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INCLUSIVE PHYSICS TEACHING WITH ARDUINO AND COLOR SENSOR

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ABSTRACT
This article is the result of the development of a project of the Institutional Program of Extension Scholarships - PIBEX of the Federal University of Pará, Salinópolis campus. It aims to propose a didactic sequence for High School Physics teachers using an experiment, focusing on facilitating the learning of all students, especially those with visual impairment. The construction of the experiment was based on a prototype called VDV Color Sensor, using 4 Arduino UNO boards, resistors, LEDs and the TCS34725 sensor. The prototype identifies colors and responds with lights and sounds, making the content more accessible. Interviews were also conducted with Physics teachers in the municipality of Salinópolis, Pará, to investigate their training and practices related to the inclusion of students with disabilities. The prototype was effective in identifying colors and responding interactively with lights and sounds, demonstrating potential for inclusion. The interviews

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revealed that the teachers did not have disciplines focused on inclusion in their initial training and there were contradictions in the answers about experiences with visually impaired students, indicating weaknesses in the preparation of teachers for inclusive practices.

Keywords: Inclusive education. Teaching of Physics. Experimentation. Arduino. Optics.

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INTRODUCTION

Inclusive education, as recommended by the guidelines of the National Policy on Special Education in the Perspective of Inclusive Education (BRASIL, 2008), seeks to ensure the right of all students to effective participation in regular education, valuing human diversity and promoting educational equity. However, the inclusion of students with disabilities, especially those with visual impairment, still faces several challenges in the school context, among which the lack of specific training of teachers and the scarcity of didactic resources adapted to the needs of these students stand out (CAMARGO, 2012).

Visual impairment, according to Beyer (2003), refers to the total or partial loss of vision, and can be classified as blindness or low vision, which is characterized by reduced visual acuity and/or limitation of the visual field. According to Almeida *et al.* (2005), the understanding of these distinctions is essential for the teacher to adopt appropriate pedagogical strategies and favor the learning of these students. In the teaching of Physics, this reality is even more complex, since the contents require, to a large extent, the visualization and interpretation of phenomena, graphs, schemes and experiments, resources that are not always available in accessible formats.

In this context, this article aims to propose an accessible didactic sequence for the teaching of Physics in High School, focusing on the content of optics, using the experimental prototype *VDV Color Sensor as a resource*. The prototype was developed with the Arduino platform, TCS34725 color sensors, LEDs and sound emission, promoting tactile, visual and auditory stimuli that favor the learning of visually impaired students. The proposal is aligned with the perspective of Botomé and Kubo (2001), who defend teaching-learning as a relationship of exchange between teacher and student, requiring practices that articulate theory and concrete experience. In addition, it is important to note that experimentation is an alternative for students to understand theoretical concepts in a practical way (BRIGIDA *et al*., 2025).

The investigation adopted a qualitative approach, of a descriptive nature, according to Marconi and Lakatos (2017), and sought to understand how High School Physics teachers in the municipality of Salinópolis-PA have dealt with the inclusion of visually impaired students. For this, a semi-structured questionnaire was applied, made available via *the Google Forms platform*, according to Miguel (2010), in order to identify the presence of specific training, the use of inclusive methodologies and the application of adapted resources in the school routine.

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This study was developed with the support of the Federal University of Pará – Salinópolis campus, in partnership with the National Professional Master's Degree in Physics Teaching – *Belém campus* and the Álvares de Azevedo Institute, a reference in Special Education. The study had financial support from the Dean of Undergraduate Education (PROEG) and the collaboration of Professor Ronaldo Alex Raiol de Carvalho, a visually impaired person, who assisted in the preparation of the materials in Braille. From this collective effort, it seeks to contribute to the construction of more inclusive and effective pedagogical practices in the teaching of Natural Sciences, especially Physics.

THE INCLUSION POLICY AND TEACHING-LEARNING IN OPTICS CLASSES WITH VISUALLY IMPAIRED STUDENTS

The policy of educational inclusion in Brazil had its first historical milestones in the nineteenth century, with the creation of institutions aimed at serving people with disabilities, such as the Benjamin Constant Institute (1854) and the National Institute for the Education of the Deaf (1857) (BRASIL, 2008). In the twentieth century, entities such as APAE and the Pestalozzi Society were founded, which reinforced the segregating character of education for people with disabilities, limiting their activities to the scope of special schools. This model, based on exclusion, predominated for decades until the emergence of legislation that began to change this reality, such as the Law of Guidelines and Bases of National Education – LDBEN No. 4,024/61, the Federal Constitution of 1988 and the Salamanca Declaration (BRASIL, 1961; BRAZIL, 1988; BRAZIL, 1994).

From the 1990s onwards, the legal frameworks began to emphasize inclusion in regular schools. The Salamanca Declaration (1994) proposed international principles aimed at the construction of inclusive educational systems, reinforced in Brazil by the new LDB No. 9.394/96 (BRASIL, 1996). In the twenty-first century, measures such as the National Policy on Special Education in the Perspective of Inclusive Education (2008), Decree No. 6,571/2008, and Resolution CNE/CEB No. 4/2009 stand out, which established guidelines for Specialized Educational Service (SES) (BRASIL, 2008; BRAZIL, 2009). These provisions began to require inclusive pedagogical actions articulated with the school curriculum, in addition to the responsibility of the State regarding the access and permanence of students with disabilities.

Subsequently, Decree No. 7,611/2011 reinforced the right to inclusive education at all levels, and the National Education Plan (2014) established as a goal universal access

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for students with disabilities to basic education and SEA, preferably in the regular school system (BRASIL, 2011; BRAZIL, 2014). In 2015, the enactment of the Statute of Persons with Disabilities consolidated legal guarantees such as free admission and the prohibition of additional charges for accessibility features (BRASIL, 2015). In addition, the 2017 National Common Curriculum Base (BNCC) reinforces inclusion through curricular flexibility and the development of skills aimed at respecting differences (BRASIL, 2017). These advances, although significant, still face challenges regarding their effective implementation in everyday school life.

The teaching of Physics from the perspective of inclusion presents numerous challenges, especially with regard to the adaptation of basic concepts for students with disabilities. However, several teachers have been developing or adapting teaching materials in order to meet the specific needs of these students, thus promoting a better understanding of the contents. The use of alternative sensory resources and specific pedagogical activities has been shown to be effective in expanding the access and participation of these students in Physics classes.

Camargo and Silva (2006) carried out structured activities aimed at visually impaired students, such as the study of a sound event that addressed the concept of the meeting of two pieces of furniture. Through auditory stimuli, such as recordings of sounds representing a collision between a car and a train, students were encouraged to develop non-visual observation skills, demonstrating advances in understanding the proposed physical problem. In another experiment, Camargo, Filho and Silva (2006) explored the concept of acceleration of gravity using sound stimuli in experiments with inclined planes and vertical tubes, which provided adequate sensory cues to students with visual impairment.

In turn, Botan (2012) developed didactic materials aimed at deaf students, using a bilingual approach based on videos and books with signs in Libras and subtitles for the concepts of kinematics. Despite the linguistic difficulties faced by the students, the initiative resulted in advances in the teaching-learning process. Camargo (2012) contributed to the creation of tactile-visual and tactile-audiovisual models, applied to the teaching of content such as electric charges, crystalline lattice, electric current, among others, reinforcing the inclusive potential of these resources for students with and without disabilities.

Other relevant initiatives include the experimental prototype proposed by Aguiar *et al.* (2018), based on Arduino, which simulates a sound thermometer for thermometry classes, and the resources developed by Barthem, Silveira and Santos (2019), aimed at

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teaching waves to students with visual and hearing impairments, using sensors for frequency conversion. Mendes and Torres (2019) developed a didactic kit with magnetized tactile pieces to represent physical phenomena from different areas of Physics. Such proposals show that the application of inclusive resources favors active and meaningful learning, and is fundamental to promote accessible and equitable scientific education.

The teaching of optics to visually impaired students has motivated several researches that seek inclusive strategies in the teaching of Physics. Camargo and Nardi (2007) analyzed the performance of undergraduates in mini-courses with visually impaired students, using resources such as audiovisual books, computer simulators and videos. The study revealed difficulties in planning inclusive classes, mainly due to the traditional conception of vision-based teaching. However, the results pointed to the overcoming of the initial challenges, with future teachers developing creativity and confidence to act with inclusion in the classroom (CAMARGO; NARDI; VERASZTO, 2008).

Almeida *et al.* (2008) proposed experimental activities with low-cost materials, such as cardboard and string, to work on concepts such as reflection, refraction, light scattering and camera obscura. Camargo and Nardi (2008) reinforced the importance of accessible language combined with tactile/auditory stimuli to explain optical phenomena. Almeida *et al.* (2011) also developed a tactile model to explain the formation of images in concave and convex mirrors, encouraging inclusive pedagogical projects. Everton *et al.* (2012) presented a low-cost kit adapted to teach properties of light to visually impaired students, favoring the understanding of concepts such as reflection and refraction.

Young (2019) revealed, through neurological studies, that people blind from birth are able to form rich concepts about colors through language, demonstrating that cognition about colors can be built without direct visual experience. Costa (2017), in his dissertation, applied experiments with tactile and auditory resources such as light sensors and acrylic lenses to approach geometric optics, promoting greater understanding among visually impaired students, even in the face of initial difficulties.

Finally, Almeida *et al.* (n.d.) developed a circuit with Arduino and sensors to recognize colors, combining sound and tactile stimuli, expanding the possibilities of including students with visual and hearing impairments in the teaching of optics. The analyzed research reinforces that the cognitive capacities of students with visual impairment are comparable to those of sighted students, highlighting the importance of

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sensory adaptation of pedagogical strategies to ensure a truly inclusive teaching of Physics (AZEVEDO; SANTOS, 2014).

Braille writing is an essential tactile system for communication and learning for people with visual impairment. Developed by Louis Braille, the system allows access to reading and writing through touch, contributing to the inclusion of these individuals both in school and in society (LEMOS; CERQUEIRA, 2014). However, despite the advances, prejudice and exclusion are still manifested, either through the absence of adequate signage in public spaces or through the scarcity of professionals trained to teach Braille (FERNANDES; SCHILESENER; MOSQUEIRA, 2014).

It is important to note that not all visually impaired students use Braille; literacy and tactile acuity are requirements for its effective application (TORRES; MAZZONI; MELLO, 2007). In cases where Braille is not used, hearing appears as an alternative tool for understanding school content. Resources such as audiobooks, detailed narrations made by sighted people and audio description in didactic materials, films or plays, play a fundamental role in this teaching process (NUNES; LOMÔNACO, 2008; COLTO; DEDEZINHO, 2019).

The use of technology and accessible methodologies is also indispensable in promoting meaningful learning for these students. Digital tools, software with auditory and tactile resources, and adapted experiments provide greater engagement of students with visual impairment. The learning of complex contents, such as those of the discipline of Physics, depends on teaching strategies that consider the student's remaining senses and the differences between those who were born blind and those who acquired the disability later (SOUZA; TEIXEIRA, 2008; SILVA, 2016).

The use of adapted teaching materials and accessible experiments is especially important in the teaching of content such as optics, which traditionally depend on the visualization of phenomena. The application of resources such as tactile models, auditory descriptions and adapted sensory objects enables students with visual impairment to build knowledge in an autonomous and participatory way (ARAÚJO *et al.,* 2015; DICKMAN; FERREIRA, 2008). The use of interactive and low-cost educational objects is a recommendation to make teaching more inclusive.

Finally, the importance of the teacher's role in the construction of methodological strategies that contemplate the students' sensory needs is highlighted. The teaching-learning process depends on teacher mediation and the use of accessible approaches,

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capable of favoring the understanding and participation of all students, regardless of their visual condition (LAPLANE; BATISTA, 2008) Studies indicate that, even with visual limitations, students are able to interpret complex concepts through sensory and linguistic meanings associated with everyday life (CAIADO, 2014 *apud* SILVA, 2016).

FUNDAMENTAL CONCEPTS OF OPTICS AND THE BIOPHYSICS OF VISION

The study of light has evolved from the mythical conceptions of Greek philosophers to the foundations of modern physics. Initially, Homer, Pythagoras and Plato believed that light emanated from the eyes, advocating a corpuscular view (BASSALO, 1990), while Aristotle proposed a wave explanation. In the seventeenth century, Huygens reinforced this theory, contrasting with Newton, who in 1704 took up the corpuscular idea. In the nineteenth century, Young confirmed the wavelike nature through light interference, and Maxwell described light as an electromagnetic wave. With the advancement of quantum physics, Planck (1900) introduced the energy quanta, Lenard (1903) observed the dependence of electronic emission on the frequency of light, and Einstein (1905) explained the photoelectric effect with photons, proposing. Bohr (1913) described stationary electronic orbits, and in 1924 De Broglie associated wavelength with particles with , consolidating the wave-particle duality of light (LLEWELLYN; TIPLER, 2014).$E = hf - \phi \lambda = \frac{h}{mv}$

Isaac Newton (1643–1727) was a central figure in the history of science, with contributions that profoundly influenced physics and mathematics. A graduate of the University of Cambridge, he stood out for the formulation of the three laws of motion, the law of universal gravitation and the foundation of the infinitesimal calculus. In the field of optics, Newton carried out experiments with prisms that culminated in important advances in the theory of light and colors, which were gathered in the work *Opticks*, published in 1704 (FORATO, 2015).

While performing experiments with a glass prism of his own construction, Newton observed the decomposition of white light into a colored spectrum as it passed through the prism. It was from this experience that he coined the term *spectrum* to designate the sequence of colors: red, orange, yellow, green, blue, indigo and violet (ALVARENGA; MÁXIMO, 2014). Newton concluded that white light is not pure, but composed of the superimposition of several colors, which are separated by refraction due to the different angles of deviation of each color.

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In addition, Newton proposed that the colors of objects result from the fact that they reflect certain colors of the spectrum more intensely than others. For example, a red object preferentially reflects red light and absorbs the others (ALVARENGA; MÁXIMO, 2014). His ideas were initially rejected by part of the scientific community of the time, especially by Robert Hooke, which led Newton to avoid publishing new studies for many years, until he later decided to publish his complete work in *Opticks*.

Visible light sources are directly related to the behavior of electrons in atoms. When an electron is excited to a higher energy level and subsequently returns to the ground state, it emits electromagnetic radiation. Some of this radiation may be in the visible range of the spectrum, between 370 and 740 nm, the range to which our eyes are sensitive. The frequency of light remains constant when it passes through different media, although its speed and wavelength change. The equation relates frequency (), velocity () and wavelength (). Colors such as violet have a higher frequency and shorter wavelength, while red has the opposite (ALVARENGA; MÁXIMO, 2014).$f = v\lambda f v\lambda$

Selective reflection explains why we see colors in the objects around us: they preferentially reflect certain frequencies of incident light. An object illuminated by white light reflects only the colors corresponding to its physical characteristics and absorbs the others. Thus, a red apple reflects red light and absorbs other colors. Color perception can vary with the light source; for example, under fluorescent lamps, bluish tones stand out, while under incandescent light, reddish tones are more evident (HEWITT, 2015). This shows that the perceived color depends on both the nature of the object and the light that illuminates it.

The additive primary colors — red, green, and blue (RGB) — are responsible for the formation of the other visible colors. When these three colors overlap, they produce white light. The superposition of two of them generates complementary colors such as yellow, cyan and magenta. This combination is directly related to the physiology of the human eye, whose cones are sensitive to these three frequency ranges. The RGB model is widely used in electronic devices such as monitors and televisions. The proper mixture of these lights allows the reproduction of any visible color, according to the principle of color addition (HEWITT, 2015).

Vision is the most complex sense with regard to biophysical aspects, being responsible for transforming light into electrical signals that the brain interprets as an image. The visual process involves three steps: the refraction of light as a wave, the conversion of light as a photon into an electrical impulse by photosensitive structures, and finally, visual perception in the brain. The human eye is composed of several parts — cornea, iris, pupil, lens, vitreous humor, retina, and optic nerve — that act together to enable vision, absorbing incoming light and directing it to the retina.

The cornea is the first structure to receive light, accounting for about 70% of refraction. The iris, with its central opening called the pupil, regulates the entry of light according to the luminous intensity of the environment. The lens adjusts the focus of light that passes through the vitreous humor until it reaches the retina, a photosensitive and nerve layer that converts light into electrical signals sent to the brain by the optic nerve. The point of greatest visual sharpness is the fovea, located in the center of the macula (HEWITT, 2015).

In the retina, there are two types of photoreceptors: rods and cones. The rods are sensitive to dim light and are distributed in the periphery of the retina, while the cones, concentrated in the fovea, are responsible for color and detailed vision. The cones are divided into three types, each sensitive to different bands of the visible spectrum (red, green, and blue). For good color perception, it is essential that the light is focused directly on the fovea, where the cones are located and there are no rods (ALMEIDA *et al.,* 2019).

The detection of light begins with its refraction in the cornea, passing through the pupil and the lens until it reaches the retina (HENEINE, 1996). Only a small amount of photons reach the retina, where visual transduction occurs. In this stage, molecules such as rhodopsin, present in rods, absorb photons and undergo structural changes, initiating a cascade of chemical reactions that culminate in the generation of an electrical signal (BERG; TYMOCZKO; STRYER, 2014). These reactions involve the activation of the transducin protein and the conversion of cGMP to GMP, causing membrane hyperpolarization and neuronal signaling.

Color perception depends on the activation of three different visual pigments in the cones, with absorption peaks at 426, 530 and 560 nm. Rhodopsin, with a maximum absorption of 500 nm, is the main pigment in rods. In cases of visual impairment, such as blindness, the retina may be compromised, preventing the photoreceptors from working properly. This makes it impossible to transduce light into nerve impulses, totally compromising the process of vision formation (ENGEL, 2015).

METHODOLOGICAL PROCEDURES

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This is an experiment that was implemented during the Scientific Initiation period that received financial resources from the Institutional Program of Extension Scholarships - PIBEX of the Federal University of Pará, *Salinópolis* campus.During the Scientific Initiation, several stages were fundamental for the development of the proposed educational product. Initially, a training of the scholarship holder was carried out focused on the use of the Arduino platform, covering both the hardware and the software of the tool.

Arduino emerged in the 2000s, in the city of Ivrea, Italy, at the initiative of Professor Massimo Banzi and his team, with the aim of making the development of electronic projects and automation systems more accessible (SILVA, 2018). It is an open-source platform, composed of easy-to-use hardware and software, which attracts from amateurs to professionals from the most diverse areas (ARDUINO PLATFORM, 2021; LEMOS *et al.,* 2015). Its great differential lies in the possibility of creating devices that interact with the environment using sensors, LEDs, motors and other components (AMORIM *et al.,* 2011). With several boards available, such as the popular Arduino Uno, the platform stands out for its flexibility and simplicity, allowing users to configure digital and analog pins to trigger or capture signals according to their needs.

The Arduino Uno board, for example, has 14 digital and 6 analog pins, which operate in different voltage ranges, enabling a wide variety of applications. In addition, it has power pins and communication interfaces that allow connecting other modules and external components (ARDUINO PLATFORM, 2021). Programming is done in C++ language through the Arduino IDE, which offers libraries to facilitate the development of projects. The USB connection facilitates the sending of the code to the board and serves as a power source (SOUZA, 2013). Due to these characteristics, Arduino is widely used in the educational environment, allowing teachers and students to explore electronics and programming concepts in a practical and accessible way.

This moment of learning was essential for the progress of the research, as it provided the necessary technical basis for the elaboration and execution of the experiment. As André and Ludke (2018) point out, the initial stages of an investigative process are crucial, as they contribute significantly to the enrichment of specific knowledge and support the theoretical and practical construction of the proposal.

After this phase, experimental tests were conducted using different electronic components, such as LEDs, color sensors, resistors, and speakers. These tests aimed to evaluate the operation of the devices individually and together, enabling adjustments and

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improvements in performance. According to Gil (2007), this step is important to define and analyze variables, ensuring that the instruments used meet the research objectives and offer effective, valid and reliable results.

With the tests validated, we set out to assemble the prototype, write the programming codes and send the instructions to the Arduino Uno boards. The entire set was later encapsulated to ensure protection and functionality of the device. According to Pereira and Oliveira (2020), the use of experiments with the support of technologies in educational environments represents not only an innovative methodology, but also a relevant pedagogical resource, which enhances the learning of scientific concepts in a concrete and contextualized way.

The prototype created was called "*VDV" Color Sensor* — an acronym for "Sighted and Visually Impaired" — precisely because of its inclusive character. The proposal aims to serve both students with full vision and students with visual impairment, promoting integration and equity in the teaching-learning process. The device consists of four Arduino Uno boards, four color sensors, a speaker and four LEDs in red, green, blue and RGB, working in a synchronized way. The sensory response occurs through light and sound stimuli, contributing to the tactile and auditory identification of colors.

In addition to the main elements, the project had several other complementary electronic components, such as cables, resistors and protoboards, all easily found in electronics stores. The complete list of materials used can be consulted in Table 1, serving as a reference for future replications of the prototype or for new applications in different educational contexts.

Table 1 - Materials used

Materials	Specifications	Quantities
Arduino Board	Uno	4
Resistors	150Ω	6
LED RGB	5mm	1
LED (red, green, blue)	Diffuser 5mm	3
Jumpers for Connections	20 cm	29
Sensors	TCS34725	4
Power supply	6V	1
Male jack plug	2.1 mm	4
Female jack plug	2.1 mm	1
Speaker	4 Ω x 0.5W	1
PVC Electrical Junction Box	15 x 15 cm	1
Elastic flap paste	Solutions	3
Acetate Paper	21 x 30 cm	1

Source: The authors (2022).

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The *VDV Color Sensor* proves to be a robust educational prototype, with a strong inclusive and didactic appeal. Its development aimed to provide a tool that helps in the teaching of physical concepts, especially those related to light, color and sensors, using a practical and accessible approach. The project stands out for being adapted to the reality of visually impaired students, while contemplating sighted students, thus promoting collaborative and inclusive learning. The integration of simple technologies such as the Arduino Uno and the TCS34725 color sensor, with pedagogical resources such as the Braille identification system and sound feedback, was fundamental for the construction of a more dynamic, participatory and accessible teaching environment.

The choice of electronic components was strategic, considering both functionality and ease of replacement and cost-effectiveness.

The TCS34725 color sensor, for example, has excellent sensitivity and accuracy, being able to identify primary and secondary tones through its RGB filter and integrated white light. This sensor communicates with the Arduino via I2C protocol, which reduces the number of wires needed in assembly, facilitating the encapsulation of the system. The use of LEDs of different colors (red, green, blue and RGB) associated with resistors of adequate value allowed the emission of clear visual signals compatible with the results expected during the experimental tests. The speaker, on the other hand, was fundamental for providing auditory information to the visually impaired user, being programmed to emit a specific sound whenever the color of the palette coincided with the color of the environment illuminated by the corresponding LED.

In addition to the electronic circuitry, the physical design of the prototype was carefully planned. The PVC box used as the external structure was divided into four environments identified by both ordinal numbers and Braille signs, using transparent acetate to ensure tactile legibility. This division allowed each space to function independently, which enables the development of practical activities such as association games, pattern recognition and stimulation of sensory perception. The insertion of the palettes in the front openings of the device also followed ergonomics and accessibility criteria. Each palette, made with colored cardboard paper on both sides and identified with its corresponding color in Braille, was cut with a chamfer at one end to indicate the correct direction of tactile reading, respecting the standard directionality of Braille reading, from left to right.

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The prototype's feeding system has also been optimized. Although each Arduino board can be powered individually by USB connection, it was decided to use a single *jack* connector with branches, capable of simultaneously supplying power to the four boards. Not only did this reduce the amount of external cables, but it also made the device more organized and portable. This solution was ideal for school environments, where practicality and safety are paramount. The programming of each board was developed on the Arduino IDE platform and uploaded via USB cable, with specific codes for the operation of the color sensor, activation of the LED and the speaker, ensuring synchronization between visual and auditory stimuli according to the color detected.

Thus, the *VDV Color Sensor* consolidates itself as an effective assistive technology, integrating knowledge of electronics, programming, accessibility and education. Not only does it facilitate the teaching of Physics and Science, but it also arouses students' interest in areas such as robotics and automation, while contributing to the formation of a fairer and more egalitarian school environment. The prototype is therefore presented as a viable and replicable solution for other educational institutions, and can be adapted to different age groups, curricular content and specific needs of students.

THE DIDACTIC PROPOSAL

This research presents a didactic sequence as a proposal to support the teacher in the use of the prototype as a tool for educational inclusion. According to Araújo (2013), the didactic sequence consists of the systematic organization of school activities, being essential for a well-planned class.

Two lesson plan proposals were elaborated: the first focused on the theoretical approach to the optics of colors, accompanied by an oral evaluation; the second dedicated to the practical application of the prototype, also finished with an oral evaluation. The objective is to observe whether the use of the didactic resource contributes significantly to the teaching-learning process of students, especially students with visual impairment (VI).

The prototype was developed during the Scientific Initiation and was tested experimentally with a focus on the identification of colors and their respective frequencies. The didactic resource is based on the Arduino Uno board and its electronic components, such as resistors, LEDs and, mainly, the TCS34725 color sensor. This sensor is composed of photodiodes capable of capturing frequencies of RGB colors (red, green and blue), in

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addition to measuring the level of luminosity. It also has an infrared filter that improves color reading, minimizing interference generated by ambient light.

The prototype has a structure with four compartments, each with a front hole intended for the recognition of color palettes through the sensor. The programming performed in the Arduino IDE defines the parameters for the colors red ($R > G$, $R > B$, $1000 < C < 5000$), green ($G > B$, $G > R$, $1000 < C < 5000$) and blue ($B > G$, $B > R$, $1000 < C < 3000$). The LEDs used are semiconductor light emitters, whose radiation occurs in the visible spectrum through the principle of electroluminescence.

When it recognizes the color, the corresponding LED is activated, simultaneously with the emission of sound through a speaker. The sound frequencies were programmed as follows: RGB LED (400, 500 or 600 Hz), red LED (400 Hz), green LED (500 Hz) and blue LED (600 Hz). In this way, the visually impaired student can identify colors through the tactile and auditory senses. According to the MEC (BRASIL, 2001, p. 35), the teaching-learning process of visually impaired students should be mediated "through the remaining senses (touch, hearing), using the Braille System as the main means of written communication".

The VDV *Color Sensor* prototype proved to be efficient in correctly recognizing colors and emitting the corresponding sound signals. In this way, its potential is evidenced not only for the inclusion of visually impaired students, but also for other educational specificities. This is an experimental resource with potential for application by Physics teachers in the classroom, aiming at the validation of the proposed didactic sequence:

Step I

• Teach a previous, adapted class on the colors of the object: perform a brief review on the optics of colors, initially addressing the trajectory and contributions of physicist Isaac Newton in the field of optics and his studies with the prism; white light scattering; explain how we see light; the colors and frequency of the colors; selective reflection).

• Divide the class into groups for the application of questionnaire 1 orally and recorded, aiming at greater interaction between colleagues and facilitating the participation of visually impaired students;

Questionnaire 1

1. According to the explanation, how do we see colors?

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2. Differentiate monochrome light from polychromatic?
3. How does the decomposition of white light in a glass prism occur?
4. What is the relationship between wavelength and frequency?

Step II

- The teacher presents the prototype explaining in an investigative way, asking the students to identify each of the environments;
- Then take the prototype to each group so that each student in the group can handle and interact in an investigative way with the didactic resource;
- Observe the visually impaired student at the time of handling if in fact he understood the subject with the help of the didactic resource;
- And then, the teacher makes an oral evaluative questionnaire for both sighted students and visually impaired students.

Step III

Quiz 2

1. Suppose that inside a room there are three objects of different colors: green, blue and red. What color, respectively, will we see these objects if this room is illuminated by a blue-colored light?

a) Blue, blue and purple;
b) Green, blue and purple;
c) Black, blue and black;
d) All blue;
e) White, blue and white.

2. (UFPB) The leaves of a tree, when illuminated by sunlight, appear green because:

a) diffusely reflect the green light of the solar spectrum;
b) absorb only green light from the solar spectrum;
c) diffusely reflect all the colors of the solar spectrum, except green;
d) diffract only the green light of the solar spectrum;
e) human vision is more sensitive to this color.

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3. Judge the following propositions:

I – The colors of objects are determined by the frequency of light;

II – When an object is illuminated by white light, part of this light is absorbed and another part is reflected;

III – An object that is black in color absorbs all the light it receives;

IV – A white material does not reflect any frequency of light.

The sequence that presents the correct answer is:

a) V, V, F, F

b) F, F, V, V

c) V, F, V, F

d) F, V, F, V

e) V, V, V, F

4. The scattering of white light in a prism breaks down into the following colors:

a) Red, orange, yellow, green, blue, cyan and violet

b) Orange, yellow, red, green, blue, cyan and violet

c) Violet, cyan, blue, green, red, yellow and orange

d) Green, blue, cyan, violet, red, orange and yellow

e) Not one of the alternatives

RESULTS AND DISCUSSIONS

To understand the reality of Physics teaching in the context of the inclusion of students with visual impairment (VD), a semi-structured questionnaire was applied through *Google Forms*, a free digital platform that allows the creation of online forms with automatic data collection and analysis. According to data from the Department of Education of the State of Pará (SEDUC), the municipality of Salinópolis has seven Physics teachers working in High School in four schools: Prof. Aracy Alves Dias, Dom Bosco, Prof. Teodato de Rezende and Dr. Miguel de Santa Brígida.

The form was sent to the seven Physics teachers working in the municipality of Salinópolis-PA, and four responses were obtained. Low adherence shows a certain resistance to participating in the research. According to André (2013), qualitative research allows us to understand the meanings attributed to the experiences lived by the subjects.

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In this context, the data obtained support the relevance of proposals such as the present study, which seeks not only to provide an accessible didactic resource — the *VDV Color Sensor* — but also to foster critical reflection on the need for a more robust and inclusive teacher training.

The investigation aimed to identify aspects such as: the initial and continuing training of teachers, experiences with the inclusion of VI students and the use of inclusive didactic resources. The results are presented below:

- **Age group**: Of the respondents, two teachers (50%) are between 21 and 30 years old, and the other two (50%) are in the age group of 31 to 45 years.
- **Gender**: Three participants (75%) identified themselves as male, and one (25%) as female.
- **Education**: Only two professors (50%) have a degree in Physics. The others are trained in related areas, such as Mathematics, Natural Sciences and Pedagogy.
- **Time working in Physics teaching**: One teacher (25%) has been working for between 1 and 3 years, while the others (75%) have between 4 and 6 years of experience.

As for the profile of the participants, three are male and one female. To preserve their identity, they will be referred to as Teachers 1, 2, 3 and 4. Teachers 1 and 2 are between 31 and 45 years old, while Teachers 3 and 4 are between 21 and 30 years old. Regarding training, Teachers 1 and 3 have a degree in Physics, and Teachers 2 and 4 have a degree in Mathematics.

- **Experience with DV students**: Half of the teachers (50%) reported having worked with visually impaired students in their educational institutions, while the others did not have this experience.

The time of experience in the teaching of Physics is 4 to 6 years for Teachers 1, 2 and 4, a stage in which, according to Huberman (2000), there is a stabilization of pedagogical practices. Teacher 3 has between 1 and 3 years of experience, characterizing the phase of entry into the teaching profession. Regarding the experience with visually impaired students, Teachers 1 and 3 responded positively, while Teachers 2 and 4 reported not having had this experience.

- **Continuing education in inclusion**: Two teachers (50%) stated that they had continuing education in the area of inclusion; the others did not have such training.

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Regarding continuing education, only Teachers 2 and 4 reported having training in this area. According to Mororó (2017), continuing education is fundamental for the adoption of new inclusive methodologies that favor the active participation of students.

- **Initial training with a focus on inclusion**: Three professors (75%) reported having received some approach to inclusion during their undergraduate studies, through short courses, academic projects or the use of manipulative materials.

Regarding the initial training focused on inclusion, only Teacher 1 stated that he had not had any approach to the theme. The others mentioned that they had contact with inclusion through mini-courses, projects and manipulative materials. However, none indicated that they had taken a specific course on inclusion, which points to a gap in the curriculum of teacher training courses. For Tavares, Santos and Freitas (2016), undergraduate courses should integrate theory and practice, preparing teachers to develop didactic resources that include all students.

- **Use of inclusive teaching resources**: Only one teacher reported using materials in Braille, and another indicated the use of manipulative materials. The others stated that they had not worked with VI students.

The question about which didactic resources they used to include visually impaired students revealed inconsistencies. Although Teachers 1 and 3 stated that they had had experience with visually impaired students, they declared that they had not used inclusive resources. On the other hand, Teachers 2 and 4 mentioned the use of Braille and manipulative materials, although they had previously declared that they had no experience with such students. For Brendler (2014), the use of these materials is essential for an inclusive pedagogical practice.

- **Difficulties in teaching practice with DV students**: Two teachers (50%) stated that they had not faced difficulties with students with visual impairment, while the other two reported never having had students with this characteristic in their classes.

Regarding the difficulties faced to include visually impaired students, all teachers claimed not to have had any difficulties. However, in visits to schools during supervised internships, the pedagogical management reported that there were no projects or resources aimed at inclusion, which contradicts the answers provided. Such a discrepancy suggests weaknesses in teacher training and in effective inclusive practice in everyday school life.

These data show important gaps in teacher training for working with visually impaired students, especially with regard to the use of accessible teaching resources. Although there is a certain level of awareness and contact with topics related to inclusion, the results indicate that most teachers still do not feel fully prepared to develop truly inclusive pedagogical practices in the teaching of Physics.

FINAL CONSIDERATIONS

The inclusion of students with disabilities in regular classrooms should be a shared responsibility between the school and the teachers, who need to be properly prepared to ensure a meaningful teaching-learning process for all students, with or without disabilities. As evidenced in the theoretical framework, the use of adapted didactic resources in the classroom represents an important tool for the construction of a truly inclusive education (MENDONÇA, 2015).

The prototype developed throughout this research presents itself as a viable and effective proposal to be used by high school Physics teachers, providing visually impaired students with the possibility of actively participating in classes. The functionality of the prototype was experimentally validated, demonstrating that it is possible to promote inclusion through low-cost and accessible technological solutions.

During the data collection through the questionnaires applied to teachers in the municipality of Salinópolis-PA, there was some resistance on the part of some teachers, who chose not to participate in the research, demonstrating a lack of interest in the theme. In addition, the participants' answers showed contradictions and a certain lack of preparation related to inclusion, revealing significant gaps in both initial and continuing education of teachers.

The data obtained point to the lack of mandatory subjects aimed at inclusive education in the curricular matrices of the licentiate courses. This indicates the urgent need for a restructuring in teacher training courses, so that future teachers can experience, even during their undergraduate studies, experiences that prepare them to deal with diversity in the classroom (CASTRO; LIMA, 2012).

Another highlight was the construction of the material adapted in Braille with the use of the Perkins machine, enabling the elaboration of the palettes and environments of the prototype. This step was essential to ensure the autonomy of the visually impaired student

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during practical activities, promoting learning through the remaining senses — touch, with the Braille system, and hearing, with the sound signals emitted by the prototype.

Therefore, the present work not only reaffirms the importance of using low-cost experiments with the aid of technology in the teaching of Physics, but also reinforces the need for pedagogical practices that contemplate inclusion. It is believed that the use of prototypes such as the *VDV Color Sensor* can expand learning possibilities and encourage students to reflect critically on everyday physical phenomena.

Finally, it is highlighted that this research contributed significantly to the author's teacher training, expanding his vision of inclusive education. It is hoped that the study will serve as an incentive for other professors, researchers, and institutions to reflect on the importance of investing in inclusive practices and valuing diversity in the classroom. As a continuity, it is proposed to apply the prototype in real classes to evaluate its pedagogical effectiveness and develop new studies based on the results obtained.

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