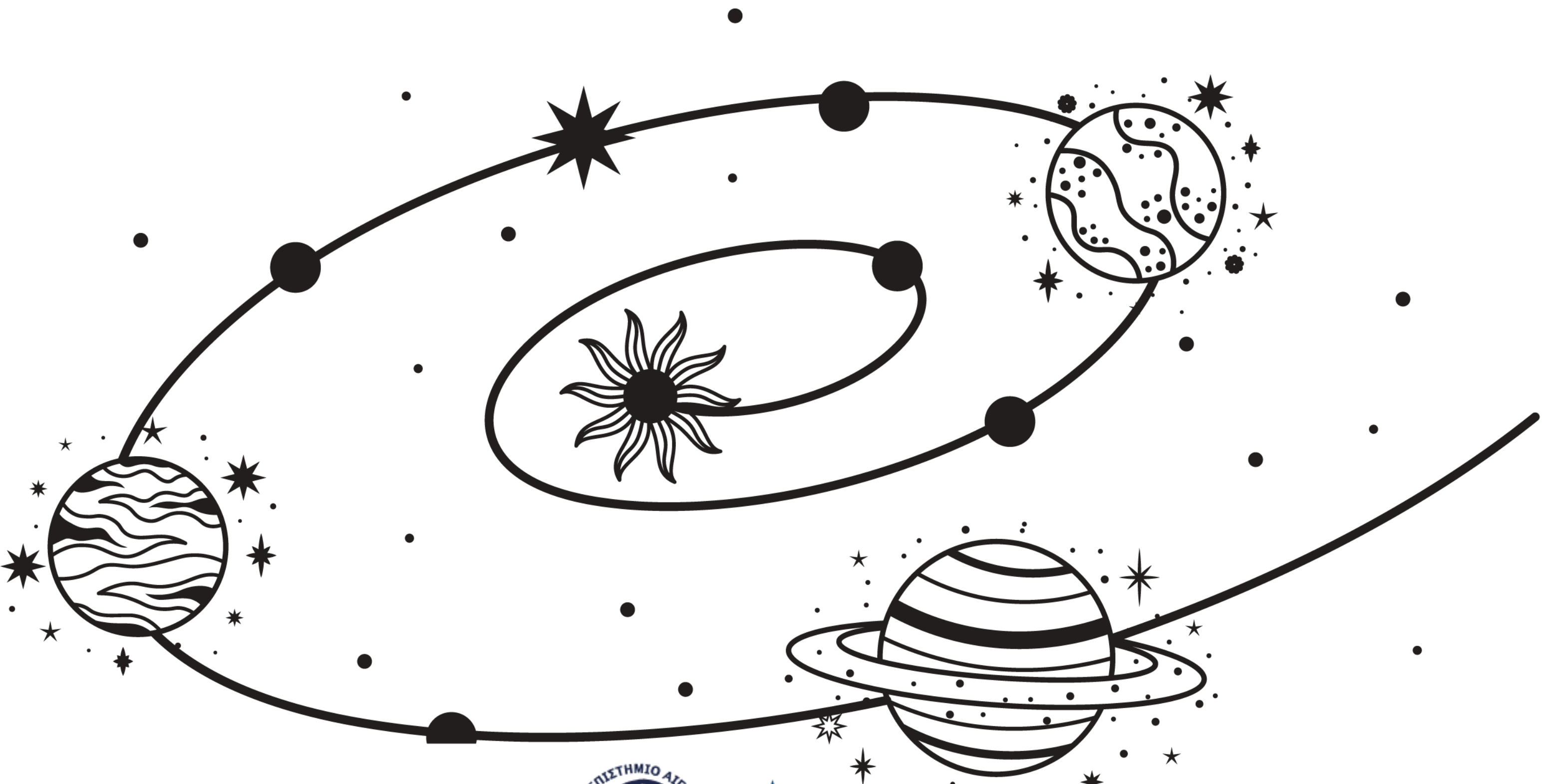
ARISTARCHUS

Theoretical Approach



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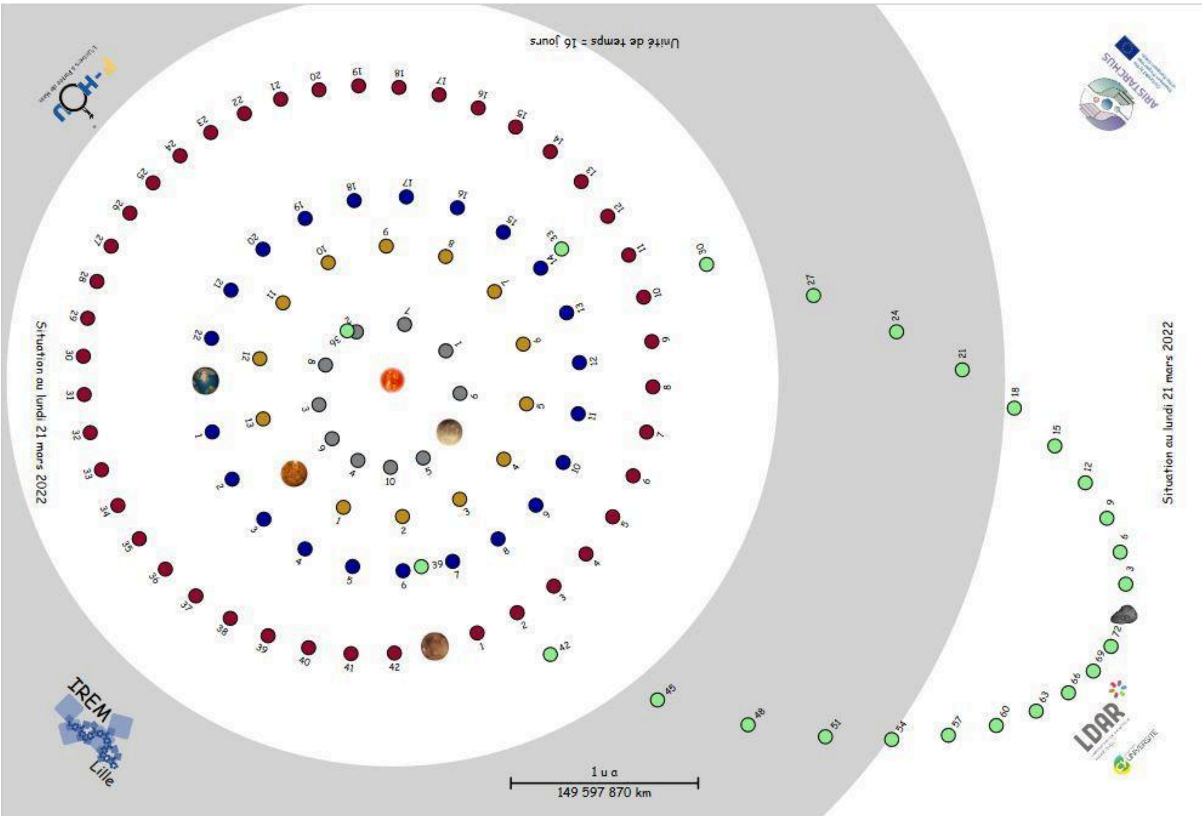
ARISTARCHUS THEORETICAL APPROACH

Aristarchus Erasmus project

October 2024

Astronomy appeals to learners at all ages, and astronomy education is present in curricula across many countries (Salimpour et al., 2021). The Human Orrery intends to facilitate the emergence of a scientific model of the solar system in schools, from primary to secondary level by integrating physical movement and sensory experiences into educational methodologies.

In all sessions presented by the ARISTARCHUS project, learning proceeds as an inquiry process. Through this inquiry process, the tarp of the Human Orrery becomes a scene where human bodies and celestial bodies interplay and transform into each other. This follows an "enactive approach" where "learning is moving in new ways" (Abrahamson and Sánchez-García, 2016).



The French 3,4*6 square meter Human Orrery.

We make sure that the sessions proposed in the project are as accessible as possible to encourage the inclusion of all pupils. This accessibility is achieved through the activity medium proposed (the human planetary) but also through the resources provided to teachers to complement the sessions. The planetary medium provides pupils with a variety of means of action and expression (oral and written, as well as physical and motor). Its atypical nature and its ability to provide external validation can also be a real lever for engaging pupils in the proposed tasks. What's more, the session sheets highlight a series of elements that teachers can use to adapt to the needs of their pupils, such as the list of prerequisites, the obstacles inherent in the session and possible extensions.

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References:

Abrahamson, D. and Sánchez-García, R. (2016). Learning is moving in new ways: The ecological dynamics of mathematics education. *Journal of the Learning Sciences*, 25(2):203–239.

Salimpour, S., Bartlett, S., Fitzgerald, M. T., McKinnon, D. H., Cutts, K. R., James, C. R., Miller, S., Danaia, L., Hollow, R. P., Cabezon, S., et al. (2021). The gateway science: A review of astronomy in the oecd school curricula, including china and south africa. *Research in Science Education*, 51:975–996.

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History of the Human Orrery

Planetarium – a dome-shaped projection of the sky – are often used to show the motion of planets around the Sun (Brazell and Espinoza, 2009; Plummer et al., 2015). Orreries, mechanical models of the Solar System, are suitable alternatives. A mechanical orrery represents planets as visual 3D spheres and reproduces their movements through a set of mechanical devices. A Human Orrery (HO) is a flat material representation, a space-time map, of the movements of some of the bodies in the Solar System around the Sun through series of discs located at their respective positions at different times within a single static image (a chronophotography).

Always drawn in the heliocentric frame (with the Sun being at rest, the reference of the movement of other objects), they accurately figure elliptical orbits consistent with Kepler's laws. Distance between Earth and the Sun is typically of one meter, allowing participants to play the part of planets moving around the Sun. It thus allows an embodied and interdisciplinary approach, combining, knowledge of astronomy, kinematics, geometry and analysis.

The first Orrery to be created at a human scale was done in Japan (Dynic Astropark) and then at the Armagh Observatory (Asher et al., 2007). The Japanese device uses circular orbits, while the Armagh Orrery is a very accurate representation of the elliptical orbits including planets up to Saturn and two comets. Since 2015, the association F-HOU has developed a large network of Human Orreries in France and in Europe. Different teaching sequences have been set up and analysed in different research papers by the ESMEA LDAR-CY research team.

The ARISTARCHUS project has pursued this effort of research and dissemination (see the map online and a description and pictures of all Orreries around the world here).

- *References:*

Asher, D., Bailey, M., Christou, A., and Popescu, M. (2007). The human orrery: A new educational tool for astronomy. *Astronomy Education Review*, 5(2):159–176.

Brazell, B. D. and Espinoza, S. (2009). Meta-analysis of planetarium efficacy research. Astronomy education review, 8(1).

Plummer, J. D., Schmoll, S., Yu, K. C., and Ghent, C. (2015). A guide to conducting educational research in the planetarium. *Planetarian*, 44(2):8–24.

- *ESMEA References:*

Abboud, M., & Rollinde, E. (2021). Les Mathématiques du Système Solaire en plein air. Le planétaire humain au collège. *Repères IREM*, (124), 37-62.

Rollinde, E. (2017). Learning science through enacted astronomy. *International Journal of Science and Mathematics Education*, 17(2):237–252.

Rollinde, E. (2019). Enacting planets to understand occultation phenomena. arXiv preprint arXiv:1910.09403.

Rollinde, E., Decamp, N., & Derniaux, C. (2021). Should frames of reference be enacted in astronomy instruction?. *Physical Review Physics Education Research*, *17*(1), 013105.

Rollinde, E. and Maisch, C. (2023). Les orbites planetaires sont-elles circulaires? *Grand N, Revue de mathématiques, de sciences et technologie pour les maîtres de l'enseignement primaire*, (111):5–39.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them. Project Number: 2021-1-FR01-KA220-SCH-000032478

Rollinde, E., Nechache, A., and Abboud, M. (2022). Etude du travail géométrique autour des ellipses avec le planétaire humain. Septième symposium d'Etude sur le Travail Mathématique-ETM7-Strasbourg.

- *ARISTARCHUS references*:

Loch, M., Ubben, M., & Rollinde, E. (2023). Embodied Cognition and Minds in Orbit. Conference *Sciences in the flesh, embodiment in science education*. Poster online

LOCH, M. A., UBBEN, M. S., & ROLLINDE, E. Walk of the Planets. Students Concepts of the Solar System. Online document

Karampelas, K., Pyrini, A., Sarrigeorgiou, G., Tsolakidis, K., Rollinde, E., Ubben, M., ... & Pantela, N. (2024). ARISTARCHUS—ARTISTIC REALITY IN SCHOOL EDUCATION: ENACTED, REFLECTIVE AND COLLABORATIVE LEARNING WITH THE HUMAN ORRERY SPACE. *ICICTE Conference 2024. Version online*

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The design of the Human Orrery

You will find here the main conventions used across all HO's.

1. The length scale is chosen to be one meter of one Astronomical Unit (AU) for a Human Orrery, to ease conversions.
2. Different categories of objects in the Solar System are represented on most Human Orreries: (dwarf) planets, comets and asteroids.
    - Planets. When a Human Orrery is set up in a large space, almost all the planets may be shown. The largest one, in a French junior high school, includes planets up to Saturn, and will soon include the orbit of Uranus, at about 10 AU from the Sun. Printed orreries are likely to display only orbits of inner planets (Mercury, Venus, Earth and Mars, up to 1,6 AU from the Sun).
    - Comets. The orbits of one (on tarp) or two comets (in a courtyard) are usually represented: the comet Encke whose orbit extends up to 4 AU at its aphelie (position furthest away from the Sun) and Churyumov-Gersaminenko that 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, that contains a great many solid, irregularly shaped bodies called asteroids or minor planets, much smaller than planets. On the Orrery, it is represented as a 2D grey ring together with the orbit of the dwarf planet Ceres (if the size of the tarp is large enough).
3. Each orbit is represented by a series of discs of one color each with associated numbers. The duration from a position numbered *i* to the position numbered *i+1* is constant for all orbits (it is called the time step, Δt). In some cases, the numerical series goes from three to three (Encke) or alternate over two periods (Mercury). This is discussed further below.
4. The discs related to the position of the objects at a specific "initial date" are slightly larger, and - in the case of a printed tarp - represent the image of the planets or the comet. The discs related to the Sun is also slightly larger. To clarify the fact that sizes are not at scale, all discs that represent an object have the same size.

Each student travels along a specific orbit at a pace that is set by some other person (usually the instructor) who claps their hands regularly. Between two claps, all planets move, simultaneously, from one number to the next, while the Sun stays at rest (in the heliocentric frame).

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A precursor scholar model of the Solar System

The knowledge that goes into the design of the HO is adapted to teaching and learning in the classes considered (primary and secondary schools). Differences with the scientific model will not generate misconceptions, as long as they are explicit and known by the teacher and the learner. Such a model is called a precursor didactical model of the solar system [. Hereafter, it is called "the Orrery model" in short.

Considering only the Newtonian dynamic of the Solar System, objects are interacting through the gravitational forces of a N-body system, N being greater than 3. Hence, their exact trajectory cannot be computed analytically. The map of the Orrery is built through a program implemented by F. Recher (IREM de Lille) that gets real positions of any object at any date through the IMCCE web site. Hence, this position accounts for the N-body interactions in a 3D space.

1. Since the Orrery is printed, it has to be a 2D representation, even if orbits of the Solar Sytem are not co-planar. Hence, all 3D positions are projected onto the orbital plane of Earth around the Sun, called the ecliptic plane. We note that predictions of alignment of two planets with the Sun (a transit of the innermost in front of the outermost) are then more frequent (see Rollinde, 2019, for details).
2. The discrete appearance of the orbit in the chronophotography (with a set of discs instead of a continuous line) must not generate a stop-and-walk choreography by the students. They must keep moving their legs in the interval between two claps, as celestial objects are always moving.
3. We come back now to the choice for the time step (Δt). Two options are proposed usually.
   - Δt =1/24th the terrestrial year (or about 15 terrestrial days). This allows the Earth to come back exactly at point 0 after one revolution. The time step will not be written on the Human Orrery since it may be derived thanks to the movement of Earth along its orbit. Note that the duration of the last step that reach the disc 0 is not equal to Δt for other planets since their period is not an exact multiple of Δt. Yet it turns out that the duration of this last step is not so different from the others which makes it possible to walk smoothly all along the orbit.
   - Δt =16 terrestrial days. In this case, there are 23 discs along the orbit of Earth, and the time step is indicated on the Human Orrery. The duration that corresponds to one orbital period along the orbit of Earth on the Human Orrery would now be 368 days. Hence, the last step on the orbit of Earth has a duration that is about 13 terrestrial days.
   - The case of Mercury is special. Its orbital period is about 88 days. With the choice of Δt = 16 days, one orbital period corresponds to 5.5 steps. Hence a second series of discs is added to make 11 steps before reaching the position 0. The two series alternate along the orbit. With the choice of Δt =1/24th a year, 88 days corresponds to 5,78 steps, so the last step is not so different from others, and only one orbital period is drawn.
   - Comets are going much slower as they are far away from the Sun (aphelie), and much closer near the Sun (perihelie). To prevent discs from being too close one to the other at the aphelie, only one disc over three are drawn (green discs). Hence, one has to do three steps to go from one point to the next.
4. Last but not least, orbits of 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 orbit of Earth. Trajectories of each object on the Orrery may then be considered as stable over the period of

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time that will be considered in educational context, typically a dozen of orbital periods at most.

References

Rollinde, E. (2019). Enacting planets to understand occultation phenomena. arXiv preprint arXiv:1910.09403.

Weil-Barais, A. (2022). *What is a precursor model?* In Precursor models for teaching and learning science during early childhood, pages 11–32. Springer.

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The theory of Inquiry

According to the theory of inquiry introduced by J. Dewey (Barrow, 2006; Thievenaz, 2019). "Human beings develop and grow by re-establishing transactions with their environment in order to remain in continuity with it. When a break occurs and the balance of activity is disturbed or disrupted, the subject engages in intelligent behaviour aimed at regaining continuity in the course of his or her activity." To feel such an embarrassment requires that learners have a goal to attain or an action to perform.

On the Human Orrery, learners have to be able to move on the tarp as if they were planets. This action requires to understand the signs (dics, scales...) and to connect them to motor actions, which "produces new forms of knowledge in the process". We expect learners to follow the pattern of inquiry for each sign: 1) the indeterminate situation; doubt; 2) setting up the problem; 3) determining the solution to the problem; 4) reasoning; 5) the operational nature of the facts-significations.

This pattern requires learners to observe, "which involves training all the senses and coming into direct contact with things, is a concrete and accessible phase" (Zask, 2017). Different kind of observations may be distinguished:

- spontaneous observation (identifying the cause of the problem - material or cognitive obstacle - in order to overcome it)
- reflective observation: looking for a way of transforming the situation that actually exists, creating new tools
- observation with a view to collecting data, guided by our hypotheses
- observation to test a hypothesis or idea,
- Direct observation or observation using instruments
- Observation “to the power of 2”, that of the consequences of initial observations in terms of concrete effects, situated practices or existentially felt results

In short, "students learn to observe with a view to (1) discovering the nature of the perplexities with which they are confronted, (2) inferring hypothetical explanations for the incomprehensible things their observations reveal, and (3) testing the ideas thus suggested. In short, observation acquires a scientific nature".

In the context of Human Orrery we hypothesize that this investigation involves perceptual-motor activity on the part of the students on the tarp; we assume that these observations are based on the involvement of the learner’s body , through interwaving of movements, gestures and speech (Lapaire, 2022).

References

Barrow, L. H. (2006). A brief history of inquiry: From dewey to standards. Journal of Science Teacher Education, 17(3):265–278.

Lapaire, J.-R. (2022). *Le “corps apprenant”: une notion centrale en mal d’inclusion*. In (eds.) Charbonneau, C., Duval, H., Le corps dans l’enseignement-apprentissage. Québec: Presses de l’Université Laval.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them. Project Number: 2021-1-FR01-KA220-SCH-000032478

Thievenaz, J. (2019). La théorie de l’enquête de john dewey: actualité en sciences de l’éducation et de la formation. *Recherche et formation*, (92):9–17.

Zask, J. (2017). S’entraîner à observer. Questions Vives. Recherches en éducation, (27).

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Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them. Project Number: 2021-1-FR01-KA220-SCH-000032478

Human Orrery, from a tarp to a scene

The encounter of the Human Orrery is considered as a propitious situation to observation and inquiry. We assume that it functions as a "blended space" (Fauconnier, 2008), that integrates a minimum of 3 spaces:

- the physical place chosen to set up and carry out the activities (e.g. a courtyard, a playground, a classroom);
- the signified and cultural space of the solar system (traced on the ground, printed on a tarp or on an A3 sheet),
- and the social space of the classroom (where learning is institutionally organised).

The learners experience those 3 spaces jointly and simultaneously. 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 product of the imagination. The participants are also seen responding to the instructor's prompts and engaging in activities, thus acknowledging the status of the HO as a teaching-and-learning space.

All 3 spaces –physical, astronomical, educational - clearly merge into one experiential space: the blended HO space, with its own set of semiotic rules, motion properties and cognitive functioning. What holds for space also holds for the body. 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. And by complying with the physical guidance issued by the instructor and engaging in the reasoning tasks, the participants' sensing, moving and cognizing bodies manifestly behave as "learning bodies" (Lapaire, 2022). So, just as we have 3 integrated spaces, we have 3 integrated bodies, blending into one: the blended HO learning body, with its own behavioural codes, movement patterns and reflective activity.

References

Fauconnier, G. and Turner, M. (2008). *The way we think: Conceptual blending and the mind's hidden complexities.* Basic books.

Lapaire, J.-R. (2022). *Le "corps apprenant": une notion centrale en mal d'inclusion*. In (eds.) Charbonneau, C., Duval, H., Le corps dans l'enseignement-apprentissage. Québec: Presses de l'Université Laval.

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An enactive approach

By walking on the Orrery, the learner acts to perceive, tries to make connections between his movements and what they enable him to perceive and then understand. Sensorial experiences and scientific concepts may then be reconnected, particularly through “mindful attention to perception” (Wilson, 2002; Glenberg et al., 2013). This approach can be described as enactive (Varela et al., 1991) because the learner, from his point of view, is not confronted with an information-rich environment, but will bring out meanings that depend on his actions.

Enaction theory recognizes the role of perception and action in grounding abstract knowledge, and blurs the traditional separation between sensorimotor processes and abstract thought. Typically, the working hypothesis is that by engaging the learner’s body in physical enactment (embodied learning), abstract or remote notions are reframed as “tangible” and proximal. This makes the latter more accessible, and facilitates the emergence of refined knowledge structures (Johson-Glenberg & Megowan, 2017; Skulmowski & Rey, 2018; Abrahamson et al., 2020).

Embodied-learning in general is a relatively new field of research and several findings support the hypothesis of using movements and enaction to ground learning on a deeper cognitive level (Glenberg, 2010) and thus make more abstract concepts intuitively accessible to people of diverse backgrounds.

Coming back to the HO, a young learner - not very tall, surrounded by other learners, looking at the HO not from "the sky" but at eye level - perceives certain characteristics of the planets and the movements of the other learners. Furthermore, this perspective would reveal the meaning that this learner attaches to these features. Such an approach would make it possible to consider the HO as a space of encouraged actions that the learner gradually constructs for himself with the help of the teacher and the other learners, which he explores in order to gradually bring out a world of meanings.

References

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E. R., Soto, H., and Alibali, M. W. (2020). The future of embodied design for mathematics teaching and learning. In Frontiers in Education, volume 5, page 147. Frontiers Media SA.

Glenberg, A. M., Witt, J. K., and Metcalfe, J. (2013). From the revolution to embodiment: 25 years of cognitive psychology. *Perspectives on psychological science*, 8(5):573–585

Glenberg, A. M. (2010). *Embodiment as a unifying perspective for psychology*. Wiley interdisciplinary reviews: Cognitive science, 1(4):586–596.

Johnson-Glenberg, M. C. and Megowan-Romanowicz, C. (2017). Embodied science and mixed reality: How gesture and motion capture affect physics education. *Cognitive Research: Principles and Implications,* 2(1):24.

Skulmowski, A. and Rey, G. D. (2018). Embodied learning: introducing a taxonomy based on bodily engagement and task integration. *Cognitive research: principles and implications*, 3(1):6.

Varela, F. J., Thompson, E., and Rosch, E. (1991). The embodied mind: Cognitive science and human experience. MIT press.

Wilson, M. (2002). Psychonomic bulletin & review. Six views of embodied cognition, 9:625–636.

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