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Didactic Intervention for the Teaching of Stellar Astrometry in Field Educational Contexts

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ABSTRACT

Background: Astrometry is a field of study that integrates the procedures necessary to determine the position and movements of celestial bodies, which is why it uses concepts typical of the natural sciences that could be used in scientific education. **Objective**: To identify scientific concepts related to astrometry in rural secondary basic education contexts. **Design**: The sequence of activities consisted of *Diagnosis of Prior Knowledge*, *Didactic Intervention*, and *Assessment*. **Setting and Participants:** 65 students from three rural educational institutions (field schools) of the Department of Boyacá in Colombia participated. **Data Collection and Analysis**: Two questionnaires were implemented to assess students' prior concepts and strengthened concepts, which were validated by the judgment of experts in the area. The data was grouped into two categories of analysis: *Astrometric Concepts* and *Astrometric Techniques and Methods*. **Results:** The learning of astrometric concepts such as stellar evolution, parallax, classification, and principles of spectroscopy was favoured, in addition to concepts from physics such as electromagnetic spectrum, brightness, luminosity, temperature-colour ratio, and mathematical concepts, some trigonometric relationships and astronomical units. However, difficulties were evidenced in relation to knowledge of the celestial vault, movements of the stars, and management of astronomical models. **Conclusions:** The students had little previous knowledge about astrometry, strengthened through didactic intervention, enabling the association of physics, mathematical, and astronomical concepts in the classroom.

Keywords: Astrometry; Astronomy science education; Didactic intervention; Teaching.

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Intervención didáctica para la enseñanza de astrometría estelar en contextos educativos rurales

RESUMEN

Fundamento: La astrometría es un campo de estudio que integra los procedimientos necesarios para determinar la posición y movimientos de los cuerpos celestes, razón por la cual utiliza conceptos propios de las ciencias naturales que se podrían utilizar en la formación científica. **Objetivo**: Identificar conceptos científicos relacionados con la astrometría en contextos de educación básica secundaria rural **Diseño**: Se diseñó una secuencia de actividades que consta de "Diagnóstico de conocimientos previos", "Intervención Didáctica" y "Evaluación". **Ámbito y Participantes:** Participaron 65 estudiantes de 3 Instituciones Educativas Rurales del Departamento de Boyacá en Colombia. **Recolección y Análisis de Datos**: Se implementaron dos cuestionarios, para evaluación de conceptos previos y conceptos fortalecidos, los cuales fueron validados por juicio de expertos en el área y los datos se agruparon en dos categorías de análisis: "Conceptos Astrométricos" y "Técnicas y métodos astrométricos". **Resultados:** se favoreció el aprendizaje de conceptos astrométricos como evolución estelar, paralaje, clasificación y principios de espectroscopía, además de conceptos físicos como espectro electromagnético, brillo, luminosidad, relación temperatura-color y conceptos matemáticos, algunas relaciones trigonométricas y unidades astronómicas. Sin embargo, se evidenciaron dificultades en relación con conocimientos sobre bóveda celeste, movimientos de los astros y manejo de modelos astronómicos. **Conclusiones:** los estudiantes contaban con escasos conocimientos previos sobre astrometría, los cuales fueron fortalecidos a través de la intervención didáctica, permitiendo asociar conceptos físicos, matemáticos y astronómicos en el aula.

Palabras Clave: Astrometría; Astronomía Educación en Ciencias; Intervención didáctica; Enseñanza.

Intervenção didática para o ensino da astrometria estelar em contextos educacionais rurais

RESUMO

Contexto: A astrometria é um campo de estudo que integra os procedimentos necessários para determinar a posição e os movimentos dos corpos celestes, razão pela qual ela utiliza conceitos das ciências naturais que poderiam ser utilizados na educação científica. **Objetivos**: Identificar conceitos científicos relacionados à astrometria em contextos rurais do ensino médio básico. **Design**: Uma sequência de atividades foi projetada consistindo em "Diagnóstico do conhecimento prévio", "Intervenção didática" e "Avaliação". **Ambiente e participantes**: Participaram 65 estudantes de 3 instituições educacionais rurais do Departamento de Boyacá, Colômbia. **Coleta e análise de dados**: Dois questionários foram implementados para o diagnóstico e teste final, que foram validados por especialistas na área, os dados foram agrupados em duas categorias de análise; “Conceitos Astrométricos” e “Técnicas e Métodos Astrométricos”. **Resultados**: o aprendizado de conceitos astrométricos como evolução estelar, paralaxe, classificação e princípios de espectroscopia, assim como conceitos físicos como espectro eletromagnético, brilho, luminosidade, relação temperatura-cor e conceitos matemáticos, algumas relações trigonométricas e unidades astronômicas, foram favorecidos. Entretanto, foram observadas dificuldades em relação ao conhecimento da abóbada celeste, aos movimentos das estrelas e ao uso de modelos astronômicos. **Conclusões**: os alunos tinham pouco conhecimento prévio sobre astrometria, o que foi fortalecido por meio da intervenção didática, permitindo associar conceitos físicos, matemáticos e astronômicos em sala de aula.

Palavras-chave: Astrometria; Educação científica; Ruralidade; Intervenção didática; Ensino.

INTRODUCTION

Astronomy as a science has been linked to the development of most human cultures and civilisations (Montesinos, 2022). This science generates curiosity and spontaneous interest in its object of study in all populations (Camino et al., 2021). Astronomical knowledge has led to scientific and technological development that has transformed peoples’ culture throughout history (McBride et al., 2018; Valenzuela Vila, 2010). In didactic terms, its potential lies in the contextualisation of scientific phenomena for the learning of the natural sciences (Alexandre & Leite, 2021; Giordano, 2021), processes of interdisciplinarity in the classroom, (Elisa et al., 2021; Tytler et al., 2019, 2021), in the development of scientific thinking (Bailey & Lombardi, 2022; Ohyama, 2021; Ríos Martínez et al., 2021) and the strengthening of scientific skills (Guillen Muñoz & Ordoñez Suin, 2022; Pham, 2021; Pujani et al., 2022; Ramírez González, 2021).

Consequently, training in astronomy can be assumed as a didactic possibility for scientific education in different contexts (Camino et al., 2021). Within the epistemological development of astronomy, astrometry arises as a field of study responsible for applying techniques to determine the position and movement of celestial bodies, such as planets, stars, constellations, nebulae, meteors and galaxies (Altena, 2012; Kovalevsky, 2002; Astronomical Observatory UTP, 2016), using methodological and conceptual bases of sciences such as physics and mathematics.

Based on the above and to demonstrate the importance of astrometry in scientific production and substantiate this research, an exploratory review was conducted in the Web of Science database, using the term “Astrometry” to identify the documents published between 2019 and 2022. The search revealed 730 articles, with the predominance of publications in stellar astrometry (189), Instruments, Calibration or Software (113), Astrometry of Planetary Systems (99) and Astrometry of Galaxies and Clusters (140).

We found that stellar astrometry is astrometry with a greater investigative perspective, which became evident in the background information from aspects such as the identification of stars and consolidation of high-precision stellar catalogues (Apellániz et al., 2020; Luhman, 2021; Luhman & Esplin, 2020), spectral classifications to recognise characteristics such as real brightness, age, temperature, and chemical composition of stars (Kyritsis et al., 2022; Yang et al., 2020), measurement of stellar distances (Gehan et al., 2021; Guo et al., 2021), reduction of data obtained in probes and satellites to determine own movements, stellar occultations and parallaxes (Bowler et al., 2021; Gomes et al., 2022; Marchetti, 2021; Zari et al., 2021).

From the above, it was evidenced that stellar astrometry deepens into scientific knowledge and technological development; however, it has not been sufficiently explored in the educational context. Only at the higher education level has research been carried out where students delve into astrometric knowledge through image processing using telescopes, reducing scientific grade data and developing simulations, prototypes or sensors (Bampasidis et al., 2019; Boldea, 2019; Boldea & Stavinschi, 2021; Newland, 2020; Raab, 2018; Tock, 2020). On the contrary, at primary and secondary levels, astrometry is addressed from the movements of the Earth, the Moon and the Sun (Galperin & Raviolo, 2019; Güçhan, 2021; Kanellidou & Zacharia, 2019; Salimpour et al., 2021; Slater et al., 2018), but it does not delve into methods and techniques such as parallax, spectrometry, and photometry, which allow obtaining information on the nature of the stars and could contribute to the understanding of concepts such as physics and mathematics, subjects that in educational terms pose different challenges for students and whose difficulties in their learning are evident at different levels of education and particularly in the Colombian context (Palacios et al., 2021; Rosales, 2022; Torres et al., 2018).

Although some concepts of stellar astrometry are present in the Basic Standards of Competencies in Natural Sciences for grades 7 and 8 (Ministry of National Education, 2011), there are limitations in the process of addressing these issues; among others, the scarce teacher education in the subject (Ganón & Fernández, 2008; Gómez Valverde, 2015). Another problem is that there are proposals for didactic innovation on the theme in the main cities of the country, meaning that in rural environments, strategies for astronomy education are scarce, offering very few scientific educational strategies in general (Lucia et al., 2016; Mora, 2020). Based on the above, this intervention intends to offer high school students from three rural educational institutions an approach to the study of stellar astrometry, addressing topics such as movements of celestial bodies, stellar evolution, electromagnetic spectrum, H-R diagram and stellar parallax, enabling them to acknowledge technological advances such as the launch of the Hipparcos satellite, the Hubble telescope and the GAIA probe (Altena, 2008; Gouda et al., 2007)

In this study, the following research questions were posed: What is the previous knowledge about stellar astrometry of students between 13 and 17 years of age from three rural institutions in the department of Boyacá? What are the conceptual scopes of stellar astrometry following the development of a didactic intervention in the area?

METHODOLOGY

The study included a sample of 65 students from three institutions in the Department of Boyacá, Colombia, distributed as follows: the first with 33 students, 18 of them male and 15 female; the second, with 14 students, eight male and six female; the third, with 18 students, 11 male and seven female, aged between 13 and 17, whose level of schooling was between eighth and ninth grade of basic secondary education. The contexts of the research were field schools in the municipalities of Saboyá, Tibaná, and Quípama, located respectively 84.6 km, 40.8 km, and 196.4 km from the capital of the Department of Boyacá in Colombia.

The investigative nature of the study is qualitative since the process focused on the reading of a dynamic educational reality, which is interpreted in the light of the meanings and conceptualisations of the participants (Gurdián, 2010). The data were collected through questionnaires and direct observation (Osses et al., 2006). The methodological phases were *Diagnosis*, *Didactic Intervention*, and *Assessment*. The results of each of these phases were analysed through two categories of analysis: the first, *Astrometric Concepts*, where terms such as star, constellations, distance, magnitude, units of astronomical measurement, and observational astronomy were related; in the second, *Astrometric Techniques and Methods*, basic principles of spectroscopy, electromagnetic spectrum, H-R diagram, and stellar parallax were analysed.

For the first phase, a questionnaire was adapted considering CAER (1999) and the authors' contributions. This instrument consisted of 11 questions with multiple choice answers aimed at recognising prior knowledge about the solar system, measurement units, characteristics of the stars, stellar parallax, electromagnetic spectrum, and H-R Diagram. In the *Didactic Intervention* phase, four workshops related to stellar astrometry were implemented, taking into account the results obtained in the diagnostic questionnaire. Each workshop was developed in two hours, allowing the addressing of an exploratory activity and an activity to deepen into each of the topics posed. Finally, in the exit test, a 10-question multiple-choice questionnaire was designed and implemented that allowed evidence of the contributions and/or aspects of the didactic intervention to be improved.

Table 1 shows the statements of the diagnostic questionnaire and exit questionnaire.

Table 1

Diagnostic Questionnaire and Exit Questionnaire.

Analysis Category	Diagnostic Questionnaire Statements	Exit Questionnaire Statements
Astrometric Concepts	**P1**: Pioneer X is a space probe launched on March 2, 1972; its orbiting speed is 12.04 km/s. Although the last signal was received on Earth 18 years ago, it is currently heading towards the red star of Aldebaran. If we calculated the time it would take for the space probe to reach the star, assuming the distance between them is 70 light-years, in what units would we express the answer?	**P1**. Considering that the star system Alpha Centauri is located at a distance of 4.3 light years, what would be the relationship in which we can express the XXXX in Astronomical Units, knowing that one light year is equivalent to 63241.1 Astronomical Units?
	P2. How do you measure the distance between the Earth and a star other than the Sun?	**P5**. Red or M-class stars have a very _______________ temperature compared to blue or O-type stars.
	P4. Which of the following drawings most accurately shows the Earth's orbit around the Sun?	**P7**. The International Astronomical Union defined three characteristics for a celestial body to be considered a planet. If around the star Alpha Centauri B, a planet is found. Indicate the incorrect statement.

	P5. A Cepheid star is one that I) ___________________ in astrometry is important since II) _______________________.	**P9**. If an astronomer wanted to make measurements of the stars mentioned in the text from Earth, the ideal place would be the Atacama Desert, whose geographical coordinates are latitude -23.65236 and longitude -70.3954. Taking into account these coordinates, it can be mentioned that the desert is located in:
	P11. The European Space Agency's (ESA) Gaia telescope has achieved the first large mapping of the Milky Way and other neighbouring galaxies, making it possible to measure with great precision the location of stars that make up the zodiacal constellations. If at noon on a given date at the Earth’s equator, the Sun is closer to the constellation of Gemini. Near which constellation would you expect the Sun to be located at sunset?	**P10**. As seen in the sequence, to locate a star in the sky, astronomers use clusters of stars called constellations. The stars of a given constellation are named by placing Greek letters in order of magnitude of brightness, followed by the name of the constellation. From this context, we can say that:
Astrometric Techniques and Methods	**P3.** The distance to the Polar star is calculated by a method called parallax; this method concludes that this star is 323 light years away. That is approximately 133 parsecs. Taking into account the above and Figure 1, a parsec can be defined as:	**P2**. If you were a scientist and were asked to point out the angle of the annual parallax, which image would you choose?
	P6. Considering that stars, including the Sun, emit varying wave radiations. It can be said that the speed of radio waves and the speed of visible light is:	**P3**. With what type of radiation was the photograph of Alpha Centauri taken?
	P7. The emission spectrum of a body accounts for its chemical elements; therefore, if an astronomer wanted to understand the chemical nature of a star like the Sun, he could use the so-called technique.	**P4**. Because Proxima Centauri is a red star, its H-R spectrum will be located in the region:
	P7. By means of spectroscopy, it was found that the star Betelgeuse, located in the constellation of Orion, emits a maximum wavelength of (0.7x10-6m).	**P6**. What would you answer if you were asked to list the steps to measure the distance

Considering the above, we can say that the temperature of the star is in the range of**:**	from Earth to the star Alpha Centauri B?
P9. If you wanted to design a space telescope to observe the behaviour of the star Betelgeuse, the wiser thing would be for it to observe in the region of the spectrum:	**P7**. If you were asked to measure the distance of one of the stars, Alpha Centauri, in parsec, and for this, you represent the frame of reference as a right-angled triangle, to what would a parsec correspond?
P10. The H-R diagram is a graph for the study of stars (Figure 2) that was designed by Hertzsprung and Russell. From this diagram, it can be said that the Sun:	**--------**

The workshops proposed for the intervention are shown in Table 2, where the coherence matrix of the didactic intervention is established, relating the names of the workshops, their objective, the proposed activities and the category of analysis focused.

Table 2

Workshops of Didactic Intervention Coherence Matrix

Workshop	Objective	Exploratory Activity	Deepening Activity	Analysis Category
Workshop 1. Let us know the heavenly bodies of the Universe!	Recognise the main characteristics of the celestial bodies of the Solar System through their scale representation of planetary diameters and distances between planets.	Draw the Solar System!	How big is the Solar System?	Astrometric Concepts
Workshop 2. Do the stars move, or are they fixed?	Recognise the main characteristics of stars and recognise the types of apparent movements.	“Stars and Constellations”	Build a Star Simulator!	

Workshop 3: Measuring stars: Stellar Parallax.	Understanding the concept of parallax using mathematical principles.	Parallax Concept	Build an astrolabe!	Astrometric Techniques and Methods
Workshop 4. How are stars measured according to the H-R diagram?	Explain the H-R diagram, relating the temperature and luminosity of stars in order to classify them.	The Colours of the Stars	Build a homemade spectrometer!	

Validation of Instruments

Some activities proposed in the intervention were based on scientific dissemination strategies of the Network for Astronomy School Education (NASE). Similarly, we considered some scientific concepts addressed by the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA) and other astronomical observatories were considered. Consequently, the didactic intervention workshops and questionnaires were validated using the expert judgment technique (Escobar & Cuervo, 2008). In this case, we had the appraisal of two teachers and researchers with experience in astronomy, dissemination, and scientific education.

To carry out this process, the experts evaluated the instruments qualitatively and quantitatively on a scale of 1 to 5, taking into account the following aspects: 1) Credibility, 2) Applicability, 3) Creativity and Flexibility, 4) Correspondence with the Objective of the Research, and 5) Consistency with the Categories of Analysis. The interpretation of the experts' judgments took into account the following: accept the items or activities with average values equal to or greater than 4.0, modify the items or activities with average values between 3.0 to 3.9 and reject the items or activities with average values less than 3.

Ethical considerations

This study followed the basic principles for the protection of human subjects in experimentation according to the Belmont report, which relates to informed consent, explanation of the benefits and risks of research and implementation of fair protocols for the selection of participants (Paz, 2018). In addition, following the Statutory Law for the Protection of Data in Colombia (Law 1581, 2012) and the Policy of Protection and Treatment of Personal Data of the Pedagogical and Technological University of Colombia (Resolution 3842, 2013), anonymity was guaranteed in student answers. We were permitted to use photographic data and images. Likewise, we did not compare the participating institutions with each other, respecting the training processes that each one addresses.

RESULTS AND ANALYSIS

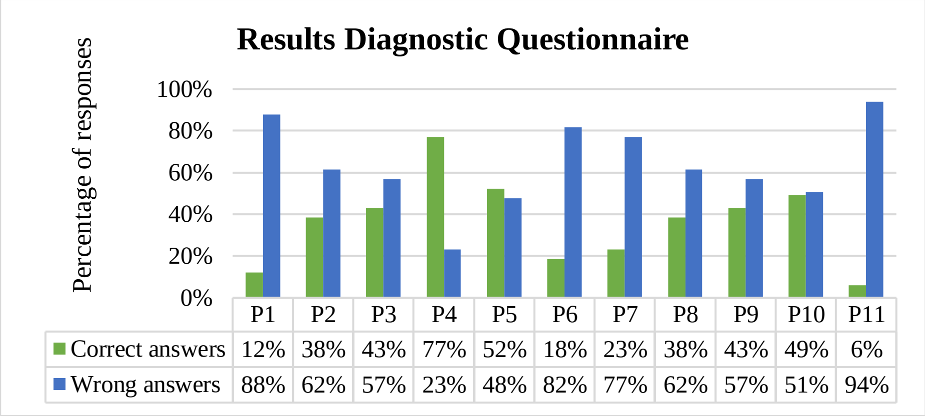
This section describes the results of the diagnostic questionnaire, didactic intervention and exit questionnaire.

Diagnostic questionnaire

Next, in Figure 1, the results of the diagnostic questionnaire can be observed, and the percentage of correct and incorrect answers appears. In general, students do not have extensive knowledge about astrometric concepts or techniques and methods used in astrometry, taking into account that the percentage of incorrect answers exceeded the correct ones, except for P4's and P5's answers.

Figure 1

Results Diagnostic Questionnaire



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Correct answers	12%	38%	43%	77%	52%	18%	23%	38%	43%	49%	6%
Wrong answers	88%	62%	57%	23%	48%	82%	77%	62%	57%	51%	94%

To analyse the results, questions P1, P2, P4, P5, and P11 referred to the analysis category *Astrometric Concepts* and questions P3, P6, P7, P8, P9, and P10 to the analysis category *Astrometric Techniques and Methods*, as described below.

Analysis Category 1 "Astrometric Concepts"

To 60% of students, "year" is the unit of time it will take a space probe to reach a particular star outside the Solar System. However, almost the remaining 40% understand the unit of length of Light-Years and Light-Seconds as units of time. In addition, 38% of the students correctly indicated that, to measure the distance between the Earth and a star different from the Sun, they must consider the variation of its position, that is, the parallax; however, we identified that 12% of the students believe that the idea that stars have similar sizes prevail and that what makes their luminosities different are the distances from the Earth.

Other authors have documented that the previous difficulty owes mainly to textbooks', teachers', and disseminators' scarce contextualisation before astronomical scales and distances (Sebastià, 2004; Solbes & Palomar, 2013), which, consequently, prevents students from building knowledge about phenomena of the Universe that can be used to pose or solve scientific problems of an interdisciplinary type, since the relationship of astrometry with mathematics and even geography is undeniable (Franco, 2017).

Concerning question P4, the topic of the Solar System and the shape of the orbits was assessed, a curricular topic for 4th, 5th, and 6th grades in Colombia (Ministry of National Education, 2011). The results found that 77% of the students answered correctly, selecting the heliocentric planetary model with elliptical orbits around the Sun. By contrast, 23% of the students selected the heliocentric planetary model with circular orbits, a difficulty that has been identified in other learning environments (Lanciano, 1998; Villanueva Ferrer, 2014).

From question P5, related to the topic of stellar evolution for the sixth and seventh grades, according to the Basic Standards of Natural Sciences in Colombia (Ministry of National Education, 2011), we identified that 52% of students correctly recognise a Cepheid star as the one that varies its luminosity cyclically and serves as a reference to determine stellar distances.

This percentage, while suggesting the need to strengthen the concept in almost half of the students, also indicated that the students possess some prior notions that could allow them to understand the methods, techniques, and principles of operation of the instruments used for astrometry.

Regarding question P11, the need to place oneself according to specific constellations was posed, identifying that 94% of the participants answered incorrectly; only 6% of the students recognised the movement of the celestial vault and proposed that the Sun would remain in the same constellation during the day. In addition, the research revealed that 35% of the students understand the apparent route that the Sun follows in the sky throughout the day and understand that at dawn, it is at the eastern cardinal point and at dusk at the western cardinal point; however, they do not know the movement of the celestial vault. These results make clear the need to address the constellations in positional astronomy since its concepts and procedures are complementary to astrometry.

Analysis Category 2 “Astrometric Techniques and Methods”

From question P3, we determined that 43% of the students answered correctly, pointing to the parsec as a unit of length in astronomy, while 57% answered incorrectly, relating it to light years, luminosity or stars' masses. These results, in addition to reiterating weaknesses in the appropriation of astronomical units, also indicate they did not know the units used to determine stellar parallaxes, taking into account the determination of the points on which a star is projected when observed at two opposite moments of Earth’s orbit (CSIC, 2005).

Regarding question P6, which inquired about the knowledge of the speed of light and radio waves, we identified that only 18% of students understood that this speed would be the same. Concerning the results obtained in question P7 that points towards understanding techniques to estimate the chemical nature of a star, 23% of the students recognised spectroscopy as a technique that allows studying the spectrum of light emitted and absorbed by an astronomical object, 33.80% of the students considered that spectroscopy allows studying the stars that emit in the yellow region of the visible spectrum, 36.9% related spectrometry as the study of the speed at which the light of the Universe travels and 6.15% considered that spectro-photography is the most appropriate technique.

Answers to question P7 established that 38.40% of students interpreted the electromagnetic spectrum diagram, a concept that explains the nature of light and allows the understanding of spectrometry as an astrometry technique. In the case of question P9, 43% understood that if they built a telescope to observe the star Betelgeuse, the region of the spectrum that should be observed would be between visible and infrared; on the other hand, 15% considered that the region is X-ray and infrared, 17% ultraviolet and infrared, and 25% radio and infrared.

From the above results, it is evident that the study of the stars should not be based solely on light emission but on electromagnetic radiation, considering that celestial bodies emit in all regions of the electromagnetic spectrum but with different intensities (Bianchi, 2004).

Regarding the understanding of the H-R diagram and its analysis to classify the type of star that is the Sun, 12.30% of the participants indicated that the spectral type is G and its location is the centre of the Universe, 49.20% indicated that the spectral type is G and that it is in the main sequence, 20% indicated that the spectral type is K and its temperature is 5,000 °C; finally, 18.40% considered that the Sun has spectral type K and its apparent magnitude is typical of a red giant.

Through the diagnostic questionnaire, we concluded that the students demonstrated a moderate approach to the heliocentric planetary model and star characterisation. However, they presented difficulties in recognising astronomical scales, terrestrial and stellar positioning, electromagnetic spectrum and its applicability in the study of stars, stellar evolution, and relationships on temperature and colour in stars, topics typical of modern physics. Therefore, the proposed didactic intervention sought to strengthen knowledge in these aspects.

Didactic Intervention

Workshop 1. Let us know the heavenly bodies of the Solar System!

As presented in Table 2, this workshop integrated activities so we could recognise students' previous knowledge of the Solar System and develop some simple mathematical procedures to model the scales of diameters and distances while discussing concepts such as planets, orbit, asteroids, and satellites, among others.

Activity 1. Draw the Solar System: After providing different materials to the students, they were asked to draw or model the Solar System according to their prior knowledge.

From this activity and agreeing with what was diagnosed, we saw that all the students recognised the heliocentric model. However, when looking at the drawings (Figure 2), we observed that no student used scales to represent the Solar System, 10% of the students drew the planets in the same orbit around the Sun, the remaining 90% represented the planets in orbits with the same distance from each other, with geometric configurations very close to the circle, rather than to the ellipse. Other national studies have already evidenced these difficulties (Baquero Soler, 2019; Cruz Solano, 2020).

Figure 2

Some graphical representations of the Solar System were developed in the activity.

Activity 2. How big is the Solar System?: In this activity, we discussed and conceptualised distance units, including km, m, astronomical units, light years, and parsec; concepts of geometry such as circle, ellipse, diameter and radius, in the same way, mathematical procedures were done in order to perform the unit conversion. For this activity, the Solar System was represented through the conversion of scales of diameters, taking as reference 10,000 km per cm, and, in relation to the distance scale, every 10 million km was represented by a cm of length.

Some of the main conclusions the students enunciated from the process were: "I did not imagine that the planets were so far away from each other in the solar system (SIC)", "Mathematics are useful to solve astronomical problems and that the planets are too far from the Sun and each one from each other (SIC)". We also defined a planet according to the International

Astronomical Union (IAU) so that students could decide whether or not to include Pluto in the models made.

In this workshop, conceptual difficulties vis-à-vis the handling of scales became evident, in addition to erroneous mental models about the distribution of the Solar System, which were reconstructed with the mathematical demonstration of the relationships between distances and diameters of the different planets in relation to the Sun. In didactic terms, a popular conceptual construction of the planet as “All that orbits around the Sun” was observed, which was resignified from the IAU definition. So, there is a need to delve into the planetary characteristics from concepts of geosciences for in-depth work on these topics in a formative rather than informative way.

Workshop 2. Do the stars move, or are they fixed?

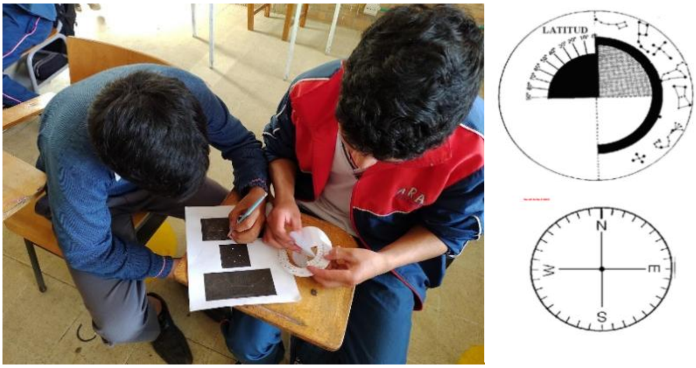
Activity 1. Stars and constellations: From this activity, the constellation was conceptualised, showing some of the most recognised constellations such as the Big Dipper, the Southern Cross, Scorpio and Taurus. From the images of these constellations, we explained the classification of the stars according to their apparent brightness so that most students could propose a classification of the stars in these constellations (see Figure 3).

Activity 2: Star simulator: In this activity, the students built the simulator of Figure 3 to classify three types of stars based on the possibilities of observation in different latitudes: circumpolar, stars that rise and set and invisible stars. To understand the operation of the simulator, it was necessary to approach the concept of latitude and geographical coordinates, for which the measurement of latitude from the Earth’s equator was explained, taking into account the degrees of the sphere and how these degrees are distributed positively towards the Earth’s North, and negatively towards the Earth’s South.

The main conceptual difficulties of this workshop reside in the geographical location; although 82% of the students are aware of the concepts of Latitude and Longitude, these concepts do not represent an application in their contextual realities, making it difficult for them to read the coordinates according to the angles with respect to the Equator or Greenwich lines. This problem had previously been referred to by Acosta (2019) and Gómez et al. (2019) in other urban educational institutions. It is necessary to deepen in observational astronomy so students can recognise the firmament and, based on it, strengthen their capacity to locate themselves, as 100% of the students showed themselves motivated in building and using the star simulator.

Figure 3

Identification of constellations, classification of apparent stellar brightness and construction of stellar simulator. To the right is the model of the simulator used.



Workshop 3. Measuring Stars: Stellar Parallax

To introduce the concept of parallax, we used the typical observation of the variation of the position of an object when viewing it in a monocular way, alternating the left and right eye. With this observation, we explained the periodicity with which the stellar parallax could be performed, and we could give them the trigonometric relationships that allow making this type of measurement. Contextualising the previous measurements, we designed a homemade astrolabe with the students, like the one seen in Figure 4, by means of which the heights of some objects were measured, such as trees, walls or flagpoles.

The main difficulties of this activity were the mathematical procedures, since 100% of the students were unaware of trigonometric relationships, but 70% had addressed concepts of basic geometry that integrated aspects of the measurement of triangles, facilitating understanding of the trigonometric relationship. Therefore, with the contextualised measurement activity, 96% of the students found the requested heights. Again, students' motivation and willingness were noticed in the activities that integrated observations and practical activities.

Figure 4

Measurement of heights using the astrolabe.

Workshop 4. How are stars measured and classified according to the H-R diagram?

This workshop contextualised the Hertzsprung-Russell diagram, which classifies stars based on their absolute magnitude, surface temperature, and luminosity. Initially, we identified students' previous perceptions of the colour of the stars by their indication: "white," "silver," "blue," "green," or "chicken yellow." To put in controversy these ideas, we had to introduce the concept of the electromagnetic spectrum so that some properties of light could be clarified.

Although these concepts are part of the basic standards of competencies in the area of natural sciences, this workshop was the one that represented the greatest complexity for students since the approach to concepts of modern physics is scarce in secondary education institutions (López Corral, 2020; Sedano Roncancio, 2020). In this sense, we realised that based on the activity, 74% of the students recognised the decomposition of the visible spectrum and the regions of the electromagnetic spectrum. However, regarding the understanding of the relationship between temperature and colour, students explained it from everyday experiences, "With clothes, when one wears dark clothes, one feels hot, and with clear clothes, one feels cooler", "Yes, there are warm colours and cold colours". Nevertheless, given students' limited prior knowledge of physics and mathematics, we could not delve into concepts such as Wien's Law, which suggests the need to implement this intervention at other levels of education.

In general terms, the intervention allowed a practical approach to astrometric concepts, such as parallax, the nature of light, electromagnetic spectrum, constellations, planets, stars, classification of stars and astronomical units, contextually, based on the interdisciplinary development of astrometry. In terms of techniques and instruments of astrometry, the ability to measure and model using scales, the contrast of stellar brightnesses, the measurement of parallaxes with the astrolabe, the location of stars and constellations with the stellar simulator, and the contextualisation of astrometry with the home spectrometer were put into practice.

Exit questionnaire

Figure 5 reveals that the exit questionnaire presents higher percentages of correct answers than the first one, except for question P10. Likewise, higher percentages of incorrect answers are observed in the diagnostic questionnaire compared to the exit questionnaire, aspects that suggest students' conceptual improvement due to the didactic intervention.

It is important to point out that questions P1, P5, P7, P9, and P10 of the exit questionnaire contributed to the analysis category on *Astrometric Concepts* and P2, P3, P4, P6, and P8 to *Astrometric Techniques and Methods*, as described below.

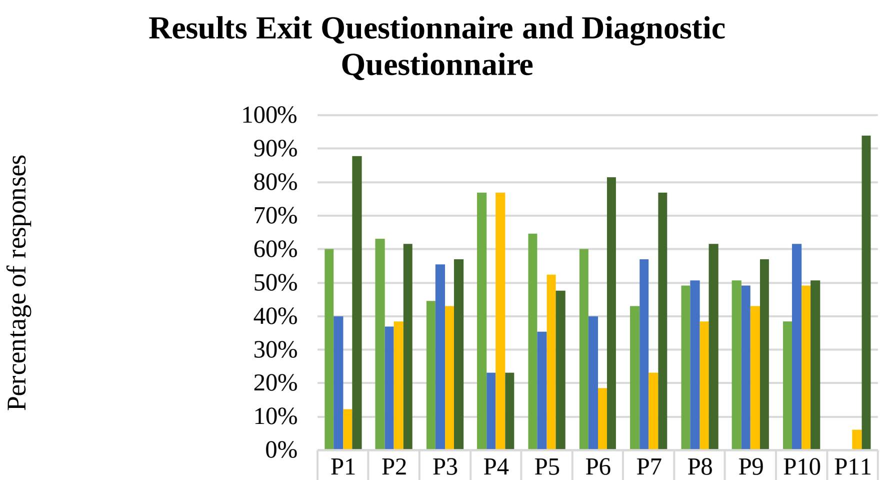
Analysis Category 1 "Astrometric Concepts"

The final test sought to evaluate the application of astrometric concepts in interpreting a scientific article entitled "The best Hubble image of Alpha Centauri A and B". The results obtained for this category are described below.

As stated in workshop 1 of the intervention, unit conversion activities were addressed, which is why question P1 proposed as a contextual situation the need to convert light years units of length to astronomical units; against this, it was evident that 60% of the students selected the correct procedure, being a significant result when comparing it with the results of question P1 of the diagnostic questionnaire, where only 12% of the students recognised the light year as a unit of length.

Figure 5

Comparison Results Exit Questionnaire and Diagnostic Questionnaire



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
Correct Exit Questionnaire	60%	63%	45%	77%	65%	60%	43%	49%	51%	38%	
Incorrect Questionnaire Exit	40%	37%	55%	23%	35%	40%	57%	51%	49%	62%	
Correct Diagnosis Questionnaire	12%	38%	43%	77%	52%	18%	23%	38%	43%	49%	6%
Incorrect Diagnosis Questionnaire	88%	62%	57%	23%	48%	82%	77%	62%	57%	51%	94%

Workshop 4 worked on the relationship between the temperature and the colour of the stars. In the final test, this relationship was evaluated with question P5, evidencing that 65% of the students understood these concepts and contextualised them from the reading of the H-R diagram, proposing that the M-type stars have a lower temperature than those of type O. This also means that it is necessary to strengthen further the concept in the remaining 36% of the students.

Regarding question P7 on planets, 43% of the students understood the definition provided by the IAU, which means that 57% did not. These results are consistent with the motivational activity of workshop 1, bearing in mind that 100% of the students presented shortcomings when representing the planets of the Solar System, drawing round orbits, planets in the same orbit or without considering planetary distances and diameters. Therefore, the didactic intervention was limited by the students' pre-incorporated models, which, in this case, were resistant to a conceptual change (Gangui, 2006).

Knowing that in the didactic intervention, the students built stellar simulators, where concepts related to terrestrial latitudes were involved, question P9 aimed to evaluate what they learned from this activity. For this reason, we gave them the coordinates of the Atacama Desert in Chile and asked them to indicate the hemisphere of that location, which 51% of the students placed correctly. These results allow us to assert that the acquisition of astrometric concepts can be affected by students' difficulties with spatial orientation, reflected in the limitation of locating places or objects with a perspective and spatial trajectory that is not close (Zapateiro et al., 2018).

Finally, about question P10, the relationship between the apparent brightness of the stars and their nomenclature in the constellation they appear is contextualised, concepts developed in workshop 2 of the intervention. Based on the above, it is evident that 38% understand that the Alpha Centaur A and B system have the same apparent brightness and are located in the constellation of the Centaur; however, it is necessary to strengthen this relationship since 52% of students found it challenging to infer it from the nomenclature of the two stars.

Analysis Category 2 "Astrometric Techniques and Methods"

As indicated above, this questionnaire was related to the news "The best Hubble image of Alpha Centauri A and B", which allowed us to analyse the questions that describe this category.

In question P2, we determined that 63% of the students correctly identified the angle of parallax of an image representing the method for calculating the distance of a star. Results that are consistent with those obtained in question P6, since 60% of students correctly list the steps to measure the distance from the Earth to a star; that is, observe the position of the Earth six months apart, know the angle of parallax and the distance from the Earth to the Sun and, finally, apply trigonometric formulas to know the distance to the star.

Despite these values to explain the parallax, in question P7, the technique is associated with a frame of reference such as that of a right-angled triangle, and only 49% of students answered correctly. This shows that it is necessary to strengthen the teaching of mathematical and geometric concepts before addressing concepts or astrometric techniques to encourage the resolution of everyday problems and, thus, achieve much more significant learning about the principle of parallax.

Concerning question P3, which inquired about the type of radiation with which the Alpha Centauri photograph was taken, 45% answered correctly, indicating that it was with infrared, which is not part of the visible spectrum. Consequently, we identified that 26% of the students showed confusion regarding infrared radiation since they classified it within the visible spectrum. Despite this, through question P4, we determined that 77% of the students indicated that Proxima Centauri, being a red star, would have a longer wavelength at the maximum emission and, in the H-R spectrum, would be located in the red region.

As can be seen above, the results obtained in this category were the most significant in terms of the final test, specifically when addressing the parallax method. This activity was posed after the didactic intervention and after they used instruments such as the astrolabe, which encouraged the study of distances. In the same way, we evidenced that the students reconceptualised their previous ideas about the colours of the stars, understanding that colour is related to the emission spectrum, a feature that can be determined along with other properties from spectroscopic techniques and instruments.

Despite the didactic intervention, the students had difficulty classifying infrared radiation, defining the concept of a planet, associating stellar parallax with geometric models and recognising the difference between the magnitude of the brightness of a binary star system, taking into account that the percentages of correct answers for questions P3, P7, P8, and P10 did not exceed 50%.

FINAL CONSIDERATIONS

This research made it possible to recognise that the students have previous concepts related mainly to astrometry, such as the Solar System, stars, planets and the heliocentric model. Likewise, we observed that these concepts are not always contextualised with their reality. For example, regarding geographical location, students define latitude and longitude but present difficulties when explaining a geographical coordinate. Therefore, it is necessary to contextualise these concepts and strengthen mathematical skills, measurement, management of scales, and astronomical units, celestial location, measurement and mathematical relationships of the stellar parallax, in addition to introducing concepts such as electromagnetic spectrum, legs and hypotenuse, stellar evolution, and heat-temperature relationships.

Concerning the didactic intervention and the results obtained in this workshop, we recognised that concepts, techniques and methods related to astrometry were strengthened, for example, stellar parallax, spectrometry, features and evolution of the stars, which allowed associating knowledge about the H-R diagram, geographical coordinates, astronomical units and scales, trigonometric identities and physical concepts such as electromagnetic spectrum, and the relationship between temperature and radiation. Finally, we recommend future interventions focused on planetary astronomy and observational astrometry to strengthen the concept of a planet, apparent movements of the celestial vault, and constellations.

The study made it possible to identify the contributions of a didactic intervention on stellar astrometry in terms of conceptual appropriation. However, the results would have been better if the students had more solid prior knowledge. Therefore, it is necessary to propose and develop educational processes that lead to internalising the learning of astronomical measurements, spectroscopy, orbits in stellar systems, dynamics of star clusters and stellar associations, planetary dynamics, and stellar chemical processes, taking into account that they can contribute to contextualising abstract concepts of physics, chemistry and mathematics.

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STATEMENT OF CONTRIBUTION OF THE AUTHORS

All authors actively participated in the discussion of the results and reviewed and approved the article's final version.

DATA AVAILABILITY STATEMENT

Data supporting the results of this study will be made available by the corresponding author, [DYPC], upon reasonable request.

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