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Astrobiology and the Inquiry-Based Science teaching

Is it possible to study exoplanets in a classroom?

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Abstract. Astrobiology studies the origin, evolution, distribution and future of life in the Universe, being, therefore, an interdisciplinary science. Topics addressed in this context are able to unify science teaching in schools, making the learning process more meaningful and interesting for everyone. In the present work, an Inquiry-Based Learning (IBL) sequence was developed for the 9th grade of Elementary School, whose main theme is "exoplanets". During four classes, consisting of both in-class and virtual activities, students have the opportunity to explore the various stages of investigative learning. For this purpose, the IBL proposed here includes not only texts and videos, but also quizzes, games, simulators, experiments and classroom dynamics. From the proposed set of activities, it is expected that students should be able to: (1) understand the basic concepts of the transit method, based on the study of eclipses; (2) assemble, interpret and analyze graphs; (3) elaborate and test hypotheses about the configuration of a planetary system; (4) discuss data and results, evaluate and justify conclusions; (5) and scientifically communicate their work. The next steps aim to test the IBL with students and improve it according to the results obtained. Hence, we hope that this material will consolidate itself as a tool to work on aspects of interdisciplinarity and teaching by investigation inside and beyond the classroom.

Resumo. A Astrobiologia estuda a origem, evolução, distribuição e o futuro da vida no Universo, sendo, portanto, uma ciência interdisciplinar. Temas abordados nesse contexto são capazes de unificar o ensino de ciências nas escolas, tornando o processo de aprendizado mais significativo e interessante para todos. No presente trabalho, foi desenvolvida uma Sequência de Ensino Investigativo (SEI) proposta para o 9º ano do Ensino Fundamental, cujo tema principal é "exoplanetas". Ao longo de quatro aulas, compostas por atividades presenciais e virtuais intercaladas, os estudantes têm a oportunidade de explorar as diversas etapas do ensino investigativo. Para isso, fazem parte da SEI não só textos e vídeos, mas também quizzes, jogos, simuladores, experimentos e dinâmicas em sala. A partir do conjunto de atividades propostas, espera-se que os estudantes sejam capazes de: (1) compreender os conceitos base do método de trânsito, a partir do estudo de eclipses; (2) montar, interpretar e analisar gráficos; (3) elaborar e testar hipóteses sobre a configuração de um sistema planetário; (4) discutir dados e resultados, avaliar e justificar conclusões; (5) e comunicar cientificamente seu trabalho. As próximas etapas visam testar a SEI com estudantes e aperfeiçoá-la conforme os resultados obtidos. Assim, esperamos que esse material se consolide como uma ferramenta para trabalhar aspectos da interdisciplinaridade e do ensino por investigação dentro e fora da sala de aula.

Keywords. Astrobiology – Teaching of Astronomy – Planets and satellites: detection

1. Introduction

Astrobiology is an interdisciplinary field that goes against recent science specialization and unites knowledge and technologies of fields such as Biology, Astronomy, Physics, Chemistry, Geology, and their respective subdivisions Paulino-Lima & Lage (2010). Many of the topics dealt with by astrobiology, such as extraterrestrial life and Mars colonization, are present in society and the popular imagination mainly due to movies, books, and sci-fi culture. It is also common to find these and other astrobiology topics present in the news, magazines, and internet websites Monteiro & Fonseca (2014). Just as in society in general, students are attracted to these themes. Such interest motivates schools to include astrobiology in their curriculum, as its Interdisciplinarity unifies science teaching and makes the learning process more meaningful and enjoyable for everyone.

In this perspective, LUCA - Ciência para Educar (Science to educate), a start-up company financed by the São Paulo Research Foundation (FAPESP) was founded. It is formed by a diverse team composed of biologists, chemists, physicists, engineers and programmers with a common interest in education. The company's objective is to research and develop didactic materials and scientific experiments, on the topics of astrobiology, for students at the end of Elementary School and High School. One of the main projects consists of the development of Inquiry-based learning (IBL) modules. This work presents the developing process, the final product, and the in-class application results of one of the most recent IBL sequences, based on the central theme "Exoplanets: How can they be detected?".

2. Development of the IBL sequence

The development process follows a well-defined protocol of steps: (1) Initial research: Selection of content and abilities and definition of the target public; (2) Fitting: How to fit into the Brazilian Education System; (3) Creation: Elaboration of activities and IBL sequence structuring; (4) Testing: Internal tests and support material creation; (5) Finalization: School tests and final product adjustments.

After the initial research step, it was decided to develop the IBL module aimed at the 9th grade of the Brazilian

Elementary School. According to the Brazilian National Common Curriculum Base (BNCC) Brasil (2018), the students in this educational phase must be stimulated to "analyze, comprehend and explain characteristics, phenomena and processes related to the natural, social and technological world, as well as the relations established between them, exercising the curiosity to ask questions, search for answers and create solutions based on the Natural Sciences knowledge". Besides that, students of this age are studying, or have studied recently, important subjects useful for the exoplanets IBL sequence. Some examples of related topics are periodicity of lunar phases, composition and structure of the solar system, the universe magnitude and astronomical measures and scales. Other abilities important for scientific research in general, such as planning, data collection, and graphics production and interpretation are also in their educational context.

To contemplate all selected subjects, four modules were developed, each composed of three stages: pre-class, class, and post-class. Both pre and post-class activities were thought to be executed in the online platform AstroLab and usually introduce and complement the content taught in class. These activities were proposed and organized according to the inquiry cycle proposed by Pedaste et al (2015), composed of five general inquiry phases: (1) Orientation; (2) Conceptualization (questioning and hypothesis generation); (3) Investigation (exploration, experimentation and data interpretation); (4) conclusion and (5) discussion (communication and reflection). Still, there is a sixth step that is desired, but not mandatory, related to "future-oriented stages", characterized by applying knowledge to new situations and starting new questions to investigate. These general inquiry phases guide the execution of the activities, but do not need to be followed linearly and inflexibly, hence, they can be superimposed, complement each other, and be revisited according to the objectives of each didactic sequence.

The following subsections present a short version of the four composing modules of the exoplanets IBL sequence, focusing on the activities thought to be executed in the classroom, as it may be useful and inspiring to teachers willing to present this topic to their students.

2.1. Module 1 - The moon and eclipses: an introduction to the transit method

The proposed activities for this module, which introduces the IBL sequence, have as main objectives to study concepts such as light and shadow, relative position, view-point and distances between and velocities of celestial bodies. These subjects are prerequisites to the development of an in-class investigation about lunar and solar eclipses. From the comprehension of these phenomena, the basic content for the next classes about the transit method, one of the main methods used for the detection of exoplanets, is expected to be understood by the students.

During the investigation activity, the students have access to different lights and spheres to explore arrangements that could explain solar and lunar eclipses. Meanwhile, during the experiments, they should discuss and answer within their groups the questions present in their material. Such questions are elaborated in a sequential way to lead the students to the final question:

"It is easy to detect a star. Just look at the night sky and you will see a bunch of them. Considering that stars emit their light, while planets don't, how is it possible to detect planets in other solar systems? "

Figure 1. Screenshot of the simulator's main screen showing, on the left side, the variables panel. The middle box represents the eclipse as seen by an observer located on the Earth's equator, and the right figure consists of a side view of the system Sun-Earth-Moon.

Figure 2. Screenshot of the simulator's main screen showing, besides the previous tools, a button for "Medidas de brilho" (Intensity measurements) on the right side, now available for the user.

2.2. Module 2 - Astronomy in the computer: simulators as important tools

The second module continues the study of eclipses, but, this time, the students will be aided by a virtual simulator developed by the LUCA programming team specially for this activity. It consists of a tool divided into four steps that aim at connecting the previously studied subjects with the transit method. The first step starts with the visual observation of the eclipse phenomena, highlighting three important elements: body positioning, diameters, and the distances between them and the observer. For that, the user can vary these parameters on the simulator and see the effect of the changes on the eclipse.

In the second step, another simulator tool is presented: the graph of light intensity as a function of time (in terrestrial days). At this moment, besides the tuning options presented in step one, the user may alter the system variables and observe how they affect the light intensity simultaneously, as when these change, so do the graphics produced by the simulator. After plenty of interaction with the new tools, the simulator hides the visual representations, stimulating the students to comprehend the situation through the graphics alone, such as is done by scientists.

In the third step, the students stop dealing with the Sun-Earth-Moon system and start studying the inner solar system, formed by Mercury, Venus, Earth and Mars as seen from Earth. Although Mars is present in the system, it is never located between Earth (the viewing point) and the Sun (the light source), therefore not interfering with the measurements, as the students should notice. Because the system is composed of two planets (Mercury and Venus, which can be differentiated by the size of

Figure 3. Screenshot of the light intensity graphs. In this simulation, the measuring equipment is located on the equator line and the study phenomena consists of the moon's transit in front of the Sun. Every time the moon passes in front of the Sun, a valley appears in the graph, as the light intensity measured decreases depending on the distances and sizes involved.

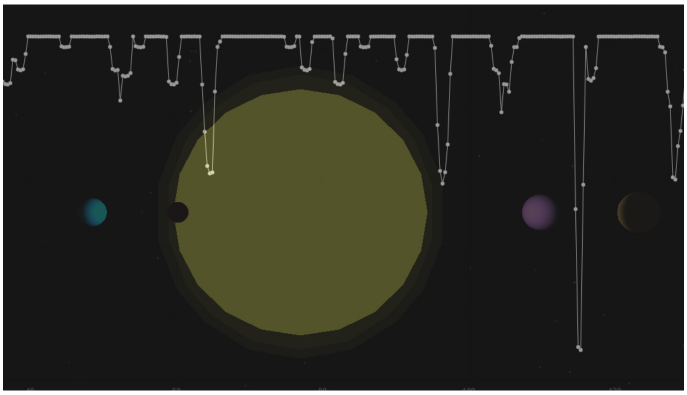

Figure 4. Screenshot of the light intensity graph yielded by a four-planets solar system and its representation in the background.

the vales) and it should be noted that Mars is not part of the system, this step has an incremented difficulty when compared to the previous.

To finish the activity, the students may create their hypothetical solar system, being able to choose the star diameter, number of planets, their sizes, and orbits, followed by a graphical analysis. This way, the fundamentals of the transit method and its applications should be comprehended.

2.3. Module 3 - Exploring the transit method: physical and virtual models

The third module was developed to be the longest of the four, with an estimated duration of two hours. Like the other modules, it should be performed in a group. The class is divided into four stations to establish more active dynamics:

Station 1 - Hypothesis: Each group only receives a simple graph of light intensity by time. With that graph only, they should be able to discuss the physical system that could have

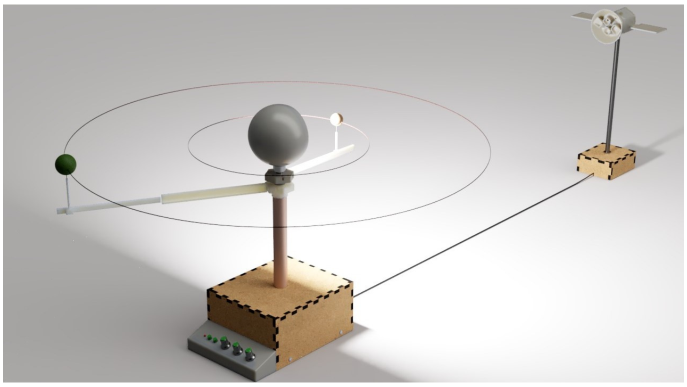

Figure 5. Provided equipment showing the buttons behind the orbital system and the adjustable rods.

generated it: *How many planets are there? How large are they? What are their orbital times?*

Station 2 - Validation: Based on the hypothesis, the group should present their theory to the teacher and defend it when questioned. If the hypothesis holds after the discussion, the group may follow to the next station. Otherwise, they can go back to the first station and discuss the system again.

Station 3 - Virtual Simulator: Using the same virtual simulator of the last module, the students should try to reconstruct the proposed system to compare the produced graph with the one they received and discussed. At this moment, small divergences are encouraged to be questioned and, in case their hypothesis is not enough to explain their observations, they should return to the first station.

Station 4 - Physical Simulator: After the proposition is validated, the group should be able to construct their system using the personalized equipment provided. The students can choose between spheres of different sizes and adjust their orbits using variable-size rods, controlling the orbit direction, velocity, and light intensity of the source. In front of the orbital system, a light detector, inspired in the form of the Transiting Exoplanet Survey Satellite (TESS), is positioned to measure the light intensities. This way, by the end of the process, the students should have three graphs: the one they received, the graph from the virtual simulator, and the graph from the physical simulator. If done correctly, the three graphs should be as close as possible, as identical graphs are impossible to acquire because each module has its limitations. These limitations are excellent topics for further discussion.

2.4. Module 4 - Working with more complex data: real-life measurements

This module consists of a discussion between the groups and the teacher to systematize the acquired knowledge about exoplanets and the transit method using data from real experiments. For that, graphs from the Trappist-1 system are provided, from which the students should be able to apply their knowledge to extract information about the number of planets and make suppositions about the planet's size and orbit according to the valleys' depths and lengths, as they are correlated. Part of the discussion is focused on the technological requirements for this type of experiment and the limitations of the methods.

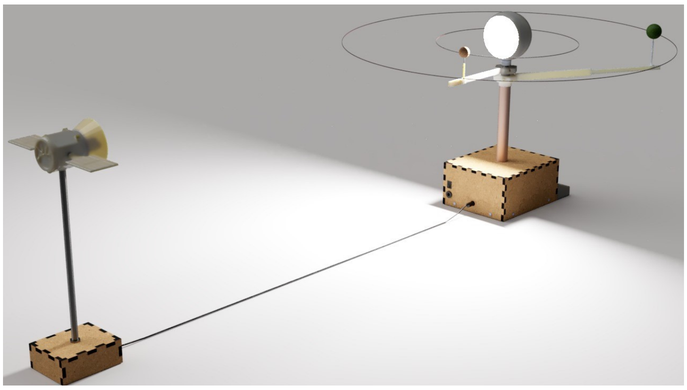

Figure 6. Provided equipment showing the satellite detector and the light source.

As the final product of this IBL sequence, the students should write a text formatted as a scientific article about the transit method and the investigating process employed.

3. Internal and external tests

After the material is developed, internal tests take place to verify coherence, if they satisfy the initial objectives, and to look for possible gaps. For that, a diagnostics tool adapted from the work of Cardoso & Scarpa (2018) is used to analyze the aspects related to the inquiry-based structure, the level of openness of investigative strategies, and the material quality in supporting students in their involvement with the process Cardoso & Scarpa (2018).

The next stage consists in employing the IBL in partner schools, delivering all the required materials, and conducting classes that are also accompanied by teachers, so that they could utilize the material properly without a LUCA team member.

Even as a non-mandatory class, the adhesion, and permanence of students were consistent and the feedback provided by the children and the school staff was mainly positive. The third module was part of the IBL sequence with most engagement from students, as the physical module was used several times and discussions were productive. After tests and feedback, the material was improved to its final form.

4. Final Considerations

Although the theme "exoplanets" may seem difficult to teach, considering its intangibility and complexity, the IBL sequence developed shows that if well organized and structured, it can be interactively and enjoyably taught such that, in a step-by-step manner, the student acquires the desirable abilities to analyze and understand real-life experiments.

Still, it is important to notice that the company's objective is the production of didactic materials, not discarding the teacher's role in the process. The IBL sequence is not supposed to be an immutable step-by-step guide to be followed, but a suggestion open to be incremented by the teacher and the school according to their own objectives.

Because of its dynamic nature, every time one IBL sequence is finished, something is learned by the team, so that the product can be updated according to necessities and suggestions.

5. Supplementary Material

As an initiative of open access, LUCA has made the transit method simulator source code and a live demo available at GitHub. Teachers and students are invited to use and contribute as they wish.

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References

Brasil. Ministério da Educação. Base Nacional Comum Curricular. Brasília, 2018.

Cardoso, M.J.C & Scarpa, D.L., 2018, Revista Brasileira de Pesquisa em Educação em Ciências, 18(3), 1025–1059

Monteiro, I.M. & Fonseca, L.C.S., 2014, Revista da SBEnBio vol. 7

Paulino-Lima, I.G. & Lage, C.A.S., 2010, Boletim da Sociedade Astronômica Brasileira, vol. 29, 14–21

Pedaste, M. et al, 2015, Educational Research Review, vol. 14, 47–61