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III Workshop for Astronomy Beyond the Common Senses for Accessibility and Inclusion (3WAI) (November 29-30, 2023)
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CONSTELARTE: A PBL EXPERIENCE OF INCLUSION IN ASTRONOMY

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RESUMEN

La Astronomía es una ciencia predominantemente visual. Sin embargo, es posible acercar su estudio a personas no videntes a través de la sonificación: transformación de la información astronómica, generalmente luz, en sonido. A partir de la selección de estrellas dentro de una constelación, estudiantes de bachillerato fueron capaces de estudiar la temperatura superficial, el color, la magnitud aparente y el brillo. Puesto que la luz y el sonido son fenómenos ondulatorios, se correlacionaron y establecieron criterios de traducción entre color y tono, y entre brillo y volumen auditivo. Mediante la programción de circuitos y armado de maquetas, los estudiantes fueron capaces de llevara a cabo una experiencia de acercamiento con diferentes personas a los cuales se les cubrió los ojos, al tiempo que recorrían la constelación con los dedos, escuchando las estrellas para establecer relaciones de diferencia de brillo/volumen y color/tono. Motivados por los resultados, los estudiantes reconocieron la importancia de ampliar y mejorar la accesibilidad y la inclusión, no solamente de la Astronomía, sino de la Ciencia como actividad socio-cultural colectiva.

ABSTRACT

Astronomy is a predominantly visual science. However, it is possible to bring its study closer to blind people through sonification: the transformation of astronomical information, usually light, into sound. By selecting specific stars within a constellation, high school students were able to study surface temperature, color, apparent magnitude and brightness. Since light and sound are both waves, a correlation was established and translation criteria were created between color and pitch, and between brightness and audible volume. By programming circuits and assembling them into models, students were able to carry out a close-up experience with the high school community. With their eyes covered, the subjects were walked through the constellation with their fingers, listening to the stars and establishing relations of difference in brightness/volume and color/pitch. Motivated by the results, the students recognized the importance of expanding and improving accessibility and inclusion, not only in Astronomy, but in all science as a collective sociocultural activity.

Key Words: accessibility and inclusion in Astronomy — blind and low vision education — PBL: Project-based learning

1. INTRODUCTION

Exploring the Universe and unraveling its mysteries has traditionally been a visually driven task, showcased through striking images taken by telescopes, that captivate the awe and curiosity of many generations. However, this visual-centric approach poses significant challenges in the quest for a truly inclusive astronomy that enables individuals with various disabilities (not only visual), to fully engage and generate new generations of scientists.

In this context, we reflect upon the inspirational life journey of Puertorican astrophysicist Wanda Díaz-Merced, who, despite facing visual limitations (and almost relegated from doing science), has defied conventional barriers to astronomical perception. Her remarkable contributions lies in exploring the cosmos through sonification, a transformative process that converts astronomical data into auditory experiences, offering a novel sensory perspective of the Universe (Diaz-Merced et al. 2008, 2011; Diaz-Merced 2013).

Within this framework, we present a project-based learning (PBL) activity, aiming to go beyond mere information transmission by fostering active participation and deep comprehension. These types of projects not only focus on knowledge acquisition but also on building meaningful connections between astronomical concepts and everyday life, thus contributing to the creation of a more inclusive and accessible educational space (ChanLin 2008; Kubiatko & Vaculová 2011; Ergül & Kargın 2014; Gary 2015).

This project aims to cultivate students' skills in stellar astrophysics through the innovative approach of sonification. Focusing on stars from common constellations of the Southern Hemisphere sky

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(Sec. 2.1), high school students of Colegio San Ignacio (Montevideo, Uruguay) tackled the challenge of conveying crucial astronomical information by converting visual data into auditory experiences. The sonification process enabled participants to explore the diverse characteristics of stars, ranging from temperature to brightness, in an effort to foster a basic understanding of stellar astrophysics to the non-astronomical community.

2. METHODOLOGY

In this section we detail all the steps of the project.

2.1. *Selection of constellation*

The selection of constellations was aimed at ensuring visibility from the southern hemisphere, specifically from Uruguay, during the course of the project (spring). Seven constellations were chosen (each one for a group of 3-4 students), all observable with the naked eye. Namely: Pavo, Hydra, Canis Major, Virgo, Scorpius, Taurus, and Orion. All of these constellations have at least two pairs of stars that have noticeably different colors and apparent magnitude. Each group had to select a pair of stars with this criterion in mind.

2.2. *Color determination*

To obtain the color of each star, a thorough investigation of various color indices was conducted by the students. In some cases, the effective temperature (T_{eff}) was needed to calculate the wavelength of maximum emission (λ_{max}) using Wien's law (Eq. 1). In most cases, the B-V color index was the most suitable.

$$T_{eff} = \frac{2.9 \times 10^{-3} mK}{\lambda_{max}} \tag{1}$$

2.3. *Apparent Magnitude*

The apparent magnitude was obtained using the Stellarium Web Online Star Map[3]. Given our need the focus on relative brightness between the two selected stars rather than their absolute brightness, a brightness ratio (B_2/B_1) was calculated based on difference in apparent magnitudes m_1 and m_2 (Eq. 2). This approach allows for the establishment of a scale criterion, facilitating a nuanced comparison of the selected stars.

$$\frac{B_2}{B_1} = 10^{\frac{m_1 - m_2}{2.5}} \tag{2}$$

[3]https://stellarium-web.org/

TABLE 1

COLOR/PITCH CRITERION

λ_{max} (nm)	Tone	color
390-423	Si (B)	Violet
424-457	La# (A#)	Violet
458-491	La (A)	Blue
492-525	Sol# (G#)	Green
526-558	Sol (G)	Green
559-591	Fa# (F#)	Yellow
592-624	Fa (F)	Orange
625-657	Mi (E)	Red
658-690	Re# (D#)	Red
691-723	Re (D)	Red
724-756	Do# (C#)	Red
757-789	Do (C)	Red

2.4. *Criteria*

Color/Pitch criterion The color/pitch criterion was established employing a linear correlation between the frequency of the visible light spectrum and the conventional twelve-tone musical scale (Tab. 1). This approach allowed for the translation of stellar colors into musical tones, which students could identify more easily if a change in pitch occurs between the two stars.

Brightness/Volume criterion Given that both brightness and audible volume (intensity of sound β in Eq. 3) follow a logarithmic scale concerning both the physical phenomena and the biological nature of perception of these variables. A linear correlation between the two parameters was established.

$$\beta = (10dB) \log_{10} \left(\frac{I}{I_0} \right) \tag{3}$$

$$I_0 = 10^{-12} W/m^2 \tag{4}$$

Using a direct proportionality calculation between the ratio of volumes and brightness, the programming criterion was defined. For star 2 (i.e.: the brightest)[4], the chosen volume (V_2) was set to the maximum allowed by the software[5]. The volume of star 1 is set by Eq. 5:

$$V_1 = V_2 \left(\frac{B_1}{B_2} \right) \tag{5}$$

[4]This choice was arbitrary.

[5]The relationship between β and V is far from trivial and will not be discuss here. See reference Serway & Jewett (2018).

However, if there is a significant difference in brightness between the two selected stars (i.e.: $B_2 \gg B_1$), the volume V_1 may fall below the audible limit in humans (i.e.: I_0). In such cases, consideration should be given to modifying the pair of stars or taking these observations into account when conducting the experiment with the community and drawing relevant conclusions.

2.5. *Programming and circuitry*

We used a *Micro:bit* circuit board, a widely used tool in high-school programming laboratories for both its range of uses and its inexpensiveness. This circuit board served as an accessible platform for students, offering a practical interface for the integration of both astronomical and programming knowledge.

Programming the *Micro:bit* board was achieved through *Microsoft's MakeCode for microbit*, a designated program within the software package utilized by Plan Ceibal, a national initiative aiming to bridge the digital divide by providing widespread access to technology and digital education tools for students. This streamlined programming environment facilitated the creation of code that translated astronomical data into auditory experiences. Several tutorials on how to program sound on *Micro:bit* are available on YouTube[6].

The circuit comprises a *Micro:bit* board powered by two AA batteries, connected to two push buttons (one for each star) that individuals must press to trigger the sound. The audio output of the board is linked to a pair of nonwireless headphones to facilitate auditory perception. Wireless headphones can be utilized; however, in our experience, they have proven inefficient. Additionally, the circuit board is interconnected with two LED lights (one for each star), each emitting its corresponding color according to Sec. 2.2. This feature enables the establishment of the aforementioned correlations after the auditory experience, ensuring a seamless transition from auditory to visual understanding of astronomical concepts. The circuitry behind the model is shown in Fig. 1. A final look at the model is shown in Fig. 2.

3. EXPERIENCE WITH COMMUNITY

The final presentation of the models involved conducting the sonification experience with the Colegio San Ignacio community, including teachers, staff and students of other grades. None of the participants in the experience were visually impaired, so the activity was carried out with blindfolds. The participants were equipped with headphones and guided through the maquette constellation by the students, who assisted in locating the push buttons. Upon activation of a button, participants identified the corresponding sound through headphones. After completing the exploration of the constellation and recognizing the sounds associated with both stars, the students posed a series of guided questions to help participants discern the color-tone and brightness-volume relationships linked to the astrophysical nature of the selected stars.

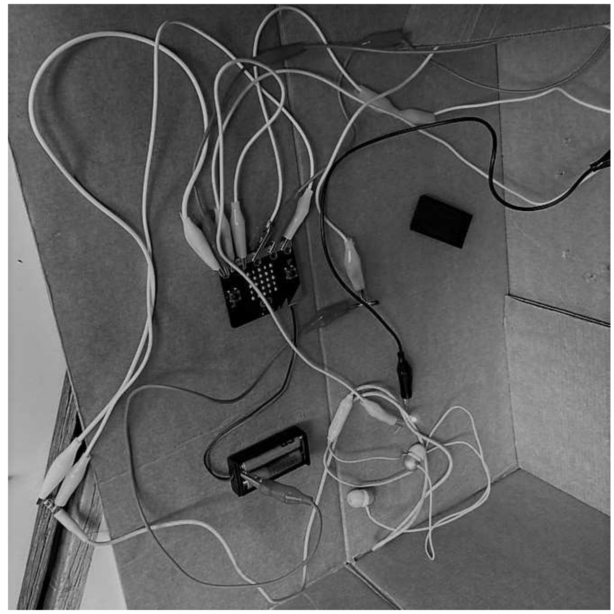

Fig. 1. Circuitry of the *Micro:bit* plate, the leds and pulsators, inside the box model.

4. FINAL REMARKS

Through the practical application of sonification, students not only did acquire fundamental knowledge about stars and their properties but also developed transferable skills such as interpreting complex data and effectively communicating astronomical concepts through non-visual means.

This interdisciplinary approach has enriched the educational experience for students as well as fostered the integration of knowledge from different fields, mirroring the collaborative nature of scientific research.

The students successfully acknowledged the importance of creating tools and environments that allow individuals with sensory disabilities to access scientific knowledge, recognizing the project as an exer-

[6] https://www.youtube.com/watch?v=QVYZIBnBSoA

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Fig. 2. A tour of the final model with the fingers. The blindfolded subject must 'finger-walk' through the constellation, pulsate on the selected stars and listen to the differences in volume and pitch. The circuitry is inside the box.

cise to build empathy and challenging them to think through the perspective of blind individuals.

We would like to emphasize that Project-Based Learning (PBL) initiatives such as this one have significant potential for replication in diverse regions and educational contexts. To our knowledge, Uruguay stands as the sole South American country to incorporate Astronomy as a compulsory subject in its high school curriculum (at least as of now). It is our belief that projects like these not only enhance scientific literacy but also foster a deeper appreciation for interdisciplinary learning, paving the way for innovative educational practices worldwide.

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Fig. 3. Oral presentation of the experience given by the students and educator at the III Workshop on Astronomy Beyond the Common Senses for Accessibility and Inclusion held in Planetario Municipal de Montevideo (Uruguay). [Photo with permission]

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