ARISTARCHUS—ARTISTIC REALITY IN SCHOOL EDUCATION: ENACTED, REFLECTIVE AND COLLABORATIVE LEARNING WITH THE HUMAN ORRERY SPACE

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Abstract

This study explores the effectiveness of a human orrery for astronomy education through the ARISTARCHUS project, which involves a consortium of four organizations across France, Cyprus, Germany and Greece. Astronomy education is crucial yet challenging due to its abstract concepts. The orrery fosters active learning and mental modeling. Projects employing orreries demonstrate significant learning outcomes, enhancing students' comprehension and attitudes towards astronomy. The ARISTARCHUS project aims to revolutionize astronomy education, promoting active learning, interdisciplinary approaches, and sustainable teaching methods across different educational systems. Evaluation through tests and teacher reports indicates promising results, suggesting a potential for transformative impacts on schools.

Introduction

This paper is a study around the use of a human orrery (a heliocentric model of the solar system) for teaching astronomy. It is based on implementing the project *ARISTARCHUS—Artistic Reality In School Education: Enacted, Reflective and Collaborative Learning with the Human Orrery Space*. The project belongs to the category of ErasmusPlus actions and is funded by the European Union. It consists of a consortium of four organizations from four countries: France, Cyprus, Germany and Greece.

Astronomy has been a major unit in science for decades. Many Nobel prizes in Physics have been awarded to scientists who are specialized in astronomy. Learners of all ages will be involved in teaching activities that involve astronomy. Even though the unit has been considered attractive, it is still considered challenging because of concepts, terms, formulas, and highly complex mathematical patterns that learners do not encounter in their everyday lives. Indeed, as with other concepts and topics of science, in astronomy, learners develop false ideas and misconceptions, which persist and prevent the understanding of actual scientific facts regarding topics such as the planets, their motion and the solar system. Teachers and schools can overcome these barriers by designing, selecting, and using appropriate tools and equipment. These tools will assist learners engaging in astronomy activities. They should motivate active participation and learning by doing, so that the misconceptions of learners will be tested, challenged, and rejected. They should be easy to use in the classroom or any teaching room in the school or otherwise. The phenomena, concepts, and basic knowledge of astronomy should be presented in a simple, easy-to-understand yet accurate and scientifically justified way, with the help of these tools (Salamah et al., 2022; Bitzenbauer et al., 2023). For schools to adopt this approach to astronomy teaching, it is necessary to implement relevant programs that can assist in establishing sustainable, feasible and relevant teaching approaches that schools can use regularly (Fullan, 2007).

This paper presents such a program, a project called ARISTARCHUS. It starts with a literature review around the teaching of astronomy, discusses mental modeling by presenting similar projects that have already been published, and moves on to the methodology, describing the project and its characteristics. It then ends with the findings and conclusions. The structure follows strictly the common outline of education research (Cohen et al., 2017).

Literature Review

To examine the potential of a project to promote effective astronomy teaching, examining the main relevant research findings and the context of the project is necessary.

Astronomy Teaching and Modeling

Astronomy education is inherently multifaceted, typically emphasizing key topics such as the Earth's orbit around the Sun, seasonal variations, and the solar system's composition and dynamics, including planetary interactions with the Sun (Lelliott & Rollnick, 2010). These foundational concepts, integral to astronomy teaching for decades, are fundamental to understanding celestial phenomena. Mental or physical models play a pivotal role in enhancing astronomy learning. Mental model building allows learners to conceptualize astronomical ideas, facilitating comprehension and inquiry into complex phenomena. Such models are aligned with contemporary pedagogical approaches, fostering familiarity and enabling learners to employ similar techniques across various disciplines. In this educational framework, students engage in tasks and activities carefully curated to enhance comprehension and construct knowledge. First, learners grasp the educational purpose of the model, drawing from their experiences and ideas to contextualize their learning. Second, learners compare and contrast their mental models with others encountered previously, advancing scientific discourse and deeper understanding. Third, learners actively participate in inquiry-based activities facilitated by models, conducting observations, collecting data, and testing hypotheses under their instructor's guidance (Taylor et al., 2003).

The human orrery emerges as a valuable tool in astronomy education, facilitating mental modeling and active learning. It dynamically portrays the solar system's complexities, offering opportunities for interactive and outdoor activities. Learners experiment, calculate, and discourse around planetary motion, orbits, and celestial mechanics. By manipulating the orrery, learners gain insights into astronomical phenomena, such as variations in planetary rotation around the Sun and the dynamics of comets and meteorites (Asher et al., 2006).

The orrery's interactive nature encourages deeper engagement compared to passive instruction methods, enhancing learners' comprehension and retention of astronomical concepts. By actively participating in learning activities facilitated by the orrery, students develop a nuanced understanding of celestial phenomena, transcending rote memorization. This active learning approach aligns with contemporary educational paradigms, emphasizing experiential learning and critical inquiry (Taylor et al., 2003).

The integration of human orrery into astronomy education offers a dynamic and effective approach to teaching complex celestial phenomena. By fostering active learning and mental modeling, students engage deeply with astronomical concepts, promoting comprehension and retention. This pedagogical approach, rooted in interactive learning and scientific inquiry, enhances astronomy education and inspires future generations of astronomers (Taylor et al., 2023; Asher et al., 2006).

The Human Orrery in Astronomy Teaching

Several projects have successfully integrated human orreries into astronomy education, demonstrating their effectiveness in enhancing learning outcomes. Rollinde (2019) conducted a study in France, where a printed orrery was utilized to teach 14-year-old students concepts of mathematics and physics of planetary motion within the solar system. The intervention centered on facilitating an understanding of velocity, space, time, inertia, gravity, and other relevant principles through active questioning and sensorimotor engagement. Learners interacted with the orrery, gaining a deep understanding of astronomical phenomena, thereby achieving cognitive goals while expressing a heightened interest in astronomy.

Similarly, Newbury (2010) implemented an astronomy teaching program for undergraduate students, incorporating sessions based on orreries. Students actively participated in constructing their orreries, engaging in mathematical calculations related to planetary characteristics and orbits. Through observational activities and hypothetical scenarios, students developed a nuanced understanding of the solar system's dynamics and astronomical laws. The interactive nature of orreries facilitated learner involvement and interaction, with positive learning outcomes.

Sansone et al (2019) utilized a human orrery in didactic laboratory activities for high-school students in Italy, focusing on understanding the solar system's scale and characteristics. Through collaborative tasks and hands-on exploration, students gained significant astronomical knowledge and developed skills in data interpretation and analysis. The orrery served as a mental model, for students to construct knowledge actively and engage in scientific discourse, fostering enthusiasm and deeper learning.

Lebofsky et al. (2011) conducted a project aimed at modeling the solar system using human orreries, involving participants from scout groups in Arizona, USA. By constructing orreries and engaging in astronomy discussions, participants gained insights into celestial phenomena and astronomical principles. The hands-on nature of the activity promoted active learning and enthusiasm among participants, highlighting the value of orreries in astronomy education.

These projects collectively underscore the benefits of using an orrery in astronomy education, providing opportunities for active participation, knowledge construction, and skill development. The hands-on approach fosters engagement and enthusiasm among learners, facilitating a deeper understanding of astronomical concepts and phenomena. By involving students in the design and construction of orrery, educators promote deeper engagement and comprehension, aligning with the principles of active learning and mental modeling in astronomy education (Taylor et al., 2003).

In conclusion, using orreries in astronomy teaching promises to engage students and enhance learning outcomes. Through hands-on activities, collaborative tasks and interactive exploration, students develop a deeper understanding of astronomical knowledge. Educators should prioritize student involvement in orrery design and construction, fostering active learning and enthusiasm for astronomy. Evaluation of such interventions should encompass observations and pre/post-tests to assess learning outcomes, ensuring the efficacy of orrery-based teaching approaches (Newbury, 2010; Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019). This approach not only promotes knowledge acquisition but also nurtures essential skills and attitudes conducive to lifelong learning in astronomy (Taylor et al., 2003).

ARISTARCHUS Project: The Context of the Study

Using a human orrery in astronomy teaching has been endorsed by previous studies (Asher et al, 2006; Newbury, 2010; Lebofsky et al, 2011; Rollinde, 2019; Sansone et al., 2019). In line with this, the ARISTARCHUS project was developed, aiming to achieve four primary goals: engagingly exploring fundamental laws of physics and mathematical concepts; fostering learners' scientific knowledge in Science, Technology, Engineering, Arts and Mathematics (STEAM) disciplines for modern scientific engagement; enhancing interdisciplinary STEAM learning and student well-being; and improving learners' scientific process skills. The project encompasses four work packages with specific deliverables, alongside teaching interventions. These interventions involve the design, development, and utilization of human orreries, a methodological framework, an educational toolkit, an augmented reality application, and an e-learning platform with gamified modules.

Three teaching interventions were implemented. To build knowledge of astronomy and the solar system, the first intervention focused on learning to use the orrery. The second addressed the orbital period of each planet around the sun, highlighting their individual rotational times. The third intervention explored concepts of day and night.

Notably, the project demonstrates innovation and significance in several dimensions. It operates across four countries with diverse educational systems, managed by a consortium of educational and research organizations. Additionally, it caters to learners of various ages and educational levels, employing a holistic approach that includes lesson-plan preparation and material development for astronomy education. The project emphasizes active student participation through project-based learning activities, including student involvement in orrery design. By prioritizing these aspects, the project aims to be innovative and effective (Asher et al., 2006; Fullan, 2007; Newbury, 2010; Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019).

Methodology

To evaluate the potential of a project such as ARISTARCHUS to have the desired learning outcomes and impact on schools, selecting appropriate research questions, data collection, and data analysis methods is necessary (Cohen et al., 2017).

The Research Questions

As the project examines the potential learning benefits of using an orrery in astronomy teaching, the research questions should relate to what the appropriate learning benefits are and how they can be achieved. At first, the role of orrery as a means for mental modeling should be emphasized. It is necessary to evaluate whether learners developed visualizations and representations of the planetary system and used them in scientific discourse, to study, understand, explain, and hypothesize regarding planets, the sun, their position, motion, orbit, and other concepts of astronomy. Mental modeling is essential (Taylor et al., 2003; Asher et al., 2006). Second, the sustainability of this project and the general impact on the schools should be emphasized. It is necessary to evaluate whether this project can help transform the way schools work, so that they can embed the use of an orrery. This implies that teachers and members of educational organizations agree on the significance of using an orrery and are not discouraged by its challenges, such as lack of space, time, and relevance to the school curriculum or syllabus (Fullan, 2007; Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019). Bearing in mind the above, the research questions are formed as follows:

1. Did the orrery help the learners develop mental models around the astronomy concepts studied?
2. Did the project help a greater change in the schools?

Data Collection and Analysis

The data for the first research questions were collected through questionnaires. A total of 200 students who took part in the project filled in a questionnaire before and after the teaching interventions. It was based on *Sustainable Development Goals for Quality Education* (Saini et al., 2023), as this tool was considered suitable for the goals of the project. The questionnaires, as presented in Table 1, included statements to which students had to express agreement or disagreement, through a Likert scale, with numbers from 1 to 4. The statements had information regarding the knowledge obtained from the instructions (questions 12–15), the skills that learners developed (Questions 4, 5, 6, 7, 8, and 11) and the attitudes they adopted (Questions 1, 2, 3, 9, and 10). Analysis was based on the classification of answers into pairs. The responses to a question were classified as negative if students responded with a 1 or 2 on the scale, or positive if students responded with a 3 or 4. The number of each country's negative and positive answers was calculated and summed up. This helped compare responses before and after the teaching activities. This method with pre-tests and post-tests is common for projects using an orrery (Newbury, 2010; Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019).

Table 1

The questionnaire that learners filled in before and after the implementation of activities (pre- and post-test), in correspondence with SDG targets.

Goal	Questions
Interest for science (Attitudes, affectionate goals)	Q1 Rate how much you liked the science lessons. Q2 Rate how comfortable you felt in the science lessons. Q9 Rate how much you have maintained your interest in your science lessons.
Novelty for science (Skills, psychomotor goals)	Q6 I discovered new science in the science lessons. Q11 I feel like I have learned new ways of discovering the world in the science lessons.
Active citizenship (Attitudes, affectionate goals)	Q3 Rate how important you felt your actions in the science lesson were. Q10 I understood what to do in the science lessons.
Appreciation of others (Skills, psychomotor goals)	Q4 Rate how much you helped others in your science lessons. Q5 Rate how much working with others helped you to better understand science lessons. Q7 Rate your degree of connection with your peers in science classes. Q8 I took help from others in the science lessons.
Universal literacy (knowledge, cognitive goals)	Q12 I can explain why Earth is a special place in the universe. Q13 I can explain why there is day and night. Q14 I can explain what a year in the solar system is. Q15 I know many different objects in the solar system.

The data for the second research question were collected from reports of teachers. A total of 14 reports were completed, as decided upon with the initial plan of the project. Within these reports, teachers explained the impact of the project on learners, teachers, leaders, and partner organizations. The impact could be relevant to challenges in the implementation of new pedagogies and shifts in functions and infrastructure. Analysis was done through a qualitative approach that relied on coding.

Parts of the report were classified into codes, depending on their content. The codes were gathered and analyzed as in qualitative research (Cohen et al., 2017). The codes were "*Learners*", "*Teachers*", "*Leaders*", "*Challenges*", "*Functions*", "*Pedagogies*" and "*Infrastructure*". Their selection was based on the main literature regarding the use of the orrery as an activity of mental modeling in astronomy from schools (Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019).

Findings and Discussion

The findings show that the learning outcomes from implementing the study were significant. In what concerns the first research question, as seen in Table 2, the learners expressed that they achieved cognitive goals to a significant extent. The data are presented in sets. The first set shows the number of participants giving negative answers (1 or 2) as opposed to the number of participants giving positive answers (3 or 4) in the pre-test. The second shows the number of participants giving negative answers (1 or 2) as opposed to the number of participants giving positive answers in the post-test.

Knowledge such as the use of the orrery, the solar system, the rotation of each planet around the sun, and the transition from day and night was improved thanks to the activities implemented. In fact, as the data reveals, the number of students who answered in the negative in the pre-tests was almost double that in one of the post-tests. This trend appears in every country. This shows that the number of students more familiar with this knowledge rose. They also developed interpersonal skills, such as cooperation with others within teamwork as well as the exchange of assistance and ideas. Last, the learners adopted positive attitudes, such as the motivation to learn more about science and to use it as a means to become better citizens.

The findings justify that the use of a human orrery can indeed assist in learning about astronomy through mental modeling. First, students have expressed confidence that their *knowledge* has increased significantly, as they have understood and can explain certain astronomical topics, concepts, or phenomena. Second, they have gained *skills* that can be used in studying astronomy, such as visualization of the solar system and the position of the sun and planets' orbits. Third, they have also adopted positive *attitudes*, such as increased motivation to learn more about this field. The learning outcomes justify the effectiveness of the implementation. This finding is compatible with others gained from similar studies (Taylor et al., 2003; Newbury, 2010; Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019).

Table 2

Percent Positive Responses to Questions (selection of "3" or "4" on a Likert Scale of 1-4)

		France		Greece		Cyprus		All	
	Number of participants	**58**		**60**		**79**		**197**	
	Question	Pre-test %	Post-test %	Pre-test %	Post-test %	Pre-test %	Post-test %	Pre-test %	Post-test %
Interest in Science (Aattitudes)	**Q1—like**	84.48	91.38	93.33	86.67	75.95	84.81	82.50	86.00
	Q2—comfortable	84.48	86.21	66.67	83.33	83.54	92.41	77.50	86.50
	Q9—interest	62.07	63.79	71.67	86.67	72.15	91.14	68.00	80.50
Novelty of Science (Skills)	**Q6—new science**	89.66	93.10	81.67	90.00	79.75	88.61	82.00	89.00
	Q11—new ways	87.93	89.66	65.00	86.67	81.01	73.42	77.00	81.00
Active citizenship (Attitudes)	**Q3—importance**	75.86	79.31	71.67	86.67	81.01	97.47	75.50	87.50
	Q10—understanding	74.14	53.45	60.00	58.33	51.90	68.35	60.00	60.00
Appreciation of others (Skills)	**Q4—help other**	81.03	81.03	71.67	85.00	72.15	82.28	73.50	81.50
	Q5—work with other	63.79	56.90	63.33	83.33	73.42	77.22	66.50	72.00
	Q7—peer connection	29.31	18.97	25.00	43.33	31.65	34.18	28.50	32.00
	Q8—took help	67.24	79.31	83.33	83.33	70.89	86.08	72.50	82.00
Universal literacy (knowledge)	**Q12—Earth**	81.03	82.76	60.00	86.67	68.35	87.34	68.50	98.00
	Q13—day/night	51.72	72.41	43.33	71.67	46.84	75.95	46.50	72.50
	Q14—a year	56.90	70.69	61.67	83.33	51.90	87.34	55.50	80.00
	Q15—objects	84.48	91.38	93.33	86.67	75.95	84.81	82.50	86.00

Concerning the second research question, as can be seen in Table 3, there were plenty of report comments classified according to the determined codes. The code "*Learners"* was used to classify report comments that verify the positive learning outcomes. The code "*Teachers*" was used frequently as well, in report comments which show that the teachers had benefited from the project, by gaining knowledge or increasing motivation to learn further about astronomy and the way to teach it. For report comments that showed approval and support on behalf of head teachers, the code "*Leaders*" was also used. The code "*Pedagogies*" was used to classify quotes, which show that teachers appreciate that the orrery supports active learning through project-based activities. The code "*Functions*" was used for report comments that show that the schools started adopting innovative activities. Moreover, it was used for report comments that demonstrate that the program can serve as an opportunity to cooperate with other schools and build partnerships. The code "*Infrastructure*" was used mainly to classify reports comments focused on the benefits of having an orrery and using it to teach astronomy. Finally, the code "*Challenges*" was used to classify report comments in which the participants generally described several barriers to fitting the activities within the structured school program.

Therefore, through the reports, teachers express that the program can have an important impact on schools. Students benefit, thanks to the learning outcomes. Teachers also benefit, gaining guidance, training and familiarity with new approaches to teaching through an orrery and mental modeling. The greater school community benefits too, with opportunities for new modes of work and cooperation. Even though fitting the activities within the school schedule is challenging, the overall response is positive and receptive towards the project. These claims lead to the conclusion that the project can lead to a greater shift in schools (Asher et al., 2006; Fullan, 2007).

Table 3

Codes, Frequencies and Exemplary Quotes from the Reports

Codes	Frequency	Exemplary Quotes
Learners	32	"The whole class actively participated and most of the class quickly learned the names of the planets in English." "'I never thought I could learn about the stars by jumping around in the yard,' said a sixth-grader."
Teachers	28	"They said that they themselves learned interesting things about the planetary system. They understood phenomena such as the presence of the aurora and the aperitif that they were unaware of." "Also, most of the other teachers in the school showed interest, and some asked if they could participate in the program next year."
Leaders	16	"The school principal applauded the project and praised the effort of the students ….".
Pedagogies	22	"The engagement of students in STEAM activities was very much active." "… to begin with pupils' preconceptions and, … to provide them with the utmost opportunity to take active responsibility for their own learning; Use of the orrery in the classroom makes it possible …".

Codes	Frequency	Exemplary Quotes
Functions	19	"…the Human Orrary (HO) is drawn and painted in our schoolyard, … many students will be willing to explore our solar system and teachers will use it as a point of reference in the future." "We also participated in the construction of the HO at the [another school]. Finally, we will help in the construction of the HO in the [another school]"
Infrastructure	16	"The HO is a helpful tool to raise awareness of STEAM and to either introduce or reinforce concepts of maths and science".
Challenges	17	"The main difficulty is to find the time to teach them how to use a human orrery. This could be done outside of normal learning time but it depends on the choices made by the hierarchy at several levels." "The timetable and course syllabus limits the time available."

Conclusions

The study explores the effectiveness of a human orrery for teaching astronomy, focusing on the ARISTARCHUS project funded by the EU. Astronomy teaching faces challenges due to complex concepts and misconceptions. Tools such as the human orrery aim to engage learners practically, facilitating active participation and challenging misconceptions through mental modeling. Projects utilizing human orreries have shown positive results in enhancing astronomy learning, fostering deeper understanding and promoting student engagement. These projects emphasize the importance of learners' active participation, including the design of orreries themselves (Newbury, 2010; Lebofsky et al., 2011; Rollinde, 2019; Sansone et al., 2019). The ARISTARCHUS project, implemented across four countries, aims to explore fundamental physics laws, improve learners' STEAM knowledge, and enhance scientific process skills. Teaching interventions involve the design and use of human orreries, coupled with project-based learning activities. Evaluation of the project's impact focuses on assessing learners' development of mental models in astronomy and examining the potential shift in schools' approaches to teaching. Data analysis from pre- and post-tests and teacher reports indicates positive learning outcomes, with learners demonstrating increased understanding, skills development, and positive attitudes towards science. Teachers also report benefits from the project, including knowledge and motivation for innovative teaching methods. Despite the challenges observed, overall responses are positive and suggest a potential for broad changes in educational practices (Taylor et al., 2003; Asher et al., 2006; Fullan, 2007).

Future research could compare studies with alternative teaching methods, analyze cross-cultural influences, and develop teacher training programs (Cohen et al., 2017).

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