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Exoplanets in physics and astronomy teaching

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ABSTRACT

This article aims to investigate Physics teaching and scientific dissemination activities with the main theme being the study of exoplanets, planets belonging to a star system distinct from our solar system. The theoretical basis of the project involves reading and writing about articles, books, theses and dissertations focused on the themes of this research. During the investigation, didactic materials about exoplanets were developed and evaluated, in different situations, in an interdisciplinary work that articulated areas such as Physics, Astronomy, Biology, Chemistry and Mathematics. In particular, the potential of the "Exoplanet Transit Hunt" software was analyzed as a didactic resource for teaching Physics concepts associated with the study of exoplanets. Audiovisual presentations and didactic workshops on exoplanets involved the use of videos, simulations, experiments, theoretical explanations and the proposal of challenges associated with real problems. The proposals were structured to be motivating for the study of Natural Sciences. In some of the activities carried out, a questionnaire, with questions about the topics covered, was answered by a total number of 113 students who participated in these actions. The obtained data were presented in graphs and tables that allowed to understand the perceptions and conceptions that the students have about exoplanets and the discipline of Astronomy, in general. The actions showed the students' great interest in the study of Astronomy themes, as well as the importance of educational practices that involve challenging investigative activities and related to those carried out by scientists.

KEYWORDS: Science Education. Simulation. Astrophysics.

INTRODUCTION

This article seeks to investigate educational actions on the theme of exoplanets – both short presentations of scientific dissemination, and longer didactic workshops – that were carried out in 2018 and 2019 with students with different levels of education. This research is justified by the growing number of exoplanets that have been discovered since the 1990s, as well as the intense way in which the media reports about these discoveries, often through vehicles that especially reach school-age students. The possibility that this theme has to contextualize the concepts of Physics that students study during their training can collaborate so that the learning process takes place in a more complete way. The potential to awaken students' interest in areas of Natural Sciences is another justification for addressing this issue in the educational environment. The hypothesis that we have worked with, since the beginning, is that the use of the study of exoplanets with students can help to stimulate interest in areas of Physics, including helping to learn scientific concepts associated with these areas.

Exoplanets are extrasolar planets, that is, planets that are not orbiting our Sun, but other stars. In 1995, there was the first report of detection of an exoplanet orbiting a star similar to the Sun, using the radial velocity method (MAYOR; QUELOZ, 1995; AMORIM; SANTOS, 2017). A few years earlier, in 1991, radio signals from a pulsar had already provided evidence for the existence of a planet outside our solar system, but in this specific case, orbiting a neutron star (WOLSZCZAN; FRAIL, 1992) which has different properties from the Sun. Currently, at the beginning of the third decade of the 21st century, something in the order of thousands of exoplanets has been detected so far. The two main methods used to detect exoplanets are the radial velocity technique (using the Doppler effect) and the planetary transit technique in front of the host star.

The radial velocity detection technique (also known as the Doppler spectroscopy method) is based on analyzing the "star-planet" system: after identifying its center of mass, through the Doppler Effect, it is possible to detect the deviation of the spectral lines to blue, when the star approaches the terrestrial observer, or to red, when the star moves away from the Earth. The detection of exoplanets, in this case, bears similarities with the characterization of binary stars (WRIGHT; GAUDI, 2012). The application of the conservation laws of physics requires that, as a planet orbits a star, the star will orbit a smaller opposite orbit around its common center of mass: in fact, strictly speaking, the planet and the star are orbiting around the center of mass of the star-planet system, but because the star's mass is generally much greater than the planet's mass, the center of mass is very close to the star's center. The size (and speed) of the star's orbit is smaller than that of the planet's orbit by the factor of their mass ratio. The component of this movement along the Earth's line of sight can, in principle, be detected as a variable radial velocity. Therefore, this detection method looks for tiny back and forth motions of the central star, due to the change in direction of the gravitational pull of an orbiting (invisible) exoplanet. Due to the Doppler effect, if the star is moving towards us, its spectrum is shifted to blue, and to red, correspondingly, when it moves away from us. By looking for these types of regular changes in a star's spectrum, periodic effects due to the influence of a star companion planet can be seen and the existence of this exoplanet is then determined: the observed variations are related to the masses of the planets that are orbiting the star (TEIXEIRA, 2016).

In turn, the planetary transit detection technique can only be applied when the planet's orbital plane has some alignment with our line of sight, that is, for a small percentage of exoplanets that obey this geometric and spatial condition in their position in relation to humans who observe these systems from Earth: as the planet passes in front of the star, partially eclipsing it, a corresponding decrease in the star's brightness is detected. By the differential photometry technique, according to which, image processing is used to compare the relative change in brightness between a target and reference stars of the same image (COWLEY; HUGHES, 2014), it is possible to measure the fluctuation in the star's luminosity during transit, which is small, usually in the order of one percent: the principle is the same as in a solar eclipse, because when the Moon passes in front of the Sun, the intensity of solar luminosity is reduced by an appreciable amount. This is an indirect method of detection, as the drop in light intensity implies the presence of the planet. As the orbit plane must be parallel to the line of sight from Earth, this limits the chances of observing a transit (GEORGE, 2011).

In 1999 the first transiting planet was observed - around HD 209458 (CHARBONNEAU *et al*., 2000). The observation of extrasolar planetary transits has become increasingly popular. The “Kepler Space Telescope” launched into space in 2009 provided data that allowed the discovery of many exoplanets by the transit method (GOULD *et al*., 2015). But today, even with telescopes with modest instrument configurations and installed in regions with light pollution, it is possible to obtain satisfactory data on planetary transit occurring in bright stars (SILVA; ROBERTO JUNIOR; ALVES, 2020). Through the transit technique it is possible to evidence the existence of the exoplanet and even calculate the size of the planet from the light curve coming from the star. When this data is combined with its mass value, obtained through the Doppler Effect, it is possible to estimate the density of the planet in question (SANTANA, 2011). The transit method is responsible for about 23% of the detections of exoplanets known to date (SANTOS; AMORIM, 2017). The radial velocity and planetary transit methods were responsible for the discovery of most exoplanets to date, but both lead to the observational bias that favors the detection of planets that are close to the host star.

In cases where two or more planets orbit the same star, the masses and radii of each planet can be estimated, allowing density determinations for all of them. In this case, the planetary transit time technique can be a method to estimate the mass, radius and density of planets with a mass on the order of Earth mass (HOLMAN; MURRAY, 2005). A useful tool for researchers studying exoplanets is the "Exoplanet Transit Follow-Up Tool"[1] which allows to plan observations by predicting when the transit time of each exoplanet around its host star will occur in the near future, such as in the 30 days after using the tool (ROBSON, 2020).

In addition to the two main detection methods presented above, there are a few other detection methods. Detection by "Direct Imaging", for example, consists of direct observation, which enables a better analysis of the composition of the observed exoplanet's atmosphere due to the spectral lines that can be evaluated from the emitted light spectrum across the planet, leading to important physicochemical parameters (MARTINS, 2013). This, due to its characteristics, is considered one of the most difficult methods to detect exoplanets.

Another technique for discovering exoplanets is based on Einstein's Theory of Relativity, which states that the trajectory of light changes when it interacts with space-time generated by the mass of an object located in the path of light to our eyes. In the case of a star-planet system, this technique can be used when light from a more distant star passes through the star system's gravitational field with an exoplanet: a “focusing” effect is produced due to the concentration of mass between the light source and the observer and thus the convergence of light will be greater for a planet-system compared to the situation when there is no presence of a planet. General Relativity describes this phenomenon by relating the distance between the observer and the lens, the distance between the lens and the source and the distance between the observer and the source (ALMEIDA, 2017). As this gravitational lensing effect - arising from the gravitational pull of a large object that bends light from distant objects - acts on the radiation from the source that is farther away, this technique can be used to study intervening objects that emit little or no light, like exoplanets orbiting stars. If the foreground mass to be studied is associated with a star that hosts a planet, then the amplified light curve of the background star will contain an additional lateral peak: the size and shape of this secondary peak will depend on mass and distance of the planet in relation to the host star.

The presence of a planet orbiting a star affects the timing of the regular signals emitted by the star itself: this phenomenon can be used to detect planets around a pulsar, a neutron star. Pulsars emit radio waves with extreme regularity as they rotate, creating a periodically pulsed beam, like a beacon. If an orbiting planet disturbs the star's motion, then the beam timing is also affected, which makes it possible for exoplanets in this situation to be detected. Because the intrinsic rotation of a pulsar is extremely regular, small anomalies in the timing of its observed radio pulses can be used to track the movement of the pulsar. Like an ordinary star, a pulsar will move in its own small orbit around the system's center of mass if it has a planet. Calculations based on pulse time observations can then reveal the parameters of that orbit, providing information about the exoplanet. Before the optical discovery of exoplanets, the technique of timing radio waves produced by pulsars provided the first evidence of a planetary system outside the solar system: in 1991, the discovery of the first planet orbiting a pulsar by Wolszczan and Frail was surprising, but also demonstrated the extraordinary accuracy that allows astronomers to detect bodies orbiting a pulsar, even allowing the detection of bodies the size of asteroids (KRAMER, 2018).

A study on how each of the exoplanet detection techniques works is important to reflect on the existing observational limitations and on the possible synergies between different methods and on what will possibly be the results of the new discoveries that should occur (FISCHER *et al*., 2015). As the study of exoplanets is located on the frontier of current Science and is related to knowledge that is being produced nowadays, educational work with this theme can help to clarify the students about the mechanisms on how Science works and is constructed from the collective effort of scientists from different parts of the world.

Exoplanets can help solve mysteries about our own solar system. The available data on different types of galaxies and stars allowed the development of theories about the formation of galaxies and stars, including our Milky Way and our Sun. The solar system is approximately 4.6 billion years old and up to the decade of 1990 this was the only planetary system we knew of. The study of other planetary systems younger than ours can provide clues to the formation of the solar system. Research indicates that protoplanetary disks are regions of dust and gas orbiting very young stars in the region where planets form. Current theories of planetary formation suggest that particulate dust begins to collapse under gravity and "clump" into larger grains. Over time, matter continues to clump together and eventually planetoids form. These small forming-stage planets are celestial objects larger than meteorites and comets, but smaller than the planets we know. After a few million years, most of the dust surrounding the star is swept away to accumulate on planetoids that grow into planets. Many of the planets found so far are large, gaseous and located very close to their stars, unlike the situation in our own solar system. The concept of orbital migration was developed to try to explain the proximity of some giant planets to their stars: this type of planet can form relatively far from its host star and then slowly spiral to a location closer to it over time (ESO, 2010).

A research topic that has been growing associated with the investigation about Exoplanets is the study about the possibilities of life outside the Earth, in particular, working with the extreme physicochemical conditions existing in many exoplanets. This field of knowledge, called Astrobiology or Exobiology, is a promising and expanding field, due to the technological development that today allows us to apply scientific methods to investigate the conditions for the existence of life elsewhere in the galaxy, a subject that is interrelated with the question of the origin of life on planet Earth (PAULINO-LIMA, 2010). Meteorites such as Orgueil (France, 1864), Murchison (Australia, 1969) and Allende (Mexico, 1969) showed evidence of the presence of amino acids; they underwent studies related to their optical properties and the results made it possible to consider that a portion of the amino acids deriving from the synthesis of the primitive hydrosphere – when life began to appear on Earth – could originate from space (CARRAPIÇO, 2001).

One of the ways to study the habitability conditions of a given exoplanet is by investigating its composition, which leads to research on the influence that stars have on the chemical composition of planets orbiting around them (SCHULZE, 2020). An important field of study related to the field of Astrobiology involves research on the atmospheric composition of exoplanets, including, for example, the detection of atmospheric molecular spectral characteristics, the observation of temperature gradients between day and night and the detection of atmospheric biosignatures (SEAGER; DEMING, 2010). A possible biosignature is associated with the fact that terrestrial vegetation plants have a marked increase in magnitude in the reflectance of their leaves between approximately 700 and 750 nm wavelength, in the so-called red border. This strong reflectance of Earth's vegetation in this spectrum band suggests that biosignatures with sharp spectral characteristics may be detectable in the light spectrum scattered by the atmosphere of an extrasolar terrestrial planet (SEAGER *et al*., 2005).

The "James Webb Space Telescope" – JWST[2] ("Telescópio Espacial James Webb"), which will possibly be launched into space by the end of 2021, will provide valuable data about the atmospheric characteristics of exoplanets in order to boost research in Astrobiology (KALTENEGGER *et al*., 2020; BEICHMAN *et al*., 2014).

Panspermia is a theory that suggests that life could spread from one planet to another or even between star systems (HAWKING, 2009), through asteroids, for example, an attempt to explain the origin of life on Earth. There are micro-organisms on our planet that survive extreme physical and geochemical conditions, being up to thousands of times more resistant to radiation than human beings; they are candidates for existing in places outside the Earth, for example, on Mars, on Titan (Saturn satellite), on Europa (Jupiter satellite) and even on bodies outside the solar system, such as exoplanets. These microorganisms received the name of extremophiles (because they live in extreme conditions) and studies point to a great variety in their typology, which would allow them to survive in the most distinct extreme environments, with regard to temperature, pH, salinity, pressure, radiation and humidity (BERNARDES, 2013).

EDUCATIONAL ACTIONS PERFORMED

In the second semester of 2018, in the context of this research, the authors of this article made short presentations of scientific dissemination about exoplanets, for students from five public schools on the north coast of São Paulo: at the State School Dulce César Tavares, located in the city of São Sebastião (SP), for high school students; at the Maria José da Penha Frúgoli State School, in São Sebastião, for high school students; at the Plínio Gonçalves de Oliveira State School, in São Sebastião, for high school students; at the Maria Aparecida Ujio Municipal School, in Caraguatatuba (SP), for students in the last years of elementary school; and, finally, at the Avelino Ferreira State School, in Caraguatatuba, for high school students. A questionnaire was designed to better understand the target audience, their knowledge of Astronomy, their relationships with the scientific subjects studied in the school environment and the impacts of the activity carried out. This questionnaire was applied in two of the aforementioned schools: the State School Dulce César Tavares and the Municipal School Maria Aparecida Ujio. In this case, 67 responses were obtained. In the first half of 2019, a new scientific dissemination presentation on exoplanets was held (with the same profile as those carried out in 2018), at another educational institution, at the Ricardo Luques Sammarco Serra Municipal School, in Caraguatatuba, for students in the last few years of elementary school.

In the first semester of 2019, with the experience accumulated in these short scientific dissemination presentations, a didactic workshop (with a longer duration) was created, involving concepts from the History of Science and mediated by the use of computers to access a simulation of exoplanet detection by the method of transit, made available by the program "*Exoplanet transit hunt*"[3]. In these workshops, students could interact directly with the simulation software with the task of trying to determine the physical characteristics of certain exoplanets, such as their average temperatures, in order to assess whether they would be habitable or not. Scientific concepts (such as radius and orbital period, centripetal acceleration, center of mass and Astronomical Unit) and the physical principles involved were presented at the beginning of each workshop, in an introduction, of an expository nature, made about the study of exoplanets. The use of the simulator to detect exoplanets was intended to help students better understand the concepts of dynamics existing in the study of a planetary system. Furthermore, these workshops allowed the contextualized approach to Kepler's laws and Newton's Law of Universal Gravitation.

These workshops were held at three times in 2019: for students in the 5th semester of the Degree Course in Mathematics course at IFSP-Caraguatatuba, in a computer lab at the institution; for students in the final years of elementary school at the Antônio Freitas de Avelar Municipal School, located in Caraguatatuba, in a computer lab at the IFSP-Caraguatatuba, during a visit they made to the Institute;

and for high school students at the Benedito Miguel Carlota State School, also located in Caraguatatuba, with computers provided by the school and made available by IFSP students who provided support for this specific action. The previously elaborated questionnaire underwent some changes and an additional question was added to it, as well as two questions were removed. This modified questionnaire was applied to students from the last two workshops that were held with students from Antônio Freitas de Avelar Municipal School and Benedito Miguel Carlota State School. In this case, 46 responses were obtained. Thus, the first workshop held for students of the Degree Course in Mathematics, when the questionnaire was not applied, was useful as a way of learning (a kind of "pilot workshop") on the best strategies to approach the theme of exoplanets in an educational activity with longer duration and more interactive.

In all the cases described above, the scientific dissemination and science teaching actions were centrally concerned with the idea of democratizing access to knowledge, as well as presenting the historical and dynamic character of science that is the result of the construction of many scientists who, collectively, create new knowledge. This is particularly evident in an area as recent as the study of exoplanets, something that helps to promote an understanding of how science works (CARVALHO; GONZAGA; NORONHA, 2011). Thus, the objective was to facilitate the understanding of scientific concepts used in the study of exoplanets, including a concern about the language that can best reach the lay public, in a frontier area of science like this (ALMEIDA, 2010).

RESULTS

The scientific dissemination activities carried out in the initial months of this research allowed for a better understanding of both the Science of exoplanets and the students involved in these actions and the profile of public schools in the region. In order to assess the educational impacts of scientific dissemination activities - and, later, of the didactic workshops held - as well as the existing understanding among students about the scientific themes associated with the study of exoplanets addressed by them, a questionnaire was created and applied to the students present at four different times (two scientific dissemination presentations and two didactic workshops), always at the end of each activity. The students who participated in the actions carried out were selected by their teachers to participate in them: one of the criteria for this was that the student had greater interest in areas of the Natural Sciences.

During the research period (2018 and 2019), responses were collected from a total number of 113 students between 13 and 17 years old, who participated in four activities in which it was possible to apply the questionnaires. Of these 113 students, 67 were students from two schools in which only one audiovisual presentation (about 30 minutes long) was made about exoplanets in 2018: for 30 high school students at the Dulce César Tavares State School, in São Sebastião (SP), and for 37 students in the last years of elementary school at the Maria Aparecida Ujio Municipal School, in Caraguatatuba (SP). The remaining 46 questionnaires (with some modifications in relation to the previously applied questionnaire) were applied to students who participated in two workshops (each lasting about 1 hour and 30 minutes in duration) held in 2019 and which involved the use of the "Exoplanet transit hunt" software: for 16 students in the final years of elementary school at the Antônio Freitas de Avelar Municipal School, in a computer lab at the IFSP-Caraguatatuba, during a visit made by these students to the IFSP (in this case, each student used a different computer) and for 30 high school students from the Benedito Miguel Carlota State School (in this case, the students gathered in groups with between 4 and 6 students and each group had access to one of the computers that were available for this workshop).

Therefore, most of the questions appeared both in the questionnaire applied to the students present in the audiovisual presentations, and in the questionnaire applied to the students present in the workshops (the answers in these cases are analyzed in Figures 1 to 7). But there were also two questions that were only presented to students present at the scientific dissemination presentations (whose answers are analyzed in Figures 8 and 9) and a question that was only presented to students present in the workshops (whose answers are analyzed in Figure 10).

The analysis of the students' responses made possible a better-founded reflection on the importance of the role of scientific dissemination activities carried out with the study of exoplanets as the thematic axis for the teaching of concepts in Physics, Astronomy and other scientific areas.

The application of the questionnaire was carried out in the context of these four activities (two shorter scientific dissemination presentations and two longer educational workshops) in order to diversify the universe of coverage as much as possible. Of a total of 113 responses, 67 responses (59 %) were given by students who had participated in a (shorter) scientific dissemination presentation (lecture-type) in which audiovisual resources and images about exoplanets were used, while 46 responses (41 %) were given by students who had participated in a (longer) didactic workshop on exoplanets in which students used computer simulations. Additionally, of the 113 students who answered this questionnaire, 60 (53 %) were from high school, while 53 (47 %) were students in the last years of elementary school.

In the following paragraphs, we will present the results of the students' responses to the questions in the questionnaires, in approximate percentage values. In total, there were 7 questions (along with two initial questions about gender and age of participants, in order to determine their profile) that were answered by all participants in the 4 activities mentioned above.

Table 1 – Distribution of percentages by gender of students who participated in the actions (N=113)

GENDER	PERCENTAGES
Female	55%
Male	45%
TOTAL	100%

Source: Authors (2021).

Of the 113 students who answered the questionnaire, a majority of 55 % were female, while 45 % were male (Table 1). In general, in the scientific dissemination actions that have been carried out with schools on the north coast of São Paulo, there is always a greater participation of female students in relation to male students: thus, female students are generally selected in greater numbers than male students by their teachers to participate of these activities. This may be an indicator that during basic education there is a greater interest by girls in areas of knowledge (such as Physics) which, paradoxically, in undergraduate courses are considered more "masculine" because they have a greater presence of men than of women in the student body. The reasons why this "inversion" occurs should be the object of more in-depth research in order to provide subsidies to combat the exclusion of female students from higher education courses due to gender.

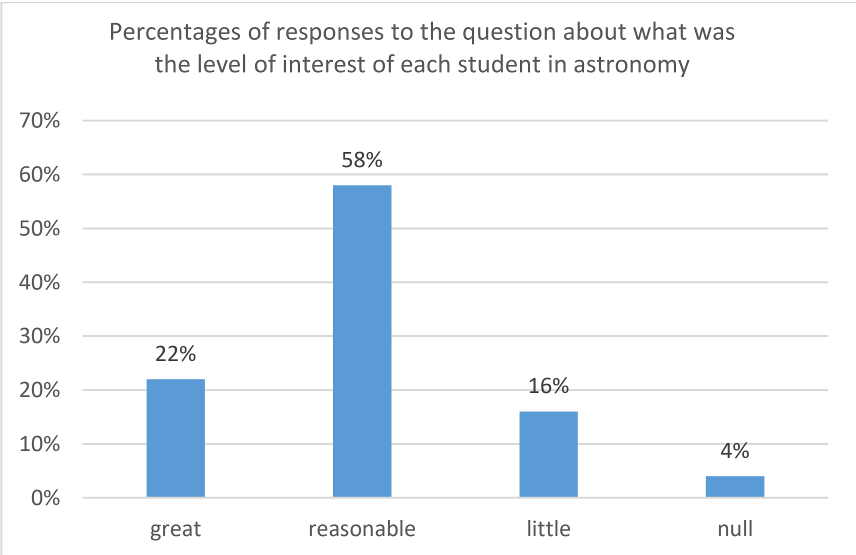
Table 2 – Distribution of percentages by age (in years) of students who participated in the actions (N=113)

AGE (years)	PERCENTAGES
13	5 %
14	34 %
15	46 %
16	13 %
17	2 %
TOTAL	100 %

Source: Authors (2021).

With regard to the age distribution (Table 2), which ranged from 13 to 17 years, almost half of the students (46 %) were 15 years old, an age mainly associated with students in the 1st year of secondary education.

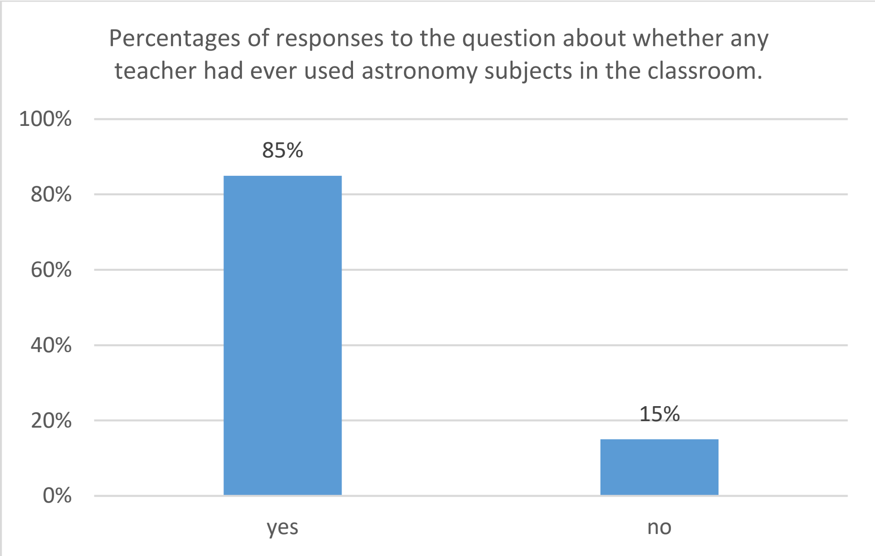
Figure 1 – Graph with the percentages of students' responses to the question about what was the level of interest of each student in Astronomy (N=113)



Source: Authors (2021).

The first question asked what was the student's level of interest in Astronomy. About 80 % of students said they have a great or reasonable interest in the field of Astronomy (Figure 1). As the students were previously selected by their professors to participate in the activity, having as one of the criteria their greater interest in the subjects of Natural Sciences, this result is not surprising.

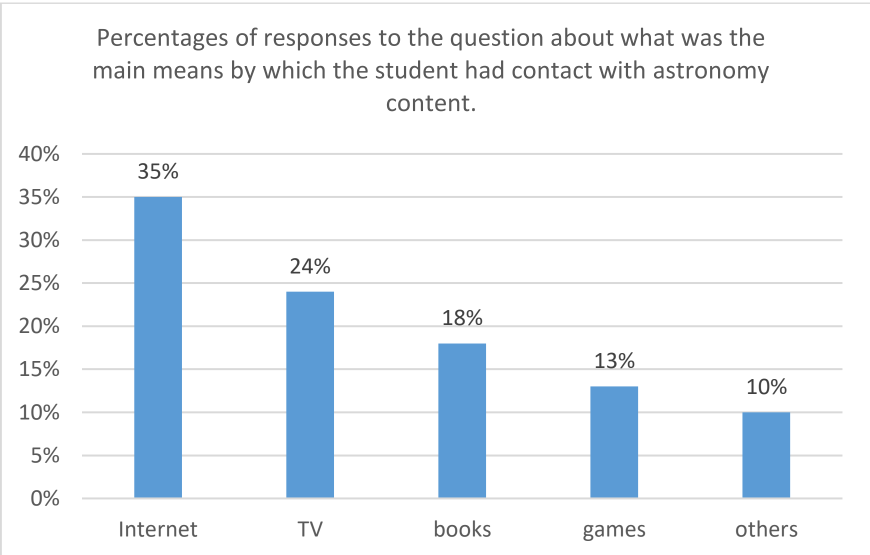
Figure 2 – Graph showing the percentages of student responses to the question about whether any teacher had ever used Astronomy topics in the classroom (N=113)



Source: Authors (2021).

The second question asked the students if any teacher had ever used any topic of Astronomy in the classroom: the vast majority (85 %) of the students answered yes (Figure 2). Among these students who answered in the affirmative, 89 % of them specified that this occurred in the Science subject (in elementary school), while 5 % said that it was in the Geography subject, 2 % that it was in the Physics subject, 2 % that it was in Mathematics and 2 % in Chemistry. These answers show that Physics still works little with Astronomy topics to discuss physical concepts and principles.

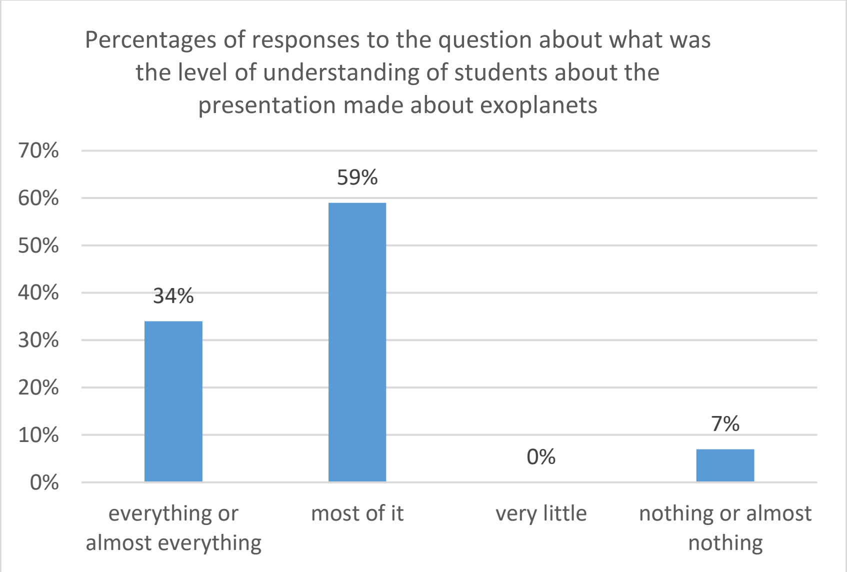
Figure 3 – Graph with the percentages of students' responses about what was the main means they used to have contact with Astronomy content (N=113)



Source: Authors (2021).

With regard to the ways by which students have contact with Astronomy content, the internet is the main ways ("media") of access to this type of information, followed by TV; these two media (internet and TV) together account for 59 % of the sources of access to scientific knowledge in the field of Astronomy (Figure 3).

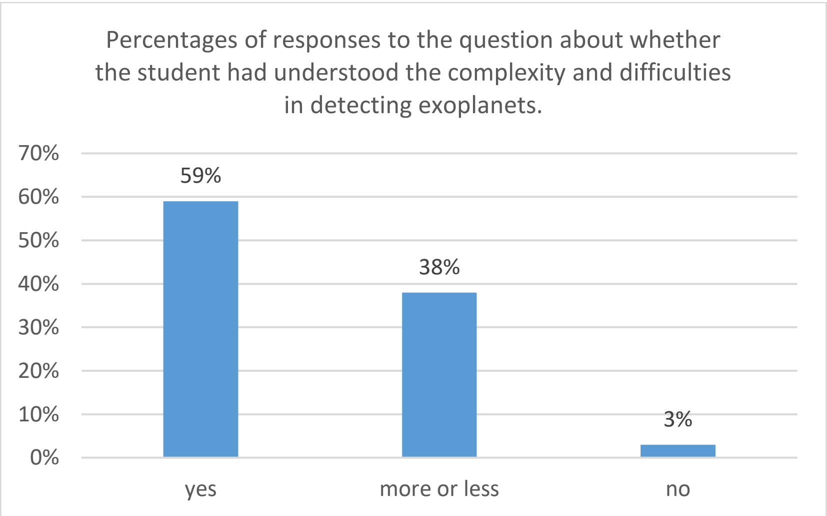
Figure 4 – Graph showing the percentages of student responses about how much of the exoplanet presentation they thought they understood (N=113)



Source: Authors (2021).

The fourth question asked about the level of understanding that students believed they had about the presentation about exoplanets they had watched: the overwhelming majority (93 %) claimed to have understood everything, almost everything or most of it (Figure 4). This result indicates that, at least from the point of view of the students present, the educational actions carried out managed to become understandable to most of those present.

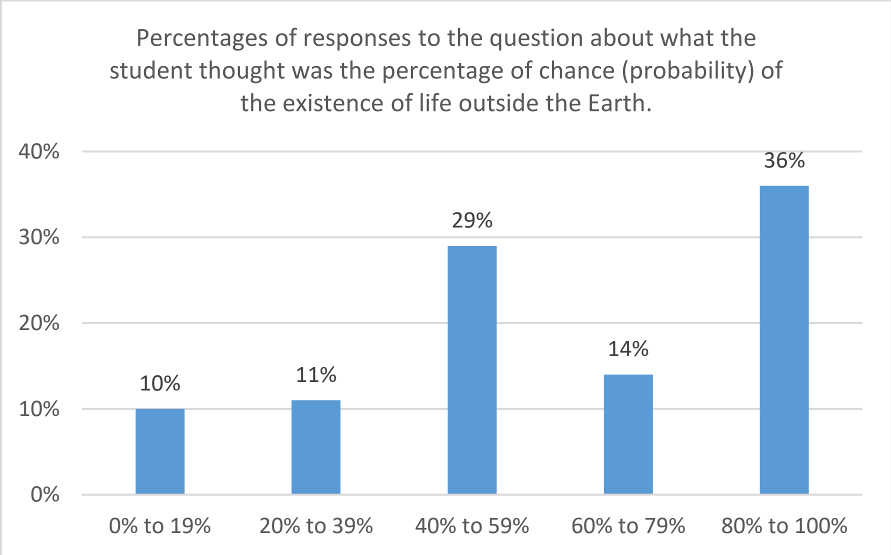
Figure 5 – Graph with the percentages of students' responses about whether they had been able to understand the complexity and difficulties in detecting exoplanets (N=113)



Source: Authors (2021).

The fifth question asked the students whether they had been able to understand the complexity and difficulties involved in detecting exoplanets: the majority (59 %) of the students answered yes, but a considerable portion (38 %) of them answered “more or less” (Figure 5). The exoplanet detection techniques (especially the two most used: the transit technique and the radial velocity technique) are very subtle and need high precision instruments and techniques to obtain data. Explaining about the complexity involved in these detection techniques was one of the objectives of the educational activities carried out, which was partially achieved by the responses of the students.

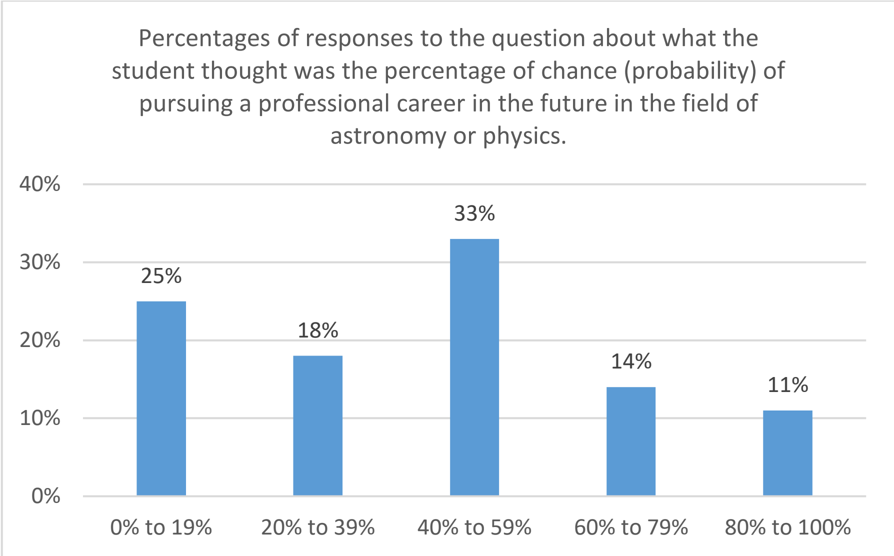
Figure 6 – Graph with the percentages of responses about what, in the opinion of each student, was the percentage of chance of the existence of life outside the Earth (N=113)



Source: Authors (2021).

The sixth question asked what, in the student's opinion, was the percentage of chance (probability) of life outside the Earth, on a scale from 0 % to 100 %: based on the data obtained, half of the students (50 %) answered that this chance should be greater than or equal to 60 % (Figure 6). A considerable portion of students with greater interests in Astronomy think that the chance of the existence of life on Earth is great: this partly comes from scientific and statistical considerations, but it can also be derived from a kind of hope that the expectation that life exists outside the Earth will materialize and that robust experimental evidence of this fact will be obtained in the near future.

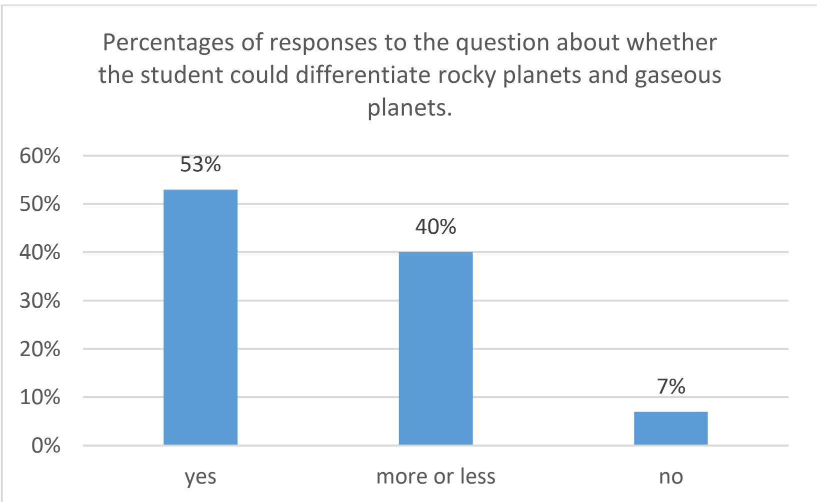
Figure 7 – Graph with the percentages of responses about what, in the opinion of each student, was the percentage of chance of following a professional career in the field of Astronomy or Physics in the future (N=113)



Source: Authors (2021).

The seventh question asked what was the chance or probability of the student in the future to pursue a professional career in the field of Astronomy or Physics, on a scale from 0 % to 100 %: 25 % of the students said that this chance was greater than or equal to 60 %, while 33 % of students stated that this chance was in the intermediate range between 40 % and 59 % (Figure 7). In particular, 6 of the 113 students surveyed stated that with certainty (100 % chance) they would in the future pursue a professional career in Astronomy or Physics. These data show that, even though they are minority, there is a not negligible amount of young people with great motivation to pursue scientific careers in the fields of Astronomy or Physics, but, as various data indicate, they give up on this purpose later on, for different reasons.

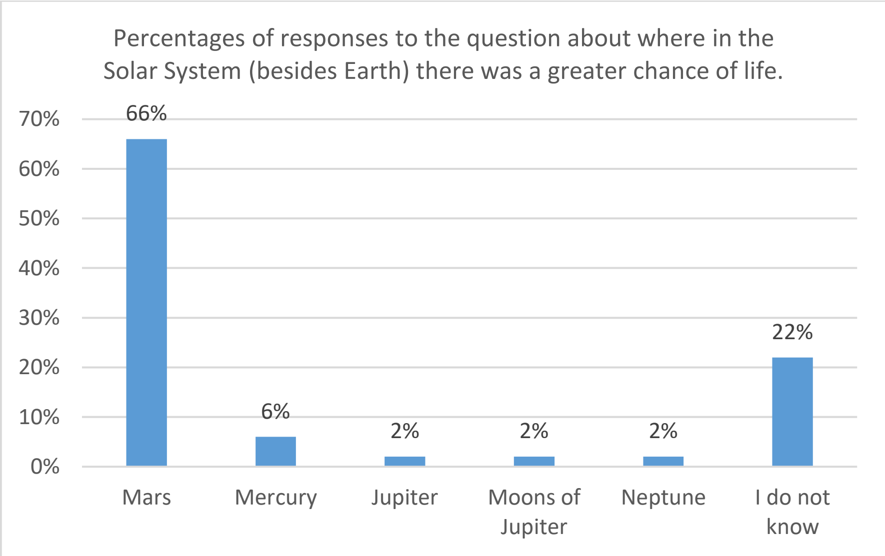
Figure 8 - Graph with the percentages of responses on whether the student could differentiate rocky planets and gaseous planets (N=67, referring to data collected in two science dissemination presentations on exoplanets held in 2018)



Source: Authors (2021).

A question asked only to the 67 students who participated in the two scientific outreach activities held in 2018, asked these students whether they were able to differentiate the rocky planets from the gaseous planets (after they had attended the educational activity on exoplanets): the majority (53 %) of the students answered yes, while 40 % answered “more or less” (Figure 8). Of the 8 planets orbiting the Sun, half are rocky and half are gaseous, and there is a robust investigation being carried out by astronomers trying to determine the nature of the detected exoplanets. Therefore, knowing how to differentiate between the nature of these two types of planets is an important skill in the process of learning scientific concepts related to the Science of exoplanets.

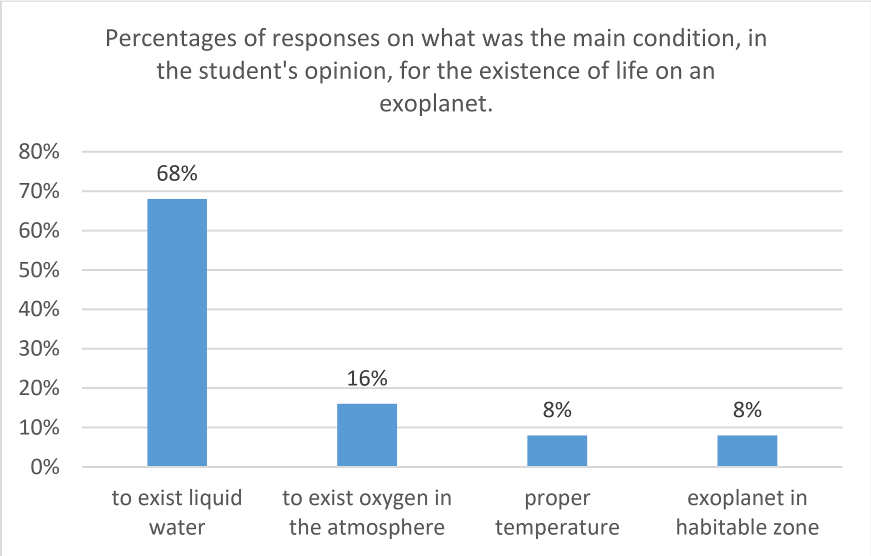
Figure 9 – Graph with the percentages of responses about where in the Solar System (besides Earth), the student thought there was a greater chance of life (N=67, referring to data collected in two science dissemination presentations on exoplanets held in 2018)



Source: Authors (2021).

Another question that was also asked only to the 67 students who participated in the two scientific outreach activities held in 2018, asked these students which planet or satellite in the solar system (besides Earth, obviously) they thought was more likely to have life. Of the respondents, a large majority (66 %) cited Mars as the place most likely to have life in the solar system; in addition, 23 % of students said they did not know how to answer this question (Figure 9). Mars really is a planet that is very present in articles published by the media and also in science fiction works, which usually arouse the interest of students with a greater affinity for school subjects related to Natural Sciences. Interestingly, no students have mentioned Venus, which together with Mars are the two closest planets to Earth.

Figura 10 – Graph with the percentages of responses about what was the main condition for the existence of life on a planet (N=46, referring to data collected in two educational workshops on exoplanets held in 2019)



Source: Authors (2021).

Finally, a question that was asked only to the 46 students who participated in the two didactic workshops held in 2019, asked which condition was considered to be the most important for the existence of life on a given planet: 68 % of the students responded that it was the existence of liquid water (Figure 10). Additionally, 8 % answered that the most important condition was temperature and another 8 % of the students answered that the most important condition was the planet being in the habitable zone around a given star. These last two conditions are also associated with the existence of liquid water, because for this to occur, the planet's temperature must be in the appropriate range and the planet must be in a region around its host star, which is also suitable. Therefore, adding the three percentages mentioned above, it appears that a considerable 84 % of students responded directly or indirectly that the main condition for the existence of life is to have liquid water on the planet in question. On the other hand, 16 % of the students answered that for life to exist, the main condition is the existence of oxygen in the atmosphere: this condition is presented as necessary (due to breathing) for the existence of animal life (including our existence, human beings), but for plant life on Earth, the predominant process is the opposite, that is, that of producing oxygen through photosynthesis, although plants obviously also breathe. In particular, on Earth we have anaerobic bacteria that don't need oxygen to survive.

DISCUSSÕES

In the didactic workshops mediated by the use of computer simulations that were carried out, the "Exoplanet transit hunt" software proved to be an extremely important tool, because by using a simulator to detect exoplanets, students were able to better understand the concepts of dynamics applied to the bodies of a planetary system. The scientific difficulties of the research on exoplanets carried out by astrophysicists became clear and perceptible to the students when they became responsible for the decisions taken in the context of the simulation, that is, when they put themselves in an active position in the detection activity, being able to reflect on the impacts of their choices, as the software only allowed progress, when data consistent with reality were obtained. Several interventions by the authors of this work were necessary during the workshops to clarify the concepts involved and to guide how to fill in some data in the program: this points to the importance of the teacher's role as a mediator in monitoring and coordination of activities made possible by the use of computers.

The workshops proved to be of great relevance for the teaching of Physics thanks to the possibilities that the software offers. The transit method – which detects the existence of an exoplanet from the observation of the decrease in the star's luminous intensity – which is used by the "Exoplanet transit hunt" program, is one of the most used methods of detecting exoplanets and provides information that leads to interesting results, obtained from algebraic manipulation. An investigative approach during the workshops was encouraged with the students, through the use of this program, as the data were collected and manipulated by themselves. In the case of the workshop applied with the class of the Degree Course in Mathematics at IFSP-Caraguatatuba, which had the presence of university students with, obviously, greater knowledge about Physics, it was possible to go deeper into the conceptual part and address the laws of Kepler and Newton's Law of Universal Gravitation.

Another relevant event, that highlighted the importance of the school's infrastructure, occurred during the implementation of the workshop at the Benedito Miguel Carlota State School, which did not have enough computers for the workshop to be held. Thus, in order to make this possible, some university students from the IFSP-Caraguatatuba made themselves available to collaborate with the authors of this work and to take their computers (notebooks) to school on the day of the workshop, making them available so that the high school students at the school could participate in the activity. As, in this case, the number of computers was limited, the students were divided into groups (with 4 to 6 members) and this conditioning factor caused an expressive interaction between students of the same group during the activity, which proved to be positive for learning the scientific concepts covered.

In the way the concepts related to this study were approached in the workshops, it became essential to use many concepts from Astrophysics and, consequently, from Physics, such as: the Doppler effect for the detection of exoplanets by the radial velocity method; Kepler's laws; the importance of the distance between a planet and its host star in applying Newton's Law of Universal Gravitation to study the behavior of exoplanets and the interaction between stars and their planets; the study of physics concepts such as center of mass, centripetal acceleration, orbital period, the concept of "Astronomical Unit" (AU) and the definition of a light-year.

FINAL CONSIDERATIONS

The experience gained from the realization of the six scientific dissemination presentations and the three didactic workshops that took place within the scope of this research, with students with different levels of education, allowed us to note that the use of exoplanets as a thematic axis can significantly collaborate to stimulate student interest in physics and astronomy, as well as to help the contextualization of the process of learning fundamental concepts of these subjects.

The analysis of data collected in this research throughout 2018 and 2019 allowed us to investigate how the teaching methods used dialogued with the expectations and perspectives of the target audience (elementary and high school students from public schools located on the north coast São Paulo), aiming at an effective dissemination of scientific knowledge, as well as a dynamization of the teaching of Physics. It was noticed that the use of educational software for simulating the detection of exoplanets presents a great potential to facilitate the understanding of the scientific concepts in question, as occurred specifically with the didactic workshops on the detection of exoplanets that used the simulation program "Exoplanet Transit Hunt”.

A fact that was evident is that Astronomy delights and motivates many students: using this advantage to teach about physics topics can be a powerful strategy in certain situations to facilitate the learning of various scientific concepts and break barriers. With the help of the “Exoplanet Transit Hunt” software and other tools, the study of exoplanets can be a great facilitator in the learning of scientific subject content in secondary and elementary schools. This type of work that was carried out also contributed to motivate young talents for scientific areas, as well as provoked improvements in the educational performance of the students involved, bringing them closer to the real way Science is done in practice. In particular, several students involved in the activities revealed that they came to better understand the importance and limits of the work carried out by scientists in universities and research institutes, something that, based on their manifestations, even gave some of them a broader awareness to analyze decisions taken about Science and Education at the national and world level.

EXOPLANETAS NO ENSINO DE FÍSICA E ASTRONOMIA

RESUMO

Este artigo tem como objetivo investigar atividades de ensino de Física e de divulgação científica tendo como eixo temático principal o estudo de exoplanetas, planetas pertencentes a um sistema estelar distinto do nosso sistema solar. A fundamentação teórica do projeto envolveu a leitura e fichamento de artigos, livros, teses e dissertações voltados para os temas desta pesquisa. Durante a investigação, foram elaborados e avaliados, em diferentes situações, materiais didáticos a respeito de exoplanetas, em um trabalho interdisciplinar que articulou áreas como Física, Astronomia, Biologia, Química e Matemática. Em especial, foram analisadas as potencialidades do software “Exoplanet Transit Hunt” como recurso didático para o ensino de conceitos de Física associados ao estudo de exoplanetas. As apresentações de cunho audiovisual e as oficinas didáticas sobre exoplanetas envolveram o uso de vídeos, simulações, experimentos, explanações teóricas e a proposição de desafios associados a problemas reais. As propostas foram estruturadas com o intuito de serem motivadoras para o estudo das Ciências Naturais. Em algumas das atividades realizadas, um questionário, com perguntas acerca dos temas abordados, foi respondido por um número total de 113 alunos que participaram destas ações. Os dados obtidos foram apresentados em gráficos e tabelas que permitiram compreender as percepções e concepções que os estudantes têm sobre exoplanetas e a disciplina de Astronomia, de modo geral. As ações evidenciaram o grande interesse dos alunos pelo estudo de temas de Astronomia, bem como a importância de práticas educacionais que envolvam atividades investigativas desafiadoras e similares aquelas realizadas pelos cientistas.

PALAVRAS-CHAVE: Educação Científica. Simulação. Astrofísica.

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NOTES

1 Available at: https://observatory.herts.ac.uk/exotransitpredict/main/.

2 Available at: https://www.jwst.nasa.gov/.

3 Available at: https://www.planetarium-activities.org/home.

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