inquiry: a disturbance that prompts learners to reorganize their experience. In the same way, the pupils early attempts to describe what they see resemble the initial observational phase described by Etkina (2023), where learners begin by identifying salient patterns before making sense of them. In our data, these observationsguided both by the didactic contract and by pupils need to restore continuityform the starting point for the semiotic processes.

Our analyses show that meaning-making and bodily engagement are inseparable in pupils encounter with the Human Orrery. The emergence of a shared model does not begin with the recognition of isolated signs, nor does it progress from concrete action to abstract reasoning. Instead, pupils engage first in a global, undifferentiated bodily participation in the activity: they move together, orient themselves collectively, and respond to the spatial invitations of the artifact. This early participation provides a perceptual and kinaesthetic grounding that supports the discrimination of salient features and the emergence of patterns.

As the activity unfolds, bodily engagement becomes increasingly differentiated. Certain movements are repeated, stabilized, or condensed into gestures; pupils shift from whole-body displacement to more focused motor actionspointing with the arm or foot, adjusting posture to signal a relation, or tracing small circular gestures to evoke continuity. By selecting and stabilizing the structural features of an experience while leaving aside its contingent details, the activity may be considered as a modeling activity (in the sense of Hestenes, 1987; Sensevy et al., 2008; Yvain-Prébiski and Chesnais, 2019). Here, bodily action becomes a medium for schematization, allowing pupils to construct relational meaning from their embodied interactions with the artifact.

This progressive differentiation of embodied activity contributes to both the mesogenesis and the chronogenesis of the situation. The milieu becomes meaningful as pupils highlight, through gesture and orientation, the spatial and relational properties that matter for the model. At the same time, meanings evolve as pupils gestures become more selective and condensed, shifting from whole-body movements to smaller schematic actions that highlight specific spatial or relational features and is evidence of their power to abstract away core features. The teachers interventions guide this process without interrupting it, helping pupils to coordinate their interpretations and integrate them into a coherent modeling of the Solar System.

Thus, what develops across the session is not a movement from the concrete to the abstract, but a transition from undifferentiated bodily participation to increasingly precise, schematized forms of embodied action. This evolution, rich in motor, attentional, mnemonic, and perceptual consequences, forms the core of pupils emerging understanding of the Human Orrery as a scientific model. Within the taxinomy proposed by Skulmowski and Rey (2018), the Human Orrery exemplifies a learning situation that combines high motoric engagement with high cognitive integration, making embodiment a constitutive component of the inquiry process rather than a pedagogical aid

or a cognitive overload.

While these embodied resources play a central role at the level of individual meaning-making, their significance also depends on how they circulate, are taken up, and stabilized within the classroom community. This collective dimension of inquiry is the focus of the next section.

7.2 The Human Orrery as a Collective Semiotic Space

Our study suggests that the Human Orrery fosters the collaborative creation of a cultural representation of the Solar System. As the session unfolds, the class moves from individual and often fragmented observations to a shared inquiry process in which pupils and teacher jointly negotiate the meaning of each sign. The institutionalization of planetary names, orbits, and spatial scales progressively transforms the tarp into a cultural and semiotic space where celestial objects and their properties can be enacted, questioned, and discussed.

This collective dynamic is mesogenetic, not just social. Pupils' movements, gestures, and proposals continually reshape the milieu, making certain relations salient and enabling new interpretations. Inquiry emerges from the interplay between spontaneous suggestions, bodily enactments, and teacher guidance. Moments of uncertainty such as the absence of the Moon or the unfamiliar representation of comets are addressed not through isolated reasoning, but through shared attempts to restore continuity.

Unlike studies - such as Euler et al. (2019) - with fine-grained analysis of gestures in dyadic settings, the Human Orrery illustrates how embodied resources function on a larger scale with multiple learners contributing simultaneously to the construction of meaning. While Euler et al. demonstrate how two participants collaboratively develop mechanistic explanations through gestures, our results reveal how similar multimodal resources circulate throughout a class, are collectively adopted and transformed, and eventually become institutionalized. This finding also resonates with the work of Scherr et al. (2012) on the theater of energy, yet differs from it in a crucial way: here, bodily activity is not an optional representational device but a structural component of the model itself, which is necessary for simulating the dynamics of the Solar System. The collective dimension observed in the Human Orrery suggests that such embodied resources can become shared semiotic tools within a classroom community. Through participation in their circulation by repeating, adjusting, or transforming gestures learners contribute to a collectively shaped interpretation of the system.

Because this inquiry unfolds through coordinated bodily activity, the resulting understanding is both embodied and culturally situated. The Human Orrery becomes a collective experiential space in which learners appropriate a scientific model by participating in its enactment, transformation, and stabilization.

8 Perspectives

Alongside our main findings, two transversal considerations emerge. One concerns the artifact itself and the role its minimalist design plays in guiding observation and inquiry (Can less be more?). The other points toward analytical developments that extend beyond the scope of this article.

8.1 Can less be more?

The language used by Grotowski (2002, pp. 17-19) to defend the "acceptance of poverty in theater" may also be used to promote economy and simplicity in astronomy education. To a certain extent, HO practice amounts to a "stripping down" of commonly accepted "artifice", a temporary relegation of the tools of "rich" pedagogy. Gone are the high definition computer screens and the smart whiteboards, the spectacular visuals and the sophisticated software. The HO presents learners with just a printed tarpaulin showing simple colored dots and lines. It uses elementary bodily actions (clapping, standing, stepping, turning, etc.) to enact mechanisms while bringing complex astronomical phenomena into awareness. As individual subjects engage in the proposed activities, they "take on an active role" and rely almost exclusively on their "own bodies and craft" to make a total physical response to the prompts and carry out reasoning tasks. The HO thus uses simple means to orchestrate powerful moments of collective imagining, acting and understanding. As is the case with Grotowski's "poor theatre" approach to drama, the poverty of means will achieve much if and only if participants make a total offering of themselves," in the here and now of their coordinated performance.

8.2 Toward a first-person account of embodied experience

Thus far, we have not conducted in the analysis presented in this paper an in-depth, phenomenological exploration of the lived bodily experience of learners. It would certainly be interesting to track external signals, such as micro-gestures, gaze orientations, and postural shifts. It would also be worth investigating the internal states, concerns, and perceptual focus that participants report at various times during the sessions. Approaches grounded in first-person or second-person access to personal experience (as proposed by Dieumegard et al., 2021) would certainly be relevant for exploring such dimensions, which interaction analysis cannot capture on its own. An option under consideration would be to embrace the internal perspective of the sentient, moving and cognizing learner whose actions and perceptions fuel each other and co-evolve, as new objects and phenomena present themselves to the senses and to the mind, and as situated understandings emerge. Such an approach would be intrinsically enactive (Varela et al., 1991) since its starting point would not be preexisting objects and mechanisms located in a ready-made information-rich environment. Rather, the HO would be construed as in invitation for the subject to immerse themselves in the flow of perceptual action and meaning-making. A study of this kind would provide insight into the experience of a young learner of average size, surrounded by her peers. This learner would view the HO at eye level and perceive certain characteristics of the planets as well as the movements of other learners. Access would be sought to the (private) meanings that this learner attaches to her perceptions. This kind of approach would make it possible to consider the HO as a space of encouraged actions that the learner gradually constructs for herself (Perrin, 2014) with the help of the teacher and collaboration of other learners. The immersion, interaction and exploration gradually bring out a world of meanings. It would be interesting, for example, to analyze how learners first perceive the movement of the planets, then their differential movement, and finally how they construe the relative movements of the planets in the sky, especially the movements of precession. This would also enable us to understand how a notion and then a concept may constitute a meaningful artifact for the learner. The artifact would structure the space of encouraged actions, as defined by the HO, from the learner's perspective.

8.3 Confirmation and extension

The broader implementation of the discovery session in the ARISTARCHUS project (Ubben et al., 2025) provides an opportu-

1	2	3	4	5	6
Planets (P)	Earth (O)	Sizes (O)	Earth (O)	Earth (O)	Discs (P)
Orbit (O)	Planets (P)	Planets (P)	Planets (U-P)	Discs (P)	Numbers (P)
Planets (O)	Sun (O)	Sun (O)	Sun (O)	Sun (O)	Moon (U)
Distance Scale (O)	Discs-Orbit (P)	Comet (O)	Moon (U)	Numbers (P)	Earth (O)
Green dots (U)	Numbers (P)	Discs and numbers (P)	Planets (O)	Planets (U)	Sun (O)
Moon (P)	Comet (O)	Orbit (P)	Numbers (O)	Date (U-O)	Comet (O)
Comet (O)	Planet (P)	Green dot (O)	Discs (O)	Planets (O)	Orbit (O)
Numbers (P)	Moon (U)	Planet (O)	Comet (O)	Time scale (U-O)	Planets (P-O)
Date (O)	Time scale (P-0)	Distance scale (0)	Moon (P)	Comet (O)	Time scale (O)
Time Scale (O)	Green dots (P)	Time scale (O)	Distance scale (O)	Distance scale (O)	Date (O)
Numbers-Encke (P)	Distance scale (O)	Date (O)	Time scale (O)		
Numbers-Mercury (O)	Date (O)				

Table 5. Summary of the choronogeneis of six sessions with the emergence of notions and their categories (Unconnected, Precursor, Overlap).

nity to confirm and extend the findings reported in this study.

One year after facilitating the "Discovery Session," the same teacher led three similar learning sessions with six classes (100 pupils). A description of how each notion emerged across these classes (Table 5) shows that their semiotic trajectory was consistent with what we have already observed. Within 30-minutes, most of the signs on the tarp were identified and interpreted. Next, they were progressively aligned with the scientific model of the Solar System. The Moon presented systematically a special case that generated an indeterminate situation. A collaborative inquiry was required that led to the Moon being discarded as a candidate orbital object. Continuity was eventually restored, as we observed in the case study.

When asked to walk the orbits, all engaged, confirming that bodily engagement is motivating and effectively aids in understanding orbital structure. Thus, it would seem that the Human Orrery works as an efficient pedagogical tool for accessing the notion of orbital motion across diverse classroom conditions.

The larger sequence developed in ARISTARCHUS extends our findings by showing how the Human Orrery can be integrated into a coherent progression covering astronomical, mathematical, and physical concepts: the alternation of day and night, the definition of time units, proportional and non-proportional relations, the construction of circles and ellipses, and homothetic transformations, as well as referential frames and inertia (see Introduction for specific references). We note that these subsequent sessions also resonate with the claim made by Euler et al. (2019) that embodied activities help learners explore metaphorical parallels between their own bodily characteristics and those of the entities they represent in a given phenomenon.

. All in all, the results suggest that the process described in this article should be understood as the first step in a broader trajectory of conceptual development, which continues across successive Human Orrery sessions.

9 Concluding remarks

Astronomy provides a highly motivating context in which learners can develop their observational skills, discover scientific inquiry methods, and explore the fundamental laws of physics and mathematical concepts. The Human Orrery offers an engaging and effective learning environment for exploring challenging mathematical and scientific concepts. It offers an excellent example of a STEM-based approach to learning, particularly when concepts are perceived as abstract and challenging by pupils and teachers alike.

A detailed analysis of how learners first "encounter" the Human Orrery has shown that they discover the meaning of each sign (symbol) through their actions as they move across the tarp from one symbol to another. They compare the things they see and experience on the tarp, building on observation and their own cultural knowledge. They then relate their understanding of the setup and action frame to a new affordance for action. The tarp becomes a Human Orrery and the pupils become celestial objects orbiting the Sun.

This approach grounds scientific concepts in sensory-motor experience, creating favourable conditions for deeper learning in the future. It shows how bodily engagement, multimodal expression and collective inquiry combine to help schoolchildren process abstract astronomical concepts. The scientific model is progressively constructed through pupils' actions, gestures, interpretations and negotiations in the classroom. Together, these actions transform the learning environment and stabilize meaning over time. The results of the present study underscore the cognitive potential of embodied and collaborative approaches in astronomy and science education from an early stage.

10 Availability of supporting data and materials

This research relies exclusively on anonymised data from a regular classroom session (video recordings and transcripts).

The recordings are used solely for research purposes and are not publicly available.

11 Declarations

11.1 Conflicts of interests

The Authors declare that there is no conflict of interest.

11.2 Consent for publication

All authors consent to the publication of this manuscript

11.3 Ethics

Our institution does not require ethics approval for reporting individual cases or case series.
Informed Consent : Written informed consent was obtained for anonymized pupils information to be published in this article, but not made publicly available.
No identifiable personal data are included in this manuscript. All data used in the study consist of fully anonymised transcripts and non-public video recordings collected during ordinary classroom activities. The video recordings were used exclusively for the purpose of analysis and are not shared, archived in public repositories, or made accessible outside the research team. No images, audio material, or any elements that could lead to the

identification of pupils are published in the article.

11.4 Funding

The learning session was implemented in the context of the Erasmus+ project ARISTARCHUS (PI: first author). The ARISTARCHUS project was funded with support from European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein. Project Number: 2021-1-FR01-KA220-SCH-000032478
The research received funding from CY Cergy Paris University, as an Emergence project (E-ESMEA, PI: first author).
We thank Chloé R. for transforming the images to ensure pupil anonymity; this work was funded by the F-HOU association.

12 Acknowledgements

We acknowledge the contribution of Jean Maheu, a French primary school teacher, to the development of the Human Orrery and the ARISTARCHUS project.
We would like to thank all the pupils and the teacher who participated in the session analyzed in this paper.

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13 Appendix

13.1 Analysis of the learning session according to the Joint Action Theory in Didactics

Table 6. Chronology of the joint actions of the teacher, student and class during the learning session "encounter with the Solar System", according to the three genesis (see text for details).

		Chronogenesis		Topogenesis		Mesogenesis	
Id	Time	Object	Category	Teacher	Student	Teacher	Student
1 (1)	0'						
2 (2)	0'06			devolving	observe	direct to-wards the HO	walk and observe the HO
3 (7)	0'17	Numbers	unconnected	monitoring	One (L) - most raise their hands		Show one number
4 (10)	0'27	planets	precursor	monitoring	One (E)		all look down to the tarp
5 (12)	0'36	Earth	precursor		One (E)		Show the disc Earth
6 (15)	0'44	Moon	unconnected (Moon = comet)		One (D)		Show the disc Encke with his arm and the "green stuff", but remains first at his position, near the orbit of Mars.
7 (26)	1'08	-	-	devolving, "where do you see the Moon ?"			
8 (30)	1'18	-	precursor (Moon = craters + color)	monitoring	group discussion		Observe the disc of the comet
9 (33)	1'26	-	unconnected (comet is not the Moon)	monitoring			
10 (36)	1'40	Blue discs	unconnected		One (N)		N shows one blue disc
11 (38)	1'46	Moon	unconnected		One (D - not telling to others)		Shows Mercury with his feet
12 (40)	1'49			monitoring		ask stu-dents to move on the side	

Table 7. Table 6 (Ctd.)

		Chronogenesis		Topogenesis		Mesogenesis	
Id	Time	Object	Category	Teacher	Student	Teacher	Student
13 (42)	1'59	Blue discs	unconnected		One (N)		N walks along blue discs
14 (45)	2'09	discs	unconnected (further away = hotter, red = hot)	monitoring	explain the observed colors	ask N to explain	N draws a straight line with her finger from inner to outer discs
15 (51)	2'31				G takes the lead of the explanation	G suggest to walk around blue discs	
16 (52)	2'37	blue discs	precursor	monitoring			
17 (53)	2'43	Blue discs		devolving	observe N walking	ask N to walk	N walks along the blue discs
18 (56)	2'50	-	overlap (Earth moves along blue discs)		One (L)		
19 (63)	3'07	-	overlap (Disc of the Earth)		One (G)		Show the disc with the image of Earth
20 (67)	3'18	-	-	institutionalizing			L moves her feet along red discs
21 (69)	3'27	orbit of planets	precursor (movement of planets)		One (Lo) + group		Lo shows blue dots and gesture a circle
22 (70-80)	3'30-4'10	-	overlap (orbit)	institutionalizing	orbit is a new name for the group		G jumps to Mercury's orbit. L moves her feet
23 (85-89)	4'23 - 4'45	planets	unconnected	monitoring	group discussion about the image of Venus and which planet it may be		Lo shows the disc of Venus and tell "it is Mars"
24 (90)	4'42	Mars	precursor (Mars = clouds)	Confirm (D) and does not give credits to the remark of L	(D) describes cloud on the disc of Mars, but (L) shows clouds on the disc of venus too		D shows the disc with the image of Mars ; L comes back to the disc of Venus
25 (94)	5'	-		institutionalizing (Mars and Earth)			
26 (100)	5'13	Moon	precursor (Moon = craters + color)	does not comment this remark	One (E), Mercury = Moon		E notices the disc of Mercury
27 (101-114)	5'20-5'57	Sun	overlap (middle or center, fire, red)		Group, E+J		Group observed the disc of the Sun
28 (117)	6'08			monitoring			move backwards around the orbit of Mars to observe the tarp
29 (125-130)	6'32-6'54	Moon	unconnected (Moon near the Sun)	monitoring	Group discussion, where is the Moon ?		J show the disc of Mercury

Table 8. Table 6 (Ctd.)

		Chronoenesis		Topogenesis		Mesogenesis	
Id	Time	Object	Category	Teacher	Student	Teacher	Student
30 (131)	6'54	Moon	overlap (Moon around Earth)	institutionalisation (Mercury not Moon, it is another planet)	(G) : Moon orbits around Earth		
31 (137-158)	7'12-8'30	planets	overlap (name and order)	institutionnalisation (inner planets)	G+ J : know the order. One difficulty for Venus	show the discs	
32 (159-183)	8'30-9'51	comet	precursor (oval)		G : pluton since its orbit is an oval		G observe the shape of the orbit
33		-	precursor (not round)		L, G, D : not a planet		L observe the image
34		-	unconnected (meteorit)	institutionnalisation (meteorit is on Earth)	J, G : different names		
35		-	overlap (comet)	institutionnalisation (comet Encke)			
36 (184)	9'59	Sun	overlap (a star)	institutionnalisation	Group answer collectively		
37 (185-189)	10'-10'13	None		institutionnalisation (summary of what has been observed)	Observe		Some in the center, some move around
38 (191)	10'22	Green discs	overlap (orbit of Encke)		D shows the green dots		
39 (192)	10'29	Red discs	overlap ("trajet" of the planet)		One (not heard by the teacher)		See the red discs
40 (192)	10'30	None	observe the logo				
41 (196-199)	10'39-10'50	date	overlap (position of disc 0)	institutionnalisation	Group discussion about the date		G reads the date on the tarp
42 (204)	11'11	spatial scale	unconnected		Lo+L design the line		observe the line
43 (210-222)	11'30-12'15	-	precursor (U=Unity in math)	monitoring	invent words for A.		read the text and then wonder
44 (222-241)	12'15-13'26	-	overlap (relates to Sun-Earth)	monitoring	search the length on the HO. G shows the distance Earth-Sun. All agree		Report the lenght of the line with their feet on the HO
45 (242)	13'27	temporal scale	unconnected		read the text		some continue to check the length of 1 AU
46 (253)	14'10	-	precursor (unit of time)	monitoring	D : duration to go from one planet to another		some continue to check the length of 1 AU
47 (255)	14'21	-	overlap (duration from one point to the next)	monitoring	L : correct proposition, other do not listen or watch first, then they move into a circle and listen		L moves one feet from one point to the next along the orbit of Mars

Table 9. Table 6 (Ctd.)

		Chronogenesis		Topogenesis		Mesogenesis	
Id	Time	Object	Category	Teacher	Student	Teacher	Student
48 (258-270)	14'36-15'10	period	precursor (number of steps and period)	monitoring (move the discussion from Mars to Earth)	know period of Earth, count the number of steps (22)		G Walks around Earth orbit
49 (270)	15'10	-	overlap (correct number of steps and period of Earth)		Lo comes back to give the correct number of steps (23)		Lo walks towards Earth
50 (271)	15'15	-	precursor (last step has a different duration)	institutionnalisation (use of a "calculatrice")	oral agreement		
51 (279)	15'51	numerical series on Mercury	precursor (search for "1")	monitoring	D : inquiry, group discussion		surprise by missing numbers ("1" is unde his feet !)
52 (282)	16'05				G talks about Encke's number, D is wondering about the disc "7" that is just before "2" for Mercury		confusion between two series (green and grey) - disc "1" is under the feet of one student
53 (284)	16'17				One students finds number "3" (two discs away)		One students shows number "3" with his feet
54 (285)	16'22		precursor (2 by 2)	devolving (have N walk from 1 to 2, then 2 to 3, until it makes two turns)	G recognise the series "2 by 2" and N follow the consign	Gives the instruction to walk twice along the orbit of Mercury	N walks along Mercury's orbit, number by number
55 (29()	16'48		overlap	institutionalizing			
56 (296)	16'52	numerical series on Encke	precursor (search for "1 and 2")	monitoring	R : inquiry, group discussion		surprise by missing numbers
57 (296)	17'	-		devolving			half on Encke's orbit ; half is looking outside the tarp
58 (302)	17'35	-	overlap	devolving (what do you observe ?)	G : 3 by 3		
59 (304)	17'45		overlap	institutionalizing			

13.2 Localisation of learners and teacher during the learning session

Table 10. Evolution of the geographical location on the tarp of teacher, students and groups. Timeline is the same as in Table 6.

		Localisation		
Id	Time	Student	Group	Teacher
1	0’		gathering on inner planets	on the side
2	0’06			
3	0’17	L on one side	all inside the inner planets	
4	0’27	E on Earth’s orbit	do not move	
5	0’36	E moves through the group to show the disc with the image of Earth	they stay at their place, E moves back to its place	
6	0’44	D moves towards the laft side of tarp, away from the planets, at the position of the disc of the comet		
7	1’08			
8	1’18		All move towards the disc of the comet	on the side near comet
9	1’26		all move back to the inner planets	
10	1’40	N on one blue disc	gather on inner planets	
11	1’46	D walking towards Mercury		
12	1’49		all move to green dots	
13	1’59	N on blue orbit	other along grreen dots	
14	2’09	alone in inner planets	G getting closer to the blue discs	
15	2’31	G getting near N		
16	2’37			
17	2’43	N walks around blue discs		
18	2’50	(L) observes and explains		
19	3’07	G on the disc		

Table 11. Table 10 Ctd..

		Localisation		
Id	Time	Student	Group	Teacher
20	3'18	L near red discs	stay on the green discs	
21	3'27	Lo makes one step towards the orbit of Mars		
22	3'30-4'10	G on Mercury		
23	4'23 - 4'45	L on the disc of Venus		
24	4'42	L goes from Mars to Venus	D+L+another on the disc of Mars	
25	5'		move back towards inner planets	
26	5'13	E+G near the disc of Mercury		
27	5'20-5'57		All around the Sun, some seat near the Sun	near them
28	6'08		move backwards around the orbit of Mars	
29	6'32-6'54	J show the disc of Mercury	all around the orbit of Mars	on the side
30	6'54			
31	7'12-8'30		all in half a circle along the orbit of Mars	on the HO
32	8'30-9'51			
33			all move to the disc of Encke	
34				
35				
36	9'59		wander all around	
37	10'-10'13		Move around	
38	10'22			
39	10'29		Move around	
40	10'30			
41	10'39-10'50			
42	11'11		all move towards the line	move towards the line

Table 12. Table 10 Ctd..

		Localisation		
Id	Time	Student	Group	Teacher
43	11'30-12'15		move around	
44	12'15-13'26		go from the tarp to the spatial scale with feets or arms	
45	13'27			
46	14'10		move along orbits or check the distance Sun-Earth	
47	14'21	L on the orbit of Mars	move along orbits or check the distance Sun-Earth	
48	14'36-15'10		move around	
49	15'10	Lo walks towards Earth, comes back to the group		
50	15'15		keep moving on the tarp	
51	15'51	D shows its problem	all around D	
52	16'05	G near the green disc that cross Mercury's orbit	all around Mercury	
53	16'17			
54	16'22	N walks	Look carefully at N's walk	
55	16'48			
56	16'52	R shows its problem - at one end of the tarp near the disc of Encke	many walk towards R	
57	17'	G stays near Encke	Girls around the orbit of Encke, boys on the side	
58	17'35			
59	17'45			

13.3 Transcription of the learning session

Table 13. Transcription generated by (c)Adobe Pro and translated by a professional company

id	time	transcription	English translation
1	00:00	Alors	So
2	00:04	Alors stop, stop, voilà stop.	Right stop, stop, that s right stop.
3	00:08	Donc on reprend Que voyez-vous, sur ce planètaire,	So let's start again. What can you see in this orrery?
4	00:11	il faut que vous disiez une chose chacun	Each of you has to say one thing
5	00:14	Alors "G1"	So, "G1"
6	00:16	- [G1] Des numéros - Il y a des numéros	-[G1] Numbers - There are numbers
7	00:19	OK et des numéros OK. d'accord des numéros	OK numbers OK. All right, numbers
9	00:24	- euh.. "B1". - [B1] des planètes - tu vois des planètes.	Er... "B1". -[B1] Planets - You can see planets.
10	00:28	Est ce que tu peux me les montrer les planètes ?	Can you show me the planets?
11	00:35	D'accord, là une planète d'accord.	All right, there s a planet, all right.
12	00:37	OK ok.	OK ok.
13	00:40	Euh. Quelqu'un d autre... "B2".	Er... Somebody else... "B2".
14	00:43	[B2] Ici on voit la Lune	[B2] Here you can see the Moon
15	00:45	[B2] avec des petits trucs verts ici	[B2] with little green things here
16	00:47	Alors où est ce que tu vois la Lune ?	So where can you see the Moon?
17	00:49	- [B2] ici	-[B2] Here
18	00:51	- Alors qu'est ce qui te fait penser que c'est la lune - [B2] Elle ressemble à la Lune	- So what makes you think it s the Moon? - [B2] It looks like the Moon.
19	00:55	Elle ressemble à la Lune	It looks like the Moon
20	00:56	oh oh ... parce que ... oh oh	Oh! Oh! ... because... Oh! Oh!
21	00:58	"B3", Est ce que tu peux te taire s'il te plaît ? "B3". Si j ai deux remarques à te faire tu repars en haut.	"B3", can you be quiet please? "B3". If I have to keep telling you, you re going to go back upstairs.
26	01:08	D accord ? Alors.	All right? Well then.
27	01:09	Qu'est ce qui... Approchez vous les enfants	What is... Come closer children
28	01:12	- Donc "B2" il pense que c'est la Lune là - (élève) Non, pas du tout	- So "B2" thinks that s the Moon there - (pupil) No, not at all
29	01:15	Alors donc qu'est ce qui te fait penser "B2" que c'est la Lune ?	So why do you think it s the Moon "B2"?
30	01:19	[B2] Parce que en fait il y a des petits cratères	[B2] Because actually there are little craters

Table 14. Table 13 Ctd.

id	time	transcription	English translation
31	01:21	- D'accord - [B2] et c'est la même couleur que la Lune.	- All right - [B2] And it s the same colour as the Moon.
32	01:25	On verra plus tard que ce n'est pas la lune mais pour l'instant... bon...	Later on we ll see that it s not the moon, but for now... well...
33	01:27	mais pour l'instant on garde l'idée de "B2"	But for the time being let's keep "B2" s idea
34	01:34	qu est-ce que vous voyez d autre ?	What else can you see?
35	01:37	- "G2" - [G2] on voit des ronds bleus.	- "G2" - [G2] You can see blue circles.
36	01:42	D accord des ronds bleus.	All right, blue circles.
37	01:44	Est ce que vous pouvez vous pousser un peu sur les côtés	Can you move a little to the sides
38	01:47	et mettez vous sur les points verts justement pour qu'on puisse voir tous un peu la même chose.	And actually stand on the green dots so that we can all see more or less the same thing.
40	01:52	Et on regarde vers ici	And we're looking over here
41	01:56	"G2" qu est ce que tu vois	"G2", what can you see?
42	01:59	[G2] des points bleus ?	[G2] Blue dots?
43	02:00	Plusieurs points bleus ?	Several blue dots?
44	02:02	Qu'est ce que c'est que ce que tu penses que c'est ça les points bleus ?	What do you think the blue dots are?
45	02:08	[G2] C est par exemple c'est de plus en plus chaud .... et .... là c'est vraiment très chaud	[G2] For example, it s hotter and hotter.... and.... there it s really hot.
46	02:16	- Qu'est ce qui te fait penser à la chaleur là ? - [G2] ben, parceque c'est rouge	- What makes you think of heat? -[G2] Well, er Because it s red
47	02:21	Comme c'est rouge ça te fait penser à la chaleur.	Because it s red it makes you think of heat.
48	02:23	Mais là tu me parlais des points bleus. Qu est-ce que c'est les points bleus ?	But you were talking about the blue dots. What are blue dots?
49	02:27	[G2] Les points bleus ça doit être euh....	[G2] The blue dots must be, er...
50	02:29	[B3] ben pour continuer sur les points bleus.	[B3] Well, er to continue with the blue dots.
51	02:33	Qu'est ce que ça pourrait être les points bleus ?	What could the blue dots be?
52	02:34	Marche sur les points bleus. Commence au premier numéro là.	Walk on the blue dots. Start at the first number there.
53	02:41	Cherche le 1. Marche sur les points bleus. Alors regardez ce que fait "G2"	Look for 1. Walk on the blue dots. Then watch what "G2" does
54	02:46	Ça vous fait penser à quoi ça ?	What does that remind you of?
55	02:46	- "G1" ? - [G1] La Terre elle tourne - Ah...	"G1"? -[G1] The Earth is rotating - Ah!
56	02:50	Ça pourrait faire penser au fait que la terre tourne. D'accord.	It might make you think about the fact that the earth rotates. All right.
59	02:56	Voilà c'est bon "G2" merci beaucoup.	Right, that s enough, "G2", thank you very much.
60	03:00	Et comment ? Vous savez ? Et vous avez dit la terre ? Mais pourquoi la terre ?	And how? Do you know? You said the Earth? But why the Earth?
61			

Table 15. Table 13 Ctd.

id	time	transcription	English translation
62	03:04	- Pourquoi vous avez dit que c'est la Terre ? - [B3] parce que là il y a la Terre	- Why do you say it s the Earth? -[B3] Because there s the Earth there
63	03:07	"B3" tu peux nous montrer - [B3] juste là.	"B3", can you show us? - [B3] Right there.
65	03:10	D'accord là donc là c'est la planète Terre.	All right, so that s planet Earth there.
66	03:12	Donc pour vous les ronds les disques bleus là c'est la Terre. OK.	So you think that the circles, the blue discs, are the Earth. OK.
67	03:19		
68	03:22	[G3] C'est que j ai compris en fait ce que ça faisait. Je pense que c'est le trajet des... [G3 et autres élèves] planètes.	[G3] That's what I think, in fact what it looked like. I think it s the path of the... [G3 and other pupils] Planets.
69	03:31	C'est le trajet des planètes. Est ce que vous connaissez un mot qui correspondrait à un trajet pour les planètes ?	It s the path of the planets. Do you know a word that corresponds to a path for planets?
70	03:39	- "G4" - [G4] le système solaire.	- "G4" - [G4] The Solar System.
71	03:43	Alors, le système solaire Ce serait plutôt l'ensemble non ? Plutôt que... Mais là vous m'avez dit le trajet des planètes.	So, the Solar System. That's more like the whole of it, isn't it? Instead of... But you said the path of the planets.
73	03:50	Est-ce qu'il y aurait un mot pour parler du trajet des planètes. Non vous connaissez pas le mot ? Non....	Is there a word for talking about the path of the planets? No, you don't know the word? No...
76	04:01	hein le trajet des planètes. Vous connaissez pas le mot	Well, the path of the planets. You don't know the word
77	04:03	On appelle ça l'orbite.	It s called the orbit.
78	04:06	[B3] Ah oui, l'orbite	[B3] Ah! Yes, the orbit.
79	04:07	On appelle ça une orbite	It s called an orbit.
80	04:10	Les traits bleus là les points bleus c'est l'orbite de la Terre.	The blue lines, the blue dots there are the Earth s orbit.
81	04:14	Alors est ce que quelqu'un... vous n avez pas Vous n'avez pas tous dit quelque chose ?	So has somebody... Not everyone Not everybody has said something?
82	04:19	"B3" toi tu as déjà dit quelque chose	"B3", you have already said something.
83	04:21	- "G5" - [G5] Je vois la planète Mars - la planète Mars ?	- "G5" - [G5] I can see the planet Mars - The planet Mars?
84	04:24	Tu peux nous la montrer ?	Can you show it to us?
85	04:28	Tu penses que c'est Mars.	You think that s Mars.
87	04:29	- hum - (élève) non je ne pense pas... - ah il y a quelqu un qui dit... - (élève) Jupiter !	- Hm - (pupil) No I don't think so... - Ah! Somebody says... - (Pupil) Jupiter!
88	04:35	- (eleve) Non ce n est même pas Jupiter - "G5", tu penses que c'est quoi toi ?	- (Pupil) No it s not even Jupiter - "G5", what do you think it is?
89	04:39	(élève 1) Jupiter elle est pas là Jupiter (élève 2) Celle-là (enseignant) Tu penses que c'est Mars ou autre chose ?	(Pupil 1) Jupiter, Jupiter isn't there (Pupil 2) That one (Teacher) Do you think it s Mars or something else?
90	04:45	Tu pense que c'est Mars. Qu est-ce qui te fait penser que c'est Mars ?	You think it s Mars. What makes you think it s Mars?

Table 16. Table 13 Ctd.

id	time	transcription	English translation
91	04:48	(élève) parce que je me souviens que j'ai vu une photo de Mars qui avait un nuage.	(Pupil) Because I remember I saw a photo of Mars which had a cloud.
92	04:53	D'accord. Dis donc tu as une sacré mémoire (élève) Mais là aussi il y a (élève) c'est Mars c'est Mars.	All right. What a memory you ve got. (Pupil) But there too (Pupil) it s Mars, it s Mars.
94	05:00	Donc on a déjà repéré Mars.	So we ve found Mars.
95	05:01	- (autre élève) là aussi - On a déjà repéré la Terre,	- (Another pupil) there too - We ve found the Earth.
96	05:04	Regardez bien parce que vous m'avez pas tout dit là	Look carefully because you haven t told me everything.
99	05:09	Encore plein de choses à dire... Alors "B1" - (élève 1) Je me suis trompé c'est ici la Lune - (élève 2) J'ai déjà dit mais...	There are still many things to say... So "B1" - (Pupil 1) I made a mistake, this is the Moon here - (Pupil 2) I ve already said but...
100	05:18	- (élève) Il y a le Soleil - (élève) non ça c'est pas la Lune - Ah C'est important ce qu'il vient de dire "B1"	- (Pupil) There's the Sun - (Pupil) No, that s not the Moon - Ah! What "B1" just said is important.
101	05:21	Il pense que c'est le soleil qui est là	He thinks that it s the sun there.
102	05:25	Pourquoi "B1" tu penses que c'est le soleil qui est là ?	Why do you think that s the sun there, "B1"?
103	05:27	[B1] C'est parce que c'est tout rouge et ça fait penser à du feu.	[B1] Because it s all red and it makes you think of fire.
104	05:30	C'est tout rouge ça fait penser à du feu. D'accord, Quoi d'autre ?	It s all red and it makes you think of fire. All right. What else?
105	05:33	Qu'est ce qui nous fait penser que c'est le Soleil ici	What makes us think that it s the Sun here?
106	05:36	- "G6" ? - [G6] parce qu'il est au milieu - parcequ'il est au milieu de tous les autres	- "G6"? - [G6] Because it s in the middle - Because it s in the middle of all the others.
107	05:41	Plutôt, oh.., oh.. plutôt que milieu... Mais il n'y a pas que ça.	Instead, oh! Oh! Instead of middle... But that isn't everything.
108	05:44	"B3". Je pense que tu vas tu va aller ailleurs.	"B3". I think that you re going to go somewhere else.
110	05:48	Alors au milieu je n'aime pas trop le mot milieu.	So in the middle, I don't like the word middle very much.
111	05:51	- Est ce que tu aurais une autre idée plutôt que milieu ? - (élève) j ai trouvé - [G6] au centre	- Have you got another idea instead of middle? - (Pupil) I know - [G6] in the centre
113	05:55	On aurait dit très bien très bien très bien.	That's right, good, good good.
114	05:59	On est bon on est bon et bon.	That's it, that s it, that s it.
115	06:02	Il y a encore plein de choses à voir et encore plein de choses.	There are still many things to see and many more things.
116	06:05	Mettez vous sur le tour le tour pour mieux voir parce que là où vous êtes oui.	Stand around the edges so that you can see better, because from where you are, yes.
117	06:10	Voilà, mettez vous sur le tour, mais restez sur la bâche pour pas avoir froid au pied	That's it, get on the edge, but stay on the sheet so that your feet don't get cold.
118	06:13	[B3] Oh moi j'ai hyper froid au pied sur la bâche	[B3] Oh! My feet are really cold on the sheet!
119	06:17	la je pense que tu vas retourner dans la classe	Right, I think you re going back to the classroom.
120	06:21	Mettez vous sur la bâche là.	Get on the sheet there.

Table 17. Table 13 Ctd.

id	time	transcription	English translation
121	06:23	Mets toi là, là, il y a encore plein de choses, il y a encore plein de choses.	Stand there, there. There are still many things, there are still many things.
122	06:26	Vous m'avez pas parlé de plein de choses	You haven t told me about a lot of things.
123	06:28	- (élève) Maître, j ai une question	- (Pupil) Sir, I ve got a question
124	06:30	Alors "G4"	So "G4"
125	06:32	- (élève) là c'est la Lune ? - montre moi avec ton doigt la Lune	- (Pupil) Is that the Moon there? - Point at the Moon for me.
126	06:37	Qu'est ce qui te fait penser que c'est la Lune.	What makes you think that it s the Moon?
127	06:39	(élève) Ben elle est à côté du Soleil déjà	(Pupil) Well, er - It s next to the Sun.
128	06:43	Et la lune, elle est proche du soleil ?	And the Moon, is it close to the Sun?
129	06:46	- (élève) oui, non, si, j en sais rien	- (Pupil) Yes, no, yes, I don't know
130	06:49	- Elle est proche du Soleil, la Lune ? - (élève) je sais pas - (élève 2) ben là, elle est proche	- Is the Moon close to the Sun? - (Pupil) I don't know - (Pupil 2) well, er It's close there.
131	06:54	c'est pas la lune, c'est pas la lune, ça c'est là, c'est une autre planète.	It s not the moon, it s not the moon, that s it there, it s another planet.
132	06:58	- [B3] elle est en orbite autour de la Terre - ah, alors "B3", il me dit la lune est en orbite autour de la Terre. Donc là, c'est pas possible	- [B3] It is in orbit around the Earth - Ah! So "B3" tells me the moon is in orbit around the Earth. So in that case, it isn't possible.
135	07:07	parce que la Terre est là et là, c'est une autre planète.	Because the Earth is there, and here it's another planet.
136	07:10	- Vous la connaissez celle là, - (élève) c'est Mars.	- You know this one. - (Pupil) It s Mars.
137	07:12	- [B3] Mercure. - Alors "B3" propose Mercure. "G6", qu est-ce que tu proposes ?	- [B3] Mercury. - So "B3" suggests Mercury. "G6", what do you suggest?
138	07:17	[G6] Mercure aussi.	[G6] Mercury too.
139	07:18	Alors, pourquoi vous dites Mercure ?	So why do you say Mercury?
140	07:21	- (élève) parce que Mercure, elle est proche du Soleil, - j'ai interrogé "G6"	- (Pupil) Because Mercury is close to the Sun, - I asked "G6"
141	07:25	[G6] parce que c'est la planète la plus proche du soleil.	[G6] because it s the closest planet to the sun.
142	07:27	D'accord, Donc on fait un petit récap au niveau des planètes.	All right. So let's remind ourselves of the planets.
143	07:30	Donc là on a Mercure.	So, here we have Mercury.
144	07:33	Là, vous n'avez toujours pas dit comment elle s'appelle celle-là.	You still haven t said what this one s called.
145	07:36	- Là, on a la Terre - (élève) j ai trouvé - et là on a Mars.	- There s the Earth - (Pupil) I ve found it - and there s Mars.
146	07:40	- Tu aurais une proposition pour celle-ci, - [B2] Uranus - Uranus, ça m étonnerait, ça me surprendrait beaucoup	- Do you have a suggestion for this one, - [B2] Uranus - Uranus, I d be surprised, I'd be very surprised
147	07:46	Oui et c'est tout le temps "G6" et "B3" qui parlent J aimerais bien que ce soit un peu "G7", "G3", "B4"... "B4" !	Yes, and it s always "G6" and "B3" talking. I d like other people to speak a little, "G7", "G3", "B4"... "B4"!
148	07:50	- [B4] Jupiter - Jupiter non c'est pas là. Jupiter elle est pas sur la carte,	- [B4] Jupiter - Jupiter, no, it isn't there. Jupiter isn't on the map.
149	07:56	elle est pas sur le planétaire, elle est trop loin	It isn't on the orrery, it s too far away.
150	08:00	On a dit Mercure, on a dit Terre, on a dit Mars.	We ve said Mercury, we ve said Earth, and we ve said Mars.

Table 18. Table 13 Ctd.

id	time	transcription	English translation
151	08:03	Qu'est ce qui manque ici ?	What is missing?
152	08:05	- "G6", elle connaît bien le système solaire on dirait. Alors, vas-y - [G6] Vénus ? - D'accord.	- "G6", she seems to know the Solar System very well. So, go on - [G6] Venus? - All right.
153	08:09	Donc on a, On fait un petit récap.	So we ve got, let's recap.
154	08:11	Sur les planètes, on a Mercure, on a Vénus on a la Terre et on a Mars.	For the planets, we ve got Mercury, we ve got Venus, we ve got the Earth and we ve got Mars.
156	08:20	On a, on a ces quatre planètes qui sont représentées et on a aussi quelque chose d'autre, hein ? - (élève) il est là bas	We ve, we ve got these four planets which are represented and we ve also got something else, eh? - (Pupil) It s over there.
158	08:26	(élève) Les points verts, les points verts, le truc qui est représenté sur la bâche. L'objet céleste.	(Pupil) The green dots, the green dots, the thing represented on the sheet. The heavenly body.
159	08:31	Toi tu proposerais quoi ?	What would you suggest?
160	08:34	- [B3] Pluton, parcequ'elle se déplace en ovale	- [B3] Pluto, because it moves in an oval.
161	08:39	Ouais, d'accord, mais...	Oh yeah, all right, but...
162	08:39	(élève) c'est vrai il y a Pluton aussi	(Pupil) It s true, there s Pluto too.
163	08:42	Oui, toi "G3", tu proposerais quoi ?	Yes, "G3", what would you suggest?
164	08:46	- [G3] moi je ne pense pas que ce soit une planète	- [G3] I don't think it s a planet.
165	08:48	- Ah, "G3" vient de nous dire quelque chose d intéressant - (élève) une météorite	- Ah, "G3" s just said something interesting - (Pupil) a meteorite.
166	08:51	- Chut, elle vient de nous dire que ce n'est pas une planète, - (élève) c'est pas une planète, - Alors ce n'est pas une planète	- Hush, she s just told us that it s not a planet, - (Pupil) it s not a planet, - So it s not a planet.
167	08:57	Pourquoi tu penses que ce n'est pas une planète - [G3] parce que déjà la forme euh	Why don't you think that it s a planet - [G3] Because its shape is, er
168	09:03	- [G3] euh, elle est pas ronde - elle est pas ronde, déjà, les planètes c'est souvent rond - (élève) ben la Terre...	- [G3] er, It isn't round - It isn't round, planets are often round - (Pupil) Well, er The Earth...
169	09:10	Alors donc si c'est pas une planète, qu'est ce que ça peut être ?	So if it s not a planet, what can it be?
170	09:14	"G5" ? [G5] une météorite	"G5"? [G5] a meteorite
172	09:17	Une météorite, ce n'est pas une météorite parce que les météorites	A meteorite, it s not a meteorite because meteorites
173	09:21	- si c'était une météorite, - (élève) un astéroïde, - un astéroïde.	- if it was a meteorite, - (Pupil) an asteroid, - an asteroid.
174	09:25	Je ne sais pas si c'était une météorite, ce serait où ?	I don't know, if it was a meteorite, where would it be?
175	09:26	une météorite, elles sont sur le sol de la terre.	A meteorite, they re on the ground on Earth.
176	09:29	(élève) Ben oui, ben non.	(Pupil) Well yes, well, er no.
177	09:32	(élève) astéroïde - Oui d'accord, mais là il est dans l'espace. Donc ça ça colle pas.	(Pupil) asteroid - Yes, all right, but this is in space. So that doesn t make sense.
179	09:36	Une question, attends, deux secondes avec les questions... "B3" ?	A question, wait, wait a minute with the questions... "B3"?
180	09:38	[B3] j'ai deux propositions, euh.. Astre ou euh comète	[B3] I ve got two suggestions, uh A star or, um, a comet

Table 19. Table 13 Ctd.

id	time	transcription	English translation
181	09:44	Moi je retiendrais plutôt le terme de comète. Là, c'est la comète d Encke, c'est une comète	I d use the term comet. This is Encke s Comet, it s a comet.
183	09:52	Alors les noms des planètes, c'est bon. On a parlé des planètes, alors le soleil, c'est une planète les enfants ?	So the names of the planets, we're there. We've talked about the planets. So is the sun a planet, children?
185	10:00	- (élèves) Non - Non, C'est quoi - (élèves) une étoile - une étoile, d'accord	- (Pupils) No - No, what is it - (pupils) a star - a star, all right.
187	10:03	Donc on a vu l étoile, le soleil. On a vu les planètes, on a vu la comète. On a parlé des orbites.	So we have seen the star, the sun. We have seen the planets, we have seen the comet. We ve talked about orbits.
188	10:10	Il manque encore quelque chose. l y a quelque chose dont on n'a pas parlé	There s still something missing. There s something we haven't talked about.
189	10:14	- (élève) le truc vert - le truc vert, on a dit que c'était le trajet de la comète d Encke.	- (Pupil) the green thing - the green thing, we said it was the path of Encke s comet.
190	10:19	(élève) Maître il y a un truc...	(Pupil) Sir, there s something...
191	10:23	- Alors ça, ça qu est-ce que c'est ? - (élève) le trajet de cette planète	- So, what is this? - (Pupil) this planet s path.
192	10:30	- L IREM, Lille, Lille c'est une ville L IREM c'est une structure. Ca c'est un logo	- The IREM, Lille, Lille is a city The IREM is an organisation. This is a logo.
194	10:35	Alors, il y a. Sur quoi est-ce que, qu est ce que tu tu es en train de marcher sur quelque chose "B3". Qu'est ce que c'est ?	So, what is there... What are you, what are you walking on, "B3". What is it?
196	10:42	[B3] euh, situation du lundi 21 mars 2022.	[B3] er, situation on Monday 21 March 2022.
197	10:45	Donc ça ressemble à quoi ça.	So, what does that make you think of?
198	10:48	- [B3] Ça, Ça ressemble à - (élève) une date - plus à une date.	- [B3] It, it looks like - (pupil) a date - it looks like a date.
199	10:51	Ça me fait penser à une date le lundi 21 mars. 2022, cest une date, donc c'est une date qui donne une indication du moment où on a conçu ce planétaire.	It makes me think of a date, Monday 21 March. 2022, that s a date, so it s a date that tells us when this orrery was designed.
201	11:02	D'accord, c'est la situation au lundi 21 mars 2022.	All right, that s the situation on Monday 21 March 2022.
202	11:05	(élève) Il y a aussi ça	(pupil) There s also this.
203	11:08	- Alors, ah, voilà autre chose - (élève) il y a aussi ça	- So, ah! Here s something else - (pupil) There s this as well.
204	11:10	"G5", elle a... alors, il y a deux choses maintenant. Il y a "G5" et "G1" qui ont trouvé quelque chose	"G5", she s... so, now there are two things. And "G5" and "G1" have found something.
206	11:18	"G5" ... ça c'est un autre... alors.... Alors donc, "G5" nous parle de ça.	"G5" ... it s another one... so.... Right, "G5" tells us about this.
208	11:25	Regardez. 149ă500, 149ă597ă870 kilomètres. et au-dessus il y a marqué 1 U.A.	Look. 149,500, 149,597,870 kilometres. And above it is marked 1 AU.
210	11:36	On a vu en maths que U ça voulait dire.	We have seen what U means in maths.

Table 20. Table 13 Ctd.

id	time	transcription	English translation
211	11:39	- (élèves) unité - (élève) et ŞAŤ - et ŞAŤ ça pourrait être quoi ?	- (Pupils) unit - (pupil) and ŞAŤ - and what could ŞAŤ be?
212	11:42	- (élève) Şastreŧ - alors de la même famille que astre,	- (Pupil) ŞstarŤ [French Şastreŧ]- so in the same family as star,
213	11:46	un adjectif - (élève) astéroïde - non	an adjective - (pupil) asteroid - no
214	11:50	La même famille que Astre, (élèves...) - astre, astre	The same family as Star, (pupils...) - star, star
216	11:55	- (élève) amiral, - (élève) astral, - un autre adjectif, un autre, un autre adjectif de la famille de Şastreŧ.	- (pupil) admiral, - (pupil) astral - another adjective, another, another adjective in the same family as ŞstarŤ.
219	12:05	Vous voyez pas, vous donnez votre langue au chat ?	Anyone, you give up?
220	12:07	- (élève) astro - astro, astro - (élève) on donne notre langue au chat - (élève) astroticot	- (pupil) astro - astro, astro - (pupil) the cat s got our tongue - (pupil) astrocat
221	12:11	astro-nomie Donc c'est une unité astronomique,	astro-nomy. So it s an astronomical unit.
222	12:16	Cette longueur de l unité astronomique, essayez de me la retrouver sur sur la bâche entre deux objets.	Try to find this length of the astronomical unit on the sheet between two objects.
223	12:24	(...)	(...)
224	12:30	Bon, j'ai l'impression que "B3" a une proposition à nous faire. Vas-y	OK, I think "B3" has a suggestion for us. Go ahead.
226	12:34	[B3] J'ai trouvé que c'était ... entre le Soleil et la Terre	[B3] I found what it is ... between the Sun and the Earth.
227	12:40	D'après "B3", ce serait équivalent à la distance entre la terre et le soleil.	"B3" thinks this is equivalent to the distance between the Earth and the Sun.
228	12:46	Est ce que vous êtes d'accord avec "B3" ?	Do you agree with "B3"?
229	12:48	- (élèves) moi non / oui / non - Faites, essayez avec vos pieds ou avec vos mains	- (Pupils) I don't / yes / no - Try it with your feet or with your hands
230	12:52	- voir si ça marche - (élève) normalement ça fait un mètre	- see if it works - (pupil) it should be a metre.
231	12:54	Mais là, là, c'est pas bonne du tout.	But in this case, it s not right at all.
232	12:56	Non mais essaye de (re?)garder les mains, ce sera plus facile.	No, but try keeping on with your hands, it will be easier.
235	13:04	(élève) Ah oui	(pupil) Ah! Yes
236	13:08	Voilà, et maintenant je voudrais qu'on revienne. sur ce qu a...	There, and now I d like to go back to what...
237	13:15	on peut dire que "B3" a raison en disant que l'unité astronomique correspond approximativement à la distance entre le Soleil, la Terre.	We can say that "B3" is right when he says that the astronomical unit corresponds approximately to the distance between the Sun and the Earth.
239	13:21	Est ce que vous êtes d'accord avec ça ?	Do you agree with that?
240	13:23	- (élèves) Oui, - vous êtes d'accord avec ça ?	- (Pupils) Yes, - do you agree with that?

Table 21. Table 13 Ctd.

id	time	transcription	English translation
241	13:24	Maintenant, je voudrais qu'on revienne sur ce qu'a vu "G1" tout à l'heure.	Now, I d like to go back to what "G1" saw earlier.
242	13:28	"G1", tu peux nous rappeler ce que tu as vu tout à l'heure	"G1", can you remind us what you saw just now?
243	13:33	(élève) C est "B3" qui a raison	(pupil) "B3" is right.
244	13:36	alors "G1"	So, "G1".
245	13:39	- [G1] l unité de temps égale seize jours, - ok, unité de temps égale seize jours	-[G1] the unit of time is equal to sixteen days, - Ok, the unit of time equals sixteen days.
246	13:45	Attends, qu'est ce que ça pourrait bien vouloir dire ?	Wait a minute, what does that mean?
247	13:47	- (élève) c'est comme une énigme en fait - oui c'est ça Oui, c'est un peu comme une énigme.	- (Pupil) it s like a riddle in fact - Yes, that's it! Yes, it s a bit like a riddle.
248	13:51	Une unité de temps est égale à seize jours.	One unit of time is equal to sixteen days.
249	13:53	D'après vous, qu'est ce que ça peut vouloir dire ?	What do you think that could mean?
250	13:59	Regardez les différentes orbites des planètes.	Look at the different orbits of the planets.
251	14:02	Regardez. D après vous, qu'est ce que ça peut vouloir dire ?	Look. What do you think that could mean?
252	14:05	- Tout à l'heure, vous m'avez dit qu'il y avait des nombres... - (élève) je sais - D accord - (élève) je sais	- A little while ago, you told me that there were numbers... - (Pupil) I know - All right - (Pupil) I know.
253	14:09	- [B2] c'est la durée, les jours .. pour arriver d une planète à une autre - Peux tu être plus précis dans ta formulation.	- [B2] It s the length of time, the days ... to get from one planet to another - Can you put that more precisely.
254	14:16	- [G5] En fait, en fait, la planète ... Mars... le temps qu'il va de là à là	- [G5] In fact, the planet... Mars... the time it takes to go from there to there.
255	14:22	Alors "G5" me dit qu'elle proposerait éventuellement que ce soit le temps qui correspond à ... entre deux points pour chaque, pour chaque planète.	So "G5" tells me she thinks it might be either the time that corresponds to... between two points for each, for each planet.
257	14:33	- [B3] et là Il a 42 fois 16 - est-ce que vous pensez que c'est possible, - [B3] 42 * 16	- [B3] and there we have 42 times 16 - do you think it s possible, - [B3] 42 * 16
258	14:36	- alors 42 fois seize - [B3] pour cette planète, - pour la planète Mars, c'est ... ?	- so 42 times sixteen - [B3] for this planet, - for the planet Mars, it s ... ?
259	14:41	Qu'est ce qu'on connaît comme durée ? Nous ?	What length of time do we know? Do we?
260	14:43	- Est ce qu'on connaît la durée du tour de l'orbite de la révolution autour du Soleil de Mars ? - (élèves) Non.	- Do we know how long it takes for Mars to orbit around the Sun? - (Pupils) No.
261	14:49	- Vous la connaissez vous ? - (élèves) non - moi personnellement je ne la connais pas	- Do you know how long? - (Pupils) No - Personally I don't know how long.
262	14:51	Est-ce que j'en connais une ?	Do I know one?
263	14:53	- Est ce que j'en connais une ? - [B3] ben oui, La Terre - (élève) oui	- Do I know one? - [B3] well, er Yes, The Earth - (pupil) yes.
264	14:55	- Ah, La terre, c'est combien - [B3] 367.	- Ah! The Earth, how long is it? - [B3] 367.
265	14:58	- Bon, alors - (élève) ou 368 (?) - là, il y a combien de ...	- Right, then - (pupil) or 368 (?) - How many are there...
266	15:01	- Il y a combien de fois la Terre là - [B3] ben là 22 ... 22 là - et....	- How many times does the Earth - [B3] well, er... 22... 22 there - and....
267	15:05	Et entre 22 et 1, il y a quoi ?	And what s between 22 and 1?
268	15:07	Alors oui, comptez.	So yes, count.
269	15:08	- [G5] Mais il y a 23. - allez y, comptez - [B3] 23 - "G5" tu proposes 23.	- [G5] But there's 23. - Go ahead, count - [B3] 23 - "G5" you suggest 23.
270	15:13	- [B3] 23 du coup - alors si je fais 23 fois 16,	- [B3] So 23 then - So if I do 23 times 16,

Table 22. Table 13 Ctd.

id	time	transcription	English translation
271	15:17	je vais vous la faire, parceque vous vous n avez pas la calculatrice.	I ll do it for you, because you haven t got the calculator.
272	15:20	- (élève) on peut faire de tête - Vous voulez faire de tête, ben essayez de tête les enfants.	- (Pupil) you can do it in your head - You want to do it in your head, right, well try to do it in your head, children.
273	15:23	Allez-y, faites vous plaisir	Go ahead, off you go
275	15:29	23 fois seize. Je trouve 368, ça correspond à peu près ou pas ?	23 times sixteen. I ve got 368, is that about right or not?
276	15:35	- (élèves) ouais, ouais, bof... - ben, 368 pour 365 et un quart.	- (Pupils) yeah, well, not really... - well, er - 368 for 365 and a quarter.
277	15:41	- (élèves) Oui oui... - ben, c'est approximatif mais ça correspond à peu près OK.	- (Pupils) Yes, yes... - well, er it s approximate, but it s about right, more or less, OK.
278	15:45	- Bon, on peut passer à la deuxième partie ? - (élève) Maître - alors oui.	- Right, can we move on to the second part? - (Pupil) Sir - So, yes.
279	15:50	- (élève) il y a un truc qui n'est pas parfait ici. C'est le 2 ... le 2 du truc... mais il n y a pas le 1	- (Pupil) There s something that s not quite right here. It s the 2 ... the 2 in the thing ... but there isn't the 1.
280	15:57	- (élève) il y a le 3 là-bas - Ben, cherche le 1 alors.	- (Pupil) There s the 3 over there - Well, look for the 1 then.
281	16:00	- [B3] Non, c'est pas ça. Vous n'avez pas compris. ça c'est le 36, c'est le 36 et ça c'est le 2	- [B3] No, that s not it. You don't understand. That's 36, that s 36 and that s 2.
282	16:07	- (elève) Non c'est pas ça, il n y a pas le 1... là - je crois que "B3" a raison	- (Pupil) No, that s not right, there s no 1... there - I think "B3" is right
283	16:11	- (élève) pas le point là - Ah oui. Qui a dit ça ?	- (Pupil) not the dot there - Ah! Yes. Who said that?
284	16:14	- (élèves) il y a 2 / il y a 3 - Alors, il y a des chiffres...	- (Pupils) there s 2 / there s 3 - So, there are numbers...
285	16:20	- Alors, écartez vous tous. Ecartez vous en restant sur la bâche. Alors	- So, everybody stand aside. Stand back and stay on the sheet. So
286	16:26	- "G2", tu te mets sur le 1 s il te plaît ? - [B3] ah ça va de 2 en 2 - "G2", attends	- "G2", would stand on the 1 please? - [B3] ah it goes from 2 to 2 - "G2", wait
287	16:31	"G2", va du 1 au 2	"G2", go from 1 to 2,
288	16:33	Du deux au trois, du trois au quatre,	from two to three, from three to four,
289	16:36	du quatre au cinq, du cinq au six.	from four to five, from five to six.
290	16:39	Du six au sept. Du sept au huit, du huit au neuf, du neuf au dix.	From six to seven. From seven to eight, from eight to nine, nine to ten.
292	16:45	Maintenant va sur la planète. Voilà, on fait un médaillon sur deux à chaque fois.	Now go to the planet. That's it, every other spot each time.
293	16:49	Qu est-ce qu'il y a de bizarre, "B5" ?	What s strange about this, "B5"?
294	16:51	- [B5] en fait ici il y a le 3, mais il n y a pas le 1 et le 2	- [B5] In fact, there s a 3 here, but there isn't a 1 or a 2.
295	16:55	- [B3] est-ce que tu peux faire le tour et ... - Alors...	- [B3] Can you go around and... - So...
296	17:00	Mettez vous sur Encke, en gardant des espaces. Au moins deux points verts entre chacun.	Stand on Encke, keeping spaces. At least two green dots between each person.
297	17:08	Les filles vous restez sur la bâche, les garçons vous mettez un petit peu sur le côté là pour voir.	Girls stay on the sheet, boys go a little to the side to see.
298	17:15	Est ce que ça peut marcher ?	Will it work?
300	17:21	Décale toi un peu d un cran (...) Donc maintenant, en allant dans le sens croissant (...) dans le sens croissant (...) avancez	Move off a little (...) Right now, going in an ascending direction (...) in an ascending direction (...) move forward.

Table 23. Table 13 Ctd.

id	time	transcription	English translation
301	17:32	- Est ce que vous remarquez quelque chose déjà au niveau des nombres ? - [B3] moi...	- Do you notice anything else about the numbers? - [B3] I do...
302	17:36	- Qu est-ce qu'il y a au niveau des nombres qui vous parait bizarre ? - [B3] de 3 en 3 - de 3 en 3	- What do you find strange about the numbers? - [B3] from 3 to 3 - from 3 to 3.
303	17:41	Donc, contrairement aux autres planètes, où c'est de 1 en 1 là, pour la comète c'est de trois en trois	So, unlike the other planets, where it's from 1 to 1, for the comet it s from three to three.
304	17:48	donc Entre chaque point de la comète, c'est pas seize jours, c'est le triple, c'est trois fois seize, c'est parce que c'est beaucoup plus grand que la distance.	So between each point on the comet, it isn't sixteen days, it s three times as much, it s three times sixteen, it s because it s much greater than the distance.
308	18:00	Les points seraient trop proches là-bas sinon	The points would be too close together there otherwise.
309	18:04	Est ce que tu veux qu'on passe à la deuxième partie ?	Can we move on to the second part?