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Astronomy as a motivating theme in Mathematics classes: a didactic sequence focused on meaningful learning

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Abstract. This research applied a Didactic Sequence that used Astronomy as a contextual theme for Mathematics instruction, with the objective of fostering Meaningful Learning. The intervention involved 51 students (14–16 years old) in São Paulo/SP, Brazil, and integrated three activities based on Digital Information and Communication Technologies and Active Methodologies, following the Brazilian National Common Curricular Base guidelines. Analysis of questionnaires and classroom records demonstrates that the Astronomy-Mathematics integration strengthened student engagement and learning outcomes, while also suggesting positive socio-emotional development.

Resumo. Este estudo aplicou uma Sequência Didática usando a Astronomia como contexto para o ensino de Matemática, com o objetivo de promover Aprendizagem Significativa. A intervenção, realizada com 51 estudantes (14–16 anos) de São Paulo/SP, Brasil, combinou três atividades com Tecnologias Digitais da Comunicação e Informação e Metodologias Ativas, alinhadas à Base Nacional Comum Curricular. A análise, baseada em questionários e registros de aula, mostra que a integração entre Astronomia e Matemática potencializou o engajamento e a aprendizagem, com indícios de ganhos socioemocionais.

Keywords. Teaching of Astronomy

1. Introduction

Overcoming Mathematics education based on rote memorization of procedures and disconnected from real-world contexts remains a central challenge for Brazilian education. In this scenario, the Brazilian National Common Curricular Base emerges as a fundamental guideline, steering the development of curricula that privilege interdisciplinarity and the mobilization of knowledge to solve complex problems, aiming at the integral development of the student (Brasil, 2018).

Specifically in Mathematics teaching, a frequent disconnect is observed between the abstract concepts covered in the classroom and their application in real situations, which can lead to disinterest and learning difficulties. This gap between theory and practice limits the development of the competencies outlined in the Brazilian National Common Curricular Base, which emphasize the ability to use mathematical knowledge to investigate, argue, and solve problems in diverse contexts. The search for strategies that make Mathematics more concrete and relevant for students is, therefore, not merely a methodological issue but a necessity for integral education.

To translate this guidance into effective pedagogical practice, David Ausubel's theory of Meaningful Learning (ML) provides a solid theoretical framework. According to Ausubel (2003), genuine learning occurs when new information anchors itself in a non-arbitrary and substantive way to relevant pre-existing concepts in the learner's cognitive structure, known as subsumers. This process contrasts with rote learning, based on repetition, and requires potentially meaningful instructional material organized to facilitate these connections (Moreira, 2011).

Interdisciplinarity with Astronomy presents itself as a privileged context to create these anchors. Historically, Mathematics has been a fundamental language for understanding celestial phenomena. In contemporary education, this relationship offers a fertile ground to make abstract mathematical concepts – such as proportion, scale, and geometry – tangible and motivating by contextualizing them in the observation and interpretation of the universe (Barbosa & Voelzke, 2016; Anastácio & Voelzke, 2020). Astronomy, by its nature, sparks curiosity and allows for the visualization of concrete applications of Mathematics, fostering ML.

However, the mere juxtaposition of content does not guarantee ML. An intentional pedagogical design that places the student at the center of the process is required. For this purpose, this research adopted Team-Based Learning, an Active Methodology (AM) with well-documented efficacy (Mota & Rosa, 2018). Team-Based Learning is structured around a cycle that promotes individual accountability and collective synergy: after individual study, students take an individual Readiness Assurance Test, followed by the same test taken in teams (team Readiness Assurance Test), fostering immediate discussion and peer learning. This cycle, followed by applied activities, is enhanced by the strategic use of Digital Technologies, which expand possibilities for investigation, simulation, and creation.

Considering this theoretical-methodological framework, it becomes relevant to empirically investigate the impacts of an intervention that articulates these elements in an integrated manner. The age group of late Elementary School and early High School represents a crucial moment for consolidating conceptual foundations in Mathematics and for developing an investigative stance towards science.

Within this framework, this paper aims to present and analyze the results of applying an interdisciplinary Didactic Sequence (DS) that integrates Mathematics and Astronomy concepts through Team-Based Learning (with its individual and team Readiness Assurance Tests cycles) and various Digital Technologies tools. The intervention was carried out with 9th grade Elementary School (9th ES) and 1st grade High School (1st HS) classes, seeking to investigate to what extent this theoretical-methodological articulation can effectively promote more meaningful, critical, and contextualized mathematical learning, in line with the competencies set forth by the Brazilian National Common Curricular Base.

2. Methodology

This study is characterized as field research of a quantitative and descriptive nature, developed at Colégio Monteiro Lobato, a private institution located in the northern zone of São Paulo/SP, Brazil. The choice of this specific research design is justified by the intention to investigate the direct effects of a pedagogical intervention in its natural context of application, preserving the authentic dynamics of the classroom and the characteristic interactions of the school environment.

The research involved two distinct classes, totaling 44 participants: 17 students from the 9th grade of Elementary School and 27 from the 1st grade of High School, all aged between 14 and 16 years. The selection of these grades considered specific pedagogical criteria: these are stages in which fundamental mathematical concepts – such as proportionality, analytical geometry, and scientific notation – are in the process of consolidation, and in which Astronomy, as a curricular component of the Natural Sciences area, has already been introduced preliminarily. Furthermore, this age range represents a crucial moment for the development of hypothetical-deductive thinking and for the formation of investigative attitudes towards science. From an ethical standpoint, the project was approved by the Research Ethics Committee of Cruzeiro do Sul University under Opinion number 6.899.863, and all participants, as well as their legal guardians, signed the Free and Informed Consent Form and the Free and Informed Assent Form, respectively, ensuring data confidentiality and the anonymity of those involved.

To guide the planning of the intervention and comprehensively assess its subsequent effects, a multi-instrument methodological approach was adopted. Initially, a diagnostic questionnaire consisting of 13 multiple-choice questions on Astronomy content was administered, adapted from instruments validated in previous studies. This questionnaire was designed to cover structuring concepts such as the organization of the Solar System, Earth's rotation and revolution movements, the explanation of seasons, and the understanding of distance scales in the universe. Concurrently, diagnostic activities were conducted through the digital platforms *Khan Academy* (Khan Academy, 2025) and *Kahoot!* (Kahoot!, 2025, with the specific objective of verifying mastery of mathematical skills considered prerequisites for the development of subsequent activities – notably, the use of scientific notation, the calculation of ratios and proportions, and the resolution of problems involving indirect measurements.

The results obtained in this preliminary diagnostic questionnaire, fundamental for directing the planning of the DS in an assertive manner, are presented in Figures 1 and 2. Figure 1 synthesizes the overall performance of the 9th grade Elementary School class, while Figure 2 corresponds to the 1st grade High School class. The careful analysis of this data, conducted using appropriate statistical methods, allowed for the quantitative identification of the astronomical concepts that showed the greatest weakness in the students' cognitive structure, particularly regarding spatial reasoning and scale comprehension. This diagnostic insight was crucial for strategically designing the subsequent activities, thereby establishing the priority focuses for the pedagogical intervention and enabling the customized adaptation of the DS content and methodology to the specific needs and learning profiles of each class.

The pedagogical intervention itself consisted of the implementation of an interdisciplinary DS, meticulously planned

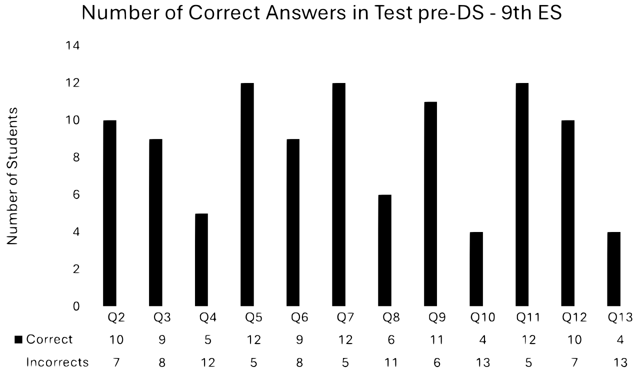

Figure 1. Performance on the pre-intervention Astronomy diagnostic questionnaire – 9th grade Elementary School

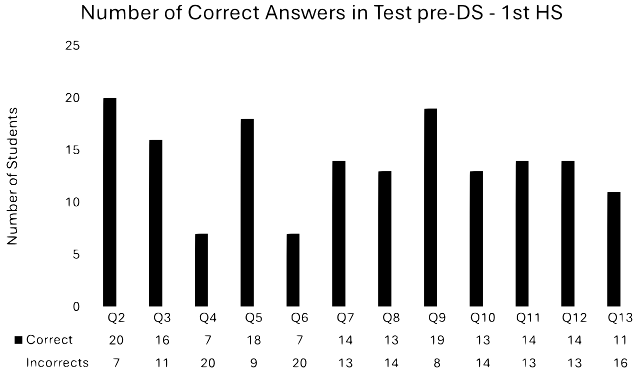

Figure 2. Performance on the pre-intervention Astronomy diagnostic questionnaire – 1st grade High School

to integrate Mathematics and Astronomy concepts in accordance with the competencies and skills outlined in the Brazilian National Common Curricular Base. The DS was organized into three sequential and progressive activities, each with clearly defined learning objectives. Its planning was grounded in the principles of AM, specifically employing the Team-Based Learning approach. This methodology was operationalized through structured cycles that included: (1) individual student preparation with prior study materials; (2) administration of Readiness Assurance Tests, first individually and immediately afterward in team mode, fostering discussion, argumentation, and collaborative learning; and (3) completion of knowledge application activities in complex contexts. This entire process was enhanced by the strategic use of Digital Technologies, such as astronomical simulators, spatial visualization software, and interactive platforms, which significantly expanded the possibilities for investigation, modeling, and representation of the studied phenomena.

To evaluate the effects of the intervention, the same Astronomy questionnaire was readministered as a post-test, maintaining a six-month time interval between the pre- and post-application. This methodological decision, based on recommendations from specialized literature, aimed to minimize potential memorization effects of the instrument items, allowing for a more reliable assessment of learning retention and significance. Throughout the implementation of the DS, systematic classroom observation was conducted, recorded in a field diary by the researcher, and systematic collection of student productions (such as digital scientific journals, calculation records, and oral presentations) was carried out. These constituted rich sources of qualitative data on the learning process, levels of engagement, and the established interaction dynamics.

Data analysis followed a mixed perspective. For the quantitative data from the questionnaires, which were configured as repeated measures (pre- and post-test of the same subjects), the paired Student's t-test for dependent samples was chosen. The tested statistical hypotheses postulated (Triola, 2018), as the null hypothesis, the absence of a difference between the mean scores at the two time points (H_0: $\mu_d = 0$) and, as the alternative hypothesis, a significant increase in performance after the intervention (H_1: $\mu_d > 0$), configuring a one-tailed test. The adopted significance level was 5.0% ($\alpha = 0.05$), and the critical values of the t-distribution were determined based on the specific degrees of freedom for each class. In parallel, qualitative analysis, of an interpretive nature, was conducted on the observation records and student productions, aiming to understand not only the quantitative results but also the nuances of the learning process, evidence of meaning-making, and the factors that influenced student engagement throughout the Didactic Sequence.

3. The Didactic Sequence

The DS was conceived as a progressive investigative journey in which astronomical concepts and mathematical tools intertwine organically and meaningfully. The first activity immersed students in the grand scale of the Solar System, challenging them to translate unimaginable distances and disproportionate sizes into manageable representations through scientific notation and proportionality calculations. They explored interactive three-dimensional models, manipulating variables and collecting data on planetary orbits, diameters, and compositions. The concrete product of this investigation was the collaborative elaboration of a Digital Scientific Journal, where teams not only compiled information but interpreted it mathematically, creating scalar comparisons, infographics, and simulations that made the dimensions of the cosmos tangible.

In a leap from the macro to the method, the second activity revived Eratosthenes' elegant experiment, transforming the classroom into an applied geometry laboratory. Students were guided to understand how local and simple observations – the shadow of a stick at two distant points – could reveal the measurement of the planet itself. They applied triangle similarity relations, circle properties, and the rule of three to real coordinates and times, using digital maps and online ephemerides to obtain the necessary data. The process of calculating the Earth's circumference and radius from their own measurements fostered deep reflection on the nature of scientific evidence and the power of mathematical abstraction to decipher the world.

The sequence culminated with a dynamic analysis of Earth's motions and their cyclical effects on the planet. Through simulators that allowed the manipulation of parameters such as axial tilt and orbital eccentricity, students visualized in real time the genesis of seasons, the variation in day length, and the mechanics of eclipses. The final integrative task challenged them to synthesize these phenomena into a rich visual representation (such as an annotated diagram or animation), in which angular, periodic, and trigonometric concepts were explicitly linked to astronomical explanations. This stage also encouraged extrapolation to socio-environmental consequences, connecting, for example, solstices to agricultural patterns or the precession of equinoxes to long-term climate changes.

Throughout this trajectory, the cyclical structure of individual study, comprehension testing, and collaborative team activity maintained each student's engagement and accountability. The permeable use of Digital Information and Communication Technologies – from astronomical databases to visualization and creation software – functioned as a magnifying glass that expanded the scope of the investigation. Each phase concluded with sharing sessions, where productions were presented, debated, and critiqued, consolidating learning through language, argumentation, and the perspective of others.

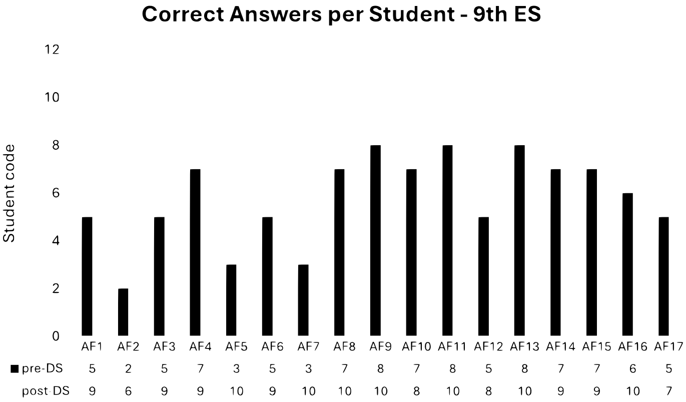

Figure 3. Pre- vs. post-test score comparison – 9th grade Elementary School

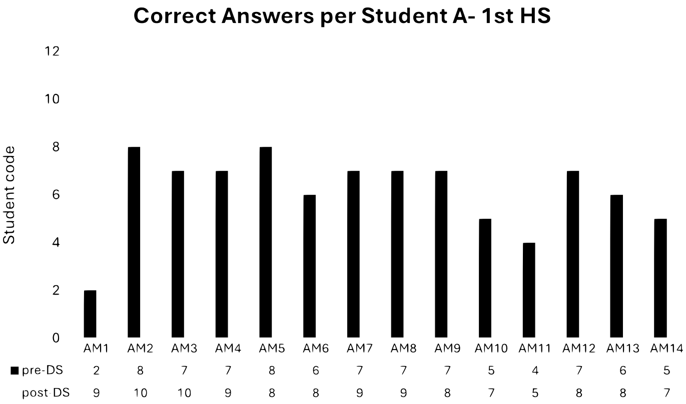

Figure 4. Pre- vs. post-test comparison (first student group) – 1st grade High School

4. Results

This section presents the main findings from the implementation of the interdisciplinary DS. The analysis focuses on quantitative data from questionnaires and qualitative observations of the intervention. The results highlight changes in astronomical knowledge and engagement with mathematical concepts within an active learning framework.

The quantitative results derived from the administration of the pre- and post-intervention questionnaires revealed substantive advances in the mastery of astronomical concepts by students from both classes. The comparative analysis, represented graphically in Figure 3 for the 9th grade of Elementary School and in Figures 4 and 5 for the 1st grade of High School, demonstrates a significant shift in the pattern of correct answers.

Not only is there an overall increase in the percentage of correct responses, but also a consistent reduction in the dispersion of individual performances, suggesting that the DS acted in a homogenizing manner, benefiting both students with greater initial gaps and those who already demonstrated some familiarity with the topics.

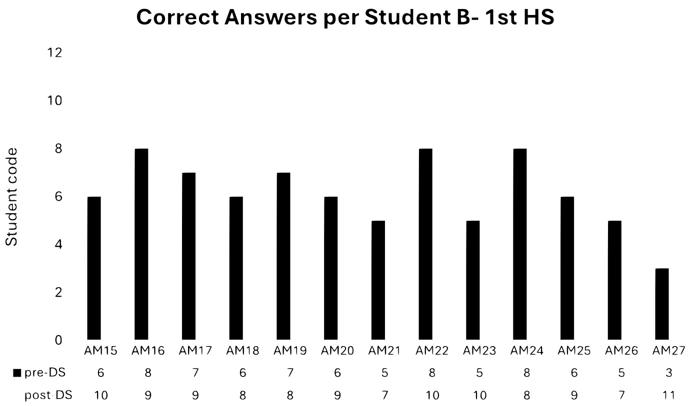

Figure 5. Pre- vs. post-test comparison (second student group) – 1st grade High School

The application of the paired Student's t-test corroborated these visual impressions with mathematical rigor (Larson & Faber, 2015). For the 9th grade class, the calculated t-value (7.86) greatly exceeded the established critical value (1.746), leading to the rejection of the null hypothesis at the 5.0% significance level. Similarly, in the 1st grade class, the calculated t-value (6.77) also exceeded its respective critical value (1.706), confirming that the positive difference between the post-test and pre-test means is statistically significant and unlikely to have occurred by chance. These results provide a solid basis for asserting that the pedagogical intervention produced a measurable and positive effect on the learning of Astronomy content.

Complementing the quantitative data, the qualitative analysis of observation records and student productions brought to light important nuances of the process. A marked increase was noted in the quality of arguments presented by students throughout the activities, with progressive use of appropriate scientific terminology and causal relationships grounded in the concepts covered. In the final debates, for example, students not only described phenomena such as seasons but articulated the Earth's axial tilt with variations in solar radiation incidence, using sketches and simple calculations to support their explanations. Collaborative engagement, already monitored by the Team-Based Learning cycles, manifested concretely in task division, mutual assistance during complex problem-solving, and cohesion in oral presentations.

It is worth highlighting that the gains were not limited to the cognitive sphere. The records indicate the development of socio-emotional competencies, such as persistence in the face of challenging tasks (like the calculations in Eratosthenes' method), the ability to receive and incorporate peer feedback, and greater autonomy in managing time and resources during research. The triangulation between questionnaires, observation, and analysis of productions allows us to conclude that the integration of Astronomy and Mathematics, mediated by Active Methodologies and Digital Technologies, was effective not only for the acquisition of specific knowledge but also for fostering a more investigative, critical, and collaborative stance among learners.

5. Conclusion

This research sought to understand how Mathematics teaching articulated with Astronomy, through AM, can promote ML in line with the Brazilian National Common Curricular Base. The obtained results indicate that the proposed integration was successful and produced positive impacts across multiple dimensions.

The DS, developed based on an accurate diagnosis of prior knowledge in Astronomy and consolidated mathematical skills, proved suitable for the school context. Its implementation, structured around three interconnected activities and supported by the strategic use of Digital Information and Communication Technologies, not only respected the institution's schedule but also catalyzed student engagement. The growing interest in astronomical themes, evidenced even in moments external to the DS – such as a guest expert lecture – reinforced the role of motivating contexts for learning.

The analysis of pre- and post-intervention questionnaires, corroborated by statistical tests (paired t-test), demonstrated significant progress in understanding astronomical concepts. Students not only absorbed new content but began using it to construct explanations and establish relationships, signaling the occurrence of substantive learning. Assessment rubrics of student productions concurrently revealed the strengthening of specific mathematical skills, with students connecting prior knowledge to new challenges more quickly and spontaneously.

The adoption of Team-Based Learning as the central Active Methodology proved to be a fitting choice. It fostered protagonism, collaboration, and individual accountability, creating an environment conducive to knowledge exchange and the development of socio-emotional competencies – such as empathy, teamwork, and the ability to receive feedback – aspects that, although not the initial focus, emerged as relevant gains aligned with the holistic vision of the Brazilian National Common Curricular Base.

The use of Digital Information and Communication Technologies permeated the DS in a critical and productive manner. Students improved their ability to search, validate, and synthesize scientific information online, developing greater discernment in using digital sources – an essential competency in contemporary times and explicitly valued by the Brazilian National Common Curricular Base.

In summary, the research confirms that the articulation between Mathematics and Astronomy, mediated by AM and aligned with national guidelines, constitutes a fertile path for promoting more ML, contextualized, and engaging. The successful experience at Colégio Monteiro Lobato, made possible by institutional support, serves as a replicable model demonstrating that it is possible to reconcile pedagogical innovation and curricular rigor. From these results, the perspective opens to extend the approach to other cross-cutting themes – such as sustainability, digital citizenship, and diversity – contributing to the consolidation of more meaningful, critical pedagogical practices aligned with contemporary educational demands.

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