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Investigating the effectiveness of using a real and a virtual model in teaching astronomy concepts to elementary students. The cases of the eclipse phenomena

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Abstract
This paper examines and compares the degree of effectiveness of utilizing a tangible, hands on model and a virtual simulation model when teaching the astronomy concepts of eclipse phenomena. A number of 77 students of the fifth and sixth grade of Primary Schools of Patras participated in the research. The didactic intervention included appropriately structured scenarios and worksheets that were utilized by the students and facilitated the teaching of the specific astronomy concepts. The method followed included the use of a pre and post-test questionnaire as well as a focus group discussion. The results highlight the effectiveness of the use of hands-on models, which enhance the learning outcomes as well as learners' motivation to participate in the educational process.

Keywords: Astronomy concepts, Real Models, Virtual models, Eclipse phenomena.

Introduction

The field of astronomy has attracted the interest of many researchers in scientific education, particularly in the area of conceptual change research (Baxter, 1995) while this interest persists even in the present day (Shen & Confrey, 2010). Upon the first day in school, students commonly possess conceptions regarding the universe that deviate significantly from the prevailing scientific consensus (Gali, 2021). Several studies have been conducted to investigate students' misconceptions in geocentric aspects of astronomy, specifically related to moon phases (Lelliot & Rollnick, 2008), the size and scale of celestial bodies (Cheek,2012) and eclipses (Pundak, 2016).

Models are used in every aspect of astronomy education (Sutter et al., 1993) to help students and teachers alike make sense of and convey their grasp of the subject matter (Taylor et al. 2014). Teachers' Pedagogical Content Knowledge includes an understanding of students' potential alternate views, with the ultimate goal of building coping techniques for optimal learning outcomes (Slater et al. 2018). Models are one of the most helpful pedagogical strategies used to teach students how to deal with these concepts (Tsihouridis et al., 2013).

In general, models play a pivotal role in the pedagogy of natural sciences, serving as indispensable instruments for elucidating and comprehending the phenomena that encompass our physical environment. They are constructed through the utilization of observations and experimental data, enabling the comprehensive depiction, comprehension, and prognostication of a system's behavior under diverse circumstances. The construction of models is a primary endeavor, undertaken by scientists, in order to investigate the operations of various systems and enhance their comprehension of the governing principles that regulate them (Halkia, 2012). Multiple definitions of models can be traced in the international literature.

Models are essential in all areas of physics for comprehending and explaining the world around us. It is important to note, however, that each model is an approximation of reality and, as such, cannot be an accurate representation of a system, as there are margins of errors when predicting the behavior of a system or various limitations that result in the emergence of a unique aspect of it each time. Therefore, it is frequently necessary to employ multiple models to optimize precision (Halkia, 2012).

In modern times, a variety of educational software and technological models, including simulations that accurately reflect laboratory settings, are used to teach Natural Sciences. The use of such virtual simulations enables learners to assume the role of a researcher, as they are often given the opportunity to handle various parameters and observe the results (Tsihouridis et al., 2007). In addition to the positive effects of simulations in the educational process, it is especially essential to note that, familiarizing students with ICT-related skills is a crucial tool and qualification for their future lives (Vavougios et al., 2009).

According to research (Tsichouridis et al. 2017), it was discovered that, incorporating alternating experimental environments in the school laboratory, along with the utilization of suitable equipment and experimental activities aligned with the teaching objectives, results in superior learning outcomes, when compared to conducting experiments solely in a single experimental environment. This rotational approach mitigates the drawbacks associated with each experimental setting, while simultaneously emphasizing their benefits. Consequently, it facilitates the enhancement of students' alternative concepts, fosters a deeper comprehension of the subject matter, and cultivates skills development. Ultimately, this instructional method maximizes the potential for optimal educational outcomes. Moreover, the consistent oscillation between virtual and physical experimental settings sustains students' engagement and fosters critical thinking, thereby augmenting the overall educational experience. In recent years, there has been a significant amount of scholarly investigation dedicated to examining the benefits of this rotational approach, which effectively integrates the favorable aspects of both models. According to Tsihouridis et al. (2015), certain studies contend that authentic experimental settings facilitate effective learning through the utilization of practical tools. Conversely, virtual environments facilitate the visualization of scenarios, thereby enhancing the instructional process.

Research conducted in the field of Engineering has indicated that students are able to effectively apply the knowledge they acquire in a virtual environment to real-world scenarios, achieving comparable levels of success to students who were exclusively taught in a physical environment (Triona & Klahr, 2003; Taramopoulos & Psyllos, 2013). According to a study conducted by Finkelstein et al. (2005), research in the domain of electrical circuits revealed that students who utilized a virtual experimental environment during instruction exhibited greater proficiency in constructing and comprehending the functioning of basic electrical circuits compared to their counterparts who utilized a physical science laboratory (Taramopoulos & Psyllos, 2013).

According to Tsihouridis et al. (2015), it has been determined that individual environments possess significant instructional value. However, a synthesis of these environments is likely optimal, as the integration of both approaches can afford students a distinct and more comprehensive outlook.

Aim of the study and research questions

The objective of this study is to examine the efficacy of different instructional methods in teaching astronomy concepts, with a specific focus on the topic of solar eclipses. The instructional approaches under investigation include teaching using a hands-on self-constructed physical model, and teaching through the use of a virtual simulation model. Based on the aforementioned the research questions were formulated as follows:

- What are the learning outcomes of teaching eclipses using a real hands-on eclipse model?
- What are the learning outcomes of teaching eclipses using a virtual simulation model?
- Which teaching approach has the best learning outcomes when teaching eclipse phenomena?

Research Sample

The research sample consisted of 77 male and female students of the fifth and sixth grades of two Primary Education schools from the area of Patras and was conducted in the period March - April 2023.

Methodology

For the purposes of the research, the mixed research approach was followed. More specifically:

Quantitative approach

The initial instrument employed in the quantitative research study was a properly structured questionnaire consisting of 21 questions on the subject of solar system and solar eclipses and was administered before and after the didactic intervention (pre, post-test). The questionnaire consisted of closed and open-ended questions. The questions were formulated using simple language, and any necessary clarifications were provided when needed. The questionnaire was tested for validity (structural and content) and reliability (internal consistency index Cronbach alpha $\alpha = 0.78$).

Regarding the models utilized in the research, the first model, referred to as the hands-on model, was collaboratively constructed by the students under the supervision of their instructor. This model placed significant emphasis on the utilization of basic materials, including a flashlight that represented the sun, a plastic ball to represent the earth, and a golf ball to represent the moon. Furthermore, the design of the model aimed to mitigate any potential misunderstandings pertaining to the true dimensions of the celestial entities and their corresponding representations within the model. The educator also mentioned specific limitations of the model, including its inability to accurately represent astronomical distances. The second model, referred to as the virtual 3D online model, is a simulation of space that showcases the orbital movements of the earth and the moon, as well as related phenomena including eclipses, day-night cycles, seasonal variations, and lunar phases. The choice of this specific model was based on its educational objectives, rigorous scientific methodology, and a user-friendly interface.

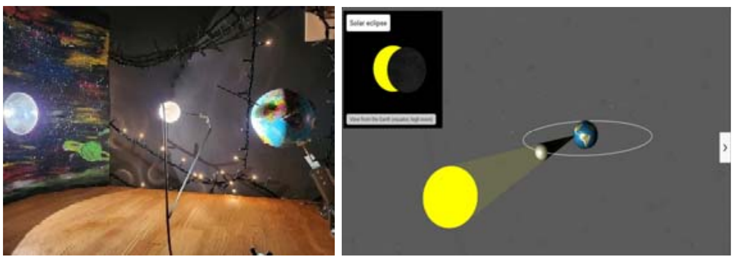

Figure 1. Screenshots of the models used for the purposes of the research.

The second instrument employed in the study consisted of appropriately designed scenarios and worksheets that were utilized by the students throughout the didactic intervention to facilitate the teaching of eclipse concepts.

Qualitative approach

During the qualitative approach, before and after the end of the intervention, discussions were held with a focus group consisting of eight randomly selected students (four boys and four girls). The questions asked to the participants, with the researcher in the position of moderator during the discussion process, were open-ended, simple, clearly formulated and did not create reticence or the feeling of shyness. These questions were grouped and moved along the same pillars as those of the quantitative research questionnaire, the solar system and solar eclipses.

For ethical reasons, the objectives of the research were explained to the students, while it was emphasized that their participation was voluntary. It was also clarified to them as well as and to the focus group that their answers would be anonymous and that no reference would be made to their personal data. For the same reasons, the opinions of the participants are referred to in the results section as S1, S2 (Student 1, Student 2, etc.). The content analysis method was used for the focus group discussion data analysis, while the SPSS statistical package and Microsoft Excel were used for the quantitative analysis of the questionnaire data.

Research Stages

The intervention lasted five hours. Two of these hours were assigned to the participants to complete the questionnaire. Specifically, one hour was assigned for the filling in of the questionnaire during the pre-intervention phase and one hour for the completion of the questionnaire after the didactic intervention. The remaining two hours were used for the implementation of the actual intervention.

Analytically

1st phase of the intervention (1- hour): During the first phase a questionnaire was administered (as a pre-test) for the purpose of recording any preliminary ideas regarding the subject taught. Interviews and discussions followed in order to further investigate students' ideas on the subject.

2nd phase of the intervention (2-hours): During the first hour of the second phase the initial activity of the intervention began. It consisted of a segment extracted from an authentic video capturing a solar eclipse. The utilization of brainstorming techniques was employed to prompt children to articulate their observations of the video and their conceptualizations of the solar eclipse subsequent to its viewing. A PowerPoint presentation on solar eclipses and the solar system was presented to the students. The lecture concluded with an interactive session involving a discussion-dialogue centered around the primary subject matter as well as around the addressing of any inquiries raised by the students. In conclusion, a worksheet containing exercises and activities were provided to the learners to reinforce the subject matter. The class engaged in collaborative discussion to collectively address the worksheet, serving as a formative assessment of the instructional goals.

During the second hour students were divided in two groups and were relocated to the computer laboratory, where they engaged in a practical experiment concerning solar eclipses, either through the real hands-on model (1st group) or the virtual one (2nd group). Consequently, participants had the opportunity to observe all three types of solar eclipses in a simulated format, including the shadow and associated phenomena.

3rd phase of the intervention (1-hour): In order to examine even further students' ideas semi-conducted interviews, and open discussions were carried out.

4th phase of the intervention (1-hour): The same initial questionnaire was administered to the same learners one week after finishing the intervention for the purpose of detecting any change in students' ideas on eclipse phenomena.

Quantitative analysis results

The results of the quantitative analysis of the questionnaire responses are presented in detail below:

Astronomy concepts regarding the Solar System

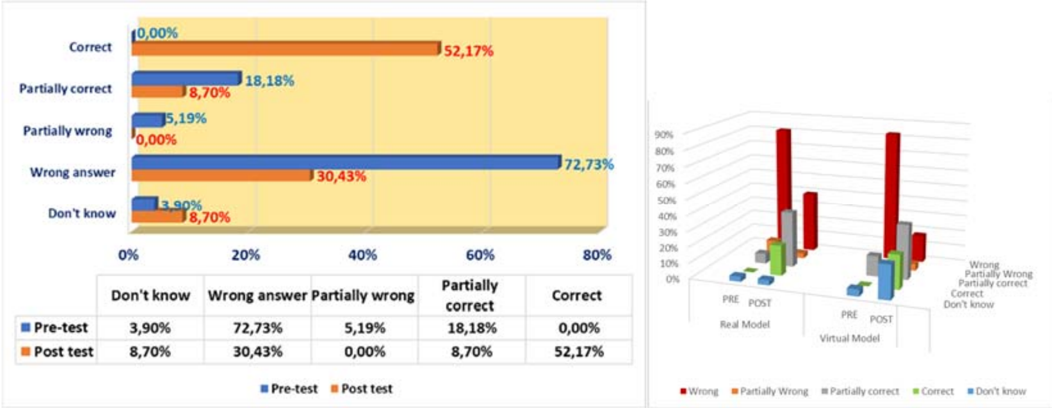

Figure 2. Students' opinion about what planets are.

The percentage of partially correct and correct answers in the pre-test was 18.18%. This percentage was modified to 57.14% after the analysis of the post-test responses. The observed data indicates a notable increase of 38.96%, which is deemed to be statistically significant. Hence, the instructional intervention demonstrated efficacy.

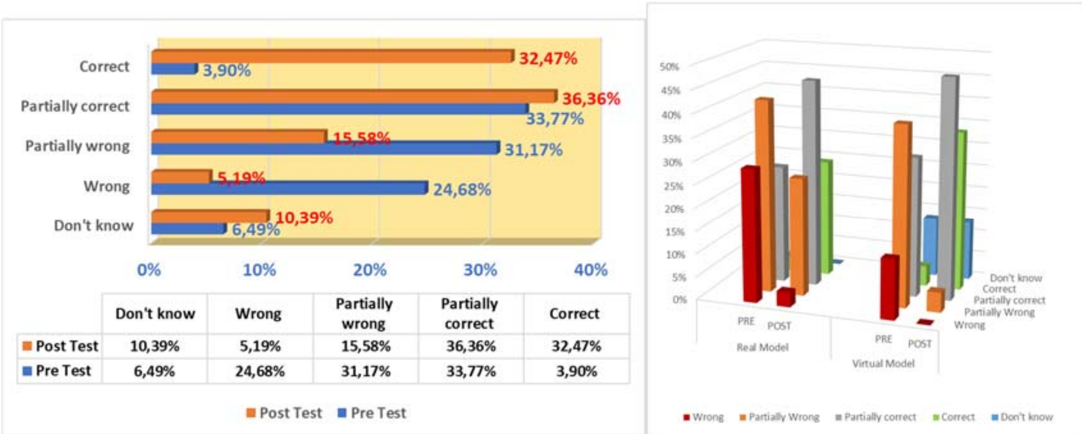

Figure 3. Students' opinion about the celestial bodies the solar system consists of.

The teaching intervention proved to be effective since there is a significantly statistical difference in the answers given before and after its processing. More specifically, the partially correct and correct answers in the pre-test increased by 31.17% in the post-test. The percentage of partially correct and correct answers in the pre-test was 18.18%.

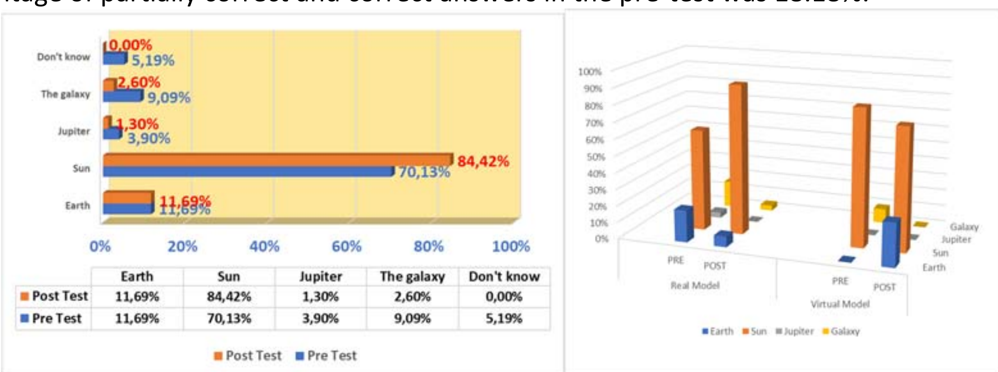

Figure 4. Students' opinion about the celestial body at the center of the solar system

There is no significant statistical difference before and after the teaching intervention. but it was noticed that there was an improvement since the opinion that the sun is in the center of the solar system was strengthened by 14.29%.

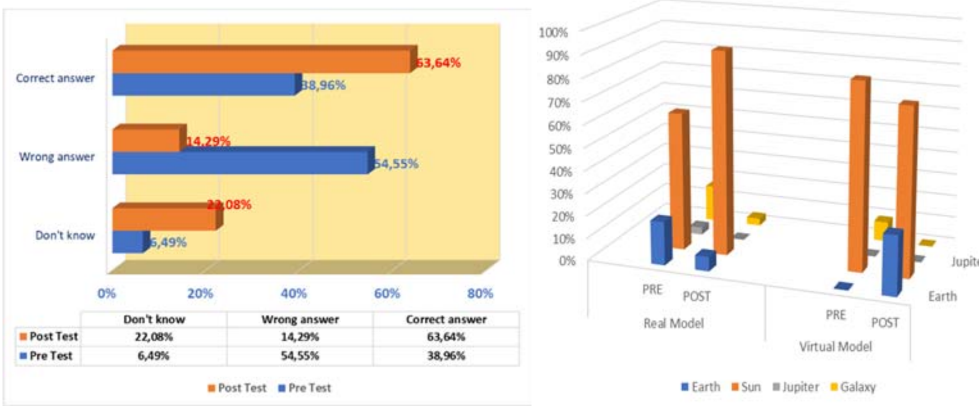

Figure 5. Students' position of the earth in the solar system

Based on the results shown in the diagram, the teaching intervention was effective since there was a significantly statistical difference between the correct answers in the pre-test and post-test. The percentage of correct answers increased from 38.96% to 63.64%.

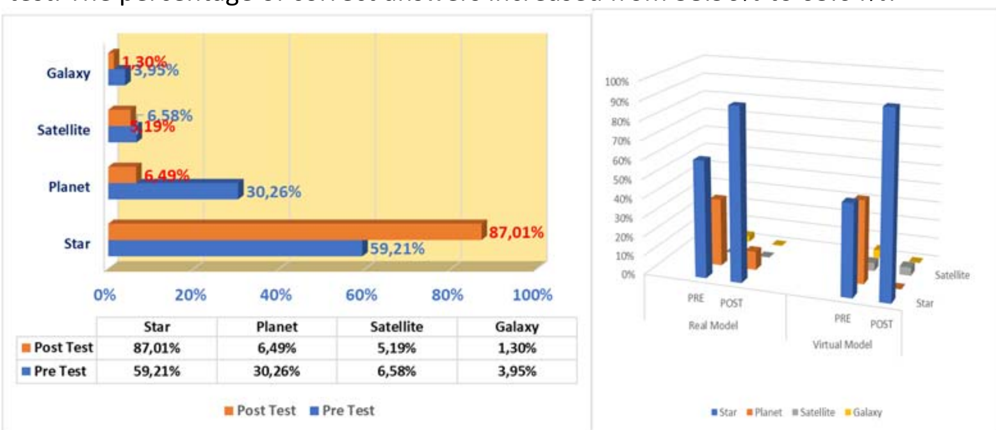

Figure 6. Students' opinion about the type of celestial body the sun is.

As it is obvious there is a significantly statistical difference of the correct answer in the pre-test and the post-test. Specifically, the answer "star" in the pre-test had a percentage of 59.21% compared to 87.01% in the post-test with a total increase of 27.8%.

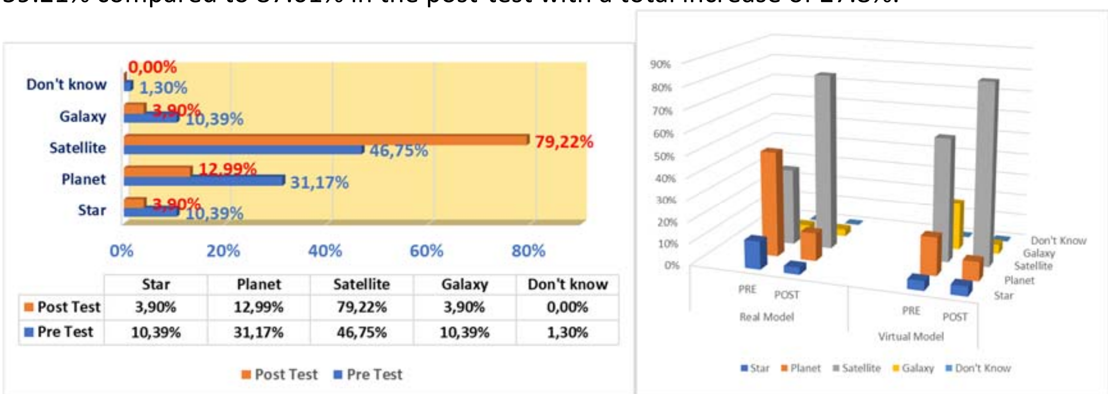

Figure 7. Students' opinion about the type of celestial body the moon is.

In this question, there was a significant improvement since the percentage of the correct answer (satellite) changed from 46.75% before the teaching intervention to 79.22%. Overall, it increased by 32.47% which shows a statistically significant difference.

Astronomy concepts regarding the solar eclipse phenomenon

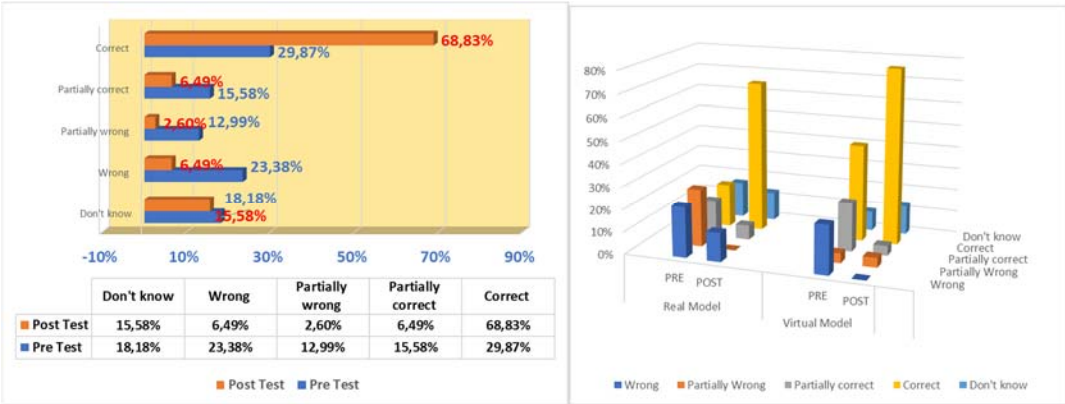

Figure 8. Students' opinion about what the solar eclipse is.

The percentage of the partially right and right answers were significantly increased by a total percentage of 29,87%, which is a statistically significant difference.

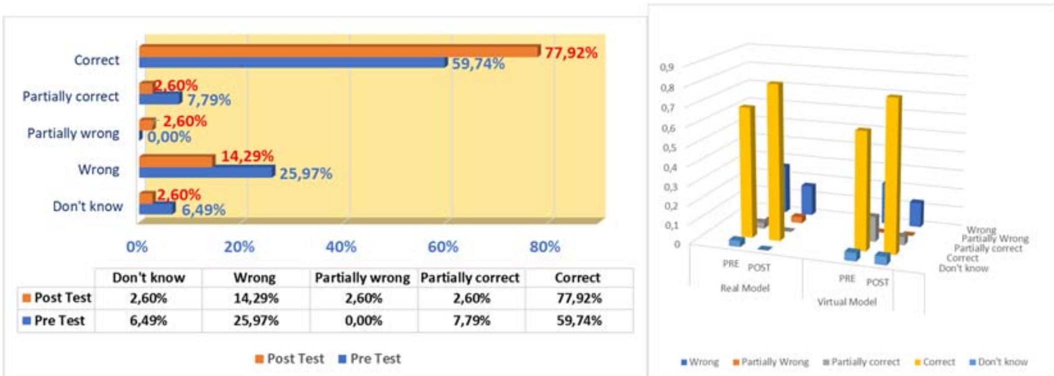

Figure 9. Students' opinion about the position of the earth, the moon and the sun during a solar eclipse.

The percentage of correct and partially correct answers did not increase significantly. Nevertheless, there was a relative increase since the percentage of the pre-test changed from 67.53% to 80.52% in the post-test. Therefore, the teaching intervention was not effective enough to form a significantly statistical difference between the pre-test and post-test results.

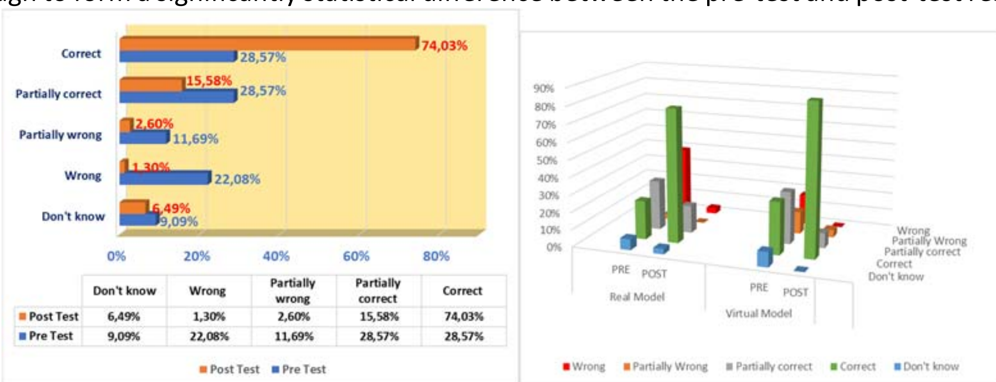

Figure 10. Students' opinion about the celestial bodies that participate in a solar eclipse.

In this question it was observed that the percentage of correct answers changed from 28.57% to 74.03%. This suggests that the didactic intervention particularly helped in understanding the above question. As for the general picture of partially correct and correct answers there is again a significantly statistical difference since the correct answers of the post-test increased by 32.47% compared to the pre-test.

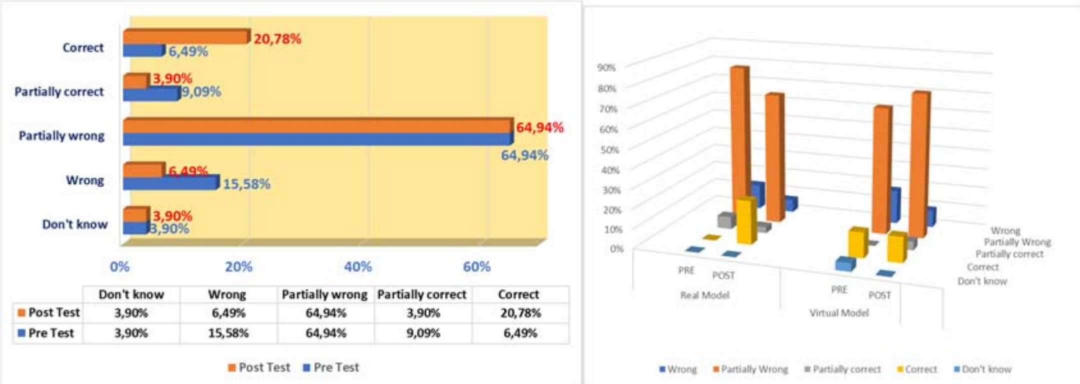

Figure 11. Students' opinion about the ability to observe a solar eclipse by all places on earth

Based on the above diagram in this question it was observed that the percentage of correct answers in the pre-test increased from 6.49% to 20.78% during the post-test. But if the partially correct answers were also included then the total percentage increased by 9,09%, which doesn't comprise a particularly significant statistically difference. So, the teaching intervention was effective but in a small percentage since the majority of 64.94% answered partially incorrectly.

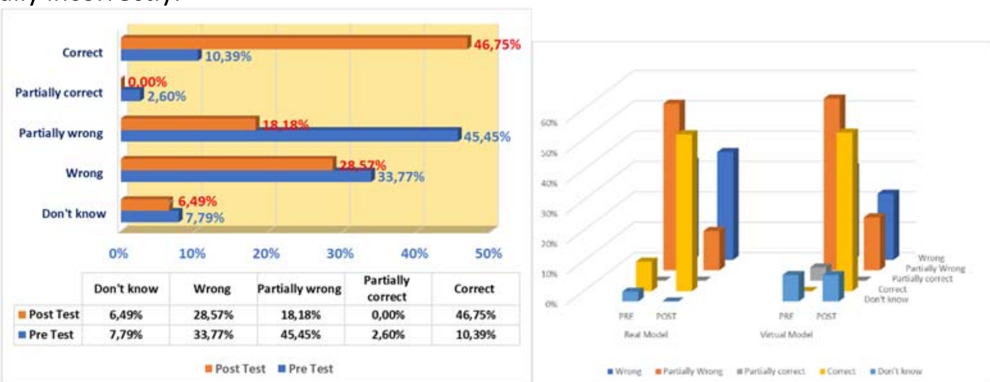

Figure 12. Students' opinion about the ability to observe a solar eclipse during day but also during night

The didactic intervention in the above question proved to be effective to a great extent since the percentage of partially correct and correct answers increased significantly in the post-test compared to the pre-test. The final increase is estimated at 33.77%.

Qualitative analysis results

As an integral component of the research, a comprehensive analysis was conducted on the various pedagogical approaches employed within the classroom setting. This analysis encompassed both qualitative and quantitative methodologies in order to provide a thorough examination. Despite the limited sample size of 77 participants, this study successfully derived findings pertaining to the most effective instructional approach for comprehending concepts and phenomena in the field of natural sciences. More specifically, the study focused on the solar eclipse, extensively examining and analyzing this subject matter within the context of the research.

The findings of the qualitative research indicate that utilizing a tangible model for teaching purposes is deemed the most optimal approach when compared to the alternative methods of traditional teaching and virtual model-based teaching. In greater detail, the behavior exhibited by the students was carefully observed and documented throughout the interview process, as well as during the direct interactions with the students in the educational interventions. They reported that *"...using a real model was a very interesting way of learning about eclipses..."* S1*, "... it was impressive that something like that can be constructed with every day materials and demonstrate the phenomenon so that it can be easily understood..."* S2. Regarding the utilization of a virtual instructional approach, the findings indicated that the children exhibited a proclivity and enthusiasm for engagement and exploration: "*…the moon rotation is shown very well in the simulation…",* S3, "*…the moon position can be changed easily through the controls…so that we can make an eclipse ourselves…"*, S4. However, over time, their attention became fragmented and their interest waned, as they experienced fatigue and weariness due to prolonged periods of computer utilization and the absence of tangible interaction with the instructional model: "*…after some time, playing with the simulation became boring…*" S5.

Regarding the subject taught, a large number of students from both groups that used the hands-on and 3D virtual model could describe the astronomy concepts related to the solar system: "*Planets are celestial bodies that move around the sun and make the solar system...*", S7 , *"...the Sun is at the center of our solar system...with the earth being ...at the 3rd place from our star (sun)..*" S8, "*…the sun is a big star compared to the earth which is a planet..*", S3, "*..the earth has a single natural satellite that revolves around it and is called moon..*", S7. Regarding the solar eclipse, a greater percentage of students from the group that used the real model, compared to the one that used the simulation, recognized that the phenomenon occurs when the earth, the moon and the sun are aligned: *"…the moon, the earth and the sun take part in a solar eclipse…which happens whenever they are at the same line…"*, S2*. "… it happens when the moon goes in front of the sun…"*, S4. Many students from the group that used the virtual model expressed their doubts about the sizes of the three participating celestial bodies while stating *"… how can a small celestial body like the moon hide the sun...*" S7.

The utilization of real models in teaching has been associated with a multitude of benefits. In a more specific manner, the students experienced a substantial enhancement in their level of self-motivation and active engagement within the course. Moreover, their attention was directed towards the content being imparted by the course. The incorporation of real-life models into the educational process imbued it with a sense of playfulness, thereby creating an environment conducive to critical analysis, visual observation, and the cultivation of students' imaginative abilities. Furthermore, a notable disparity in cognitive abilities was observed with regards to comprehension of the phenomenon. Specifically, students, who were exposed to instruction utilizing a tangible model of a solar and a lunar eclipse, demonstrated a higher level of accuracy in answering questions pertaining to conceptualizing the phenomenon on paper through visual representation (i.e., painting). In contrast, students who were exposed to an electronic model of a solar and lunar eclipse exhibited lower levels of accuracy in their responses.

Ultimately, in addition to the observed disparities in learning and behavioral outcomes between the two instructional approaches, our analysis determined that the utilization of a real hands-on model, as a teaching intervention, proved to be the most efficacious. This conclusion was primarily attributed to the alteration of classroom environments. This observed change was noted during the transition from the theoretical phase of instruction to the experimental phase. In a more specific context, electronic media served as the primary tools for delivering new concepts and completing the worksheet. Conversely, the experimental phase involved the utilizations of tangible models and experiment sheets. The transition from a virtual learning environment to a physical one has resulted in improved learning outcomes. This shift allows for the mitigation of drawbacks inherent to each environment while simultaneously capitalizing on their respective advantages. Additionally, this study demonstrated that implementing a rotational approach in the classroom maintains a high level of student engagement and fosters enhanced creative thinking, thereby facilitating and enhancing the learning experience.

Conclusions

The first conclusion relates to specific questions on the questionnaire that required students to describe the phenomenon of the solar eclipse or the solar system. It was observed that all students who attended the teaching intervention using the real model had a higher percentage of correct answers compared to those who were taught with a virtual model, with the percentages of correct answers being significantly lower. The virtual model reproduced or re-created the students' misconceptions regarding the size of celestial bodies, their alignment during a solar eclipse, etc. Regarding the second conclusion derived from the quantitative analysis, it is evident that the primary determinant influencing the performance of the educational process, specifically in relation to the subject matter, is the pre-existing knowledge and cognitive level of familiarity with the subject within the class. The impact of the teaching approach, on the other hand, is relatively less significant as compared to the aforementioned factors, provided that the educational scenario is appropriately structured and integrated. In the context of comprehensive instruction, the effective teaching of natural science courses relies on two key factors. Firstly, it necessitates careful planning of instructional interventions that take into account the unique attributes of each student. Secondly, it involves engaging students, including those with learning challenges, in practical experimentation within both physical and virtual settings. This approach employs straightforward and comprehensible queries that elicit concise responses, thereby fostering heightened motivation among students throughout the learning journey.

In summary, this study approached the research issues qualitatively and quantitatively. Upon confirming the alignment of conclusions between the two approaches, it was determined that the most effective educational approach for enhancing understanding of the phenomenon of solar eclipses and other subjects with natural science is the implementation of a comprehensive traditional teaching method, complemented by practical demonstrations, using a real model within the educational process. However, in order to attain a more profound comprehension and solidification of concepts, it is crucial for students to engage in realistic representation and experiential approaches.

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