Teaching of Physics in the context of planetology and habitability in High School: a case of successful online meaningful learning

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Abstract

The COVID-19 pandemic hastened the development of techniques and didactic sequences for online education, some that promoted learning, others that were lacking. In this contribution we |show how it was possible to achieve Ausubelian meaningful learning in Physics through remote teaching, by having as context planetology and habitability. These concepts may allow the development of expected specific competences described in the Brazilian Common National Curriculum Base (BNCC), that also have substantial media exposure and are possible to be developed in High School. At the end, the students have developed skills that allowed them to determine, based on real data, whether an exoplanet is habitable or not. Using Bardin's content analysis, it was possible to find evidence of meaningful learning of the intended skills and concepts.

Keywords: planetology; habitability; high school; physics; online education

Resumo

A pandemia COVID-19 apressou o desenvolvimento de técnicas e sequências didáticas para a educação online, algumas que promoviam o aprendizado, outras que deixavam a desejar. Nesta contribuição mostramos como foi possível alcançar uma aprendizagem significativa Ausubeliana em Física através do ensino a distância, tendo como contexto a planetologia e a habitabilidade. Esses conceitos podem permitir o desenvolvimento de competências específicas esperadas tais como descritas na Base Nacional Comum Curricular (BNCC), e que também têm grande exposição na mídia e podem ser desenvolvidas no Ensino Médio. Ao final, os alunos desenvolveram habilidades que lhes permitiram determinar, com base em dados reais, se um exoplaneta é habitável ou não. Utilizando da análise de conteúdo de Bardin, foi possível identificar evidencias de aprendizagem significativa das habilidades pretendidas e de conceitos.

Palavras-chave: planetologia; habitabilidade; ensino médio; física; educação online

Introduction

In the global educational scenario of the first half of 2020, remote education proved to be the safest way to guarantee the progress of formal activities. The covid-19 pandemic throughout the year, led us not only to different educational networks, but also led researchers to choose to carry out pedagogical activities online – and investigate them. This didactic research therefore was projected and planned to be carried out at a

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distance, fully online. Thus, we were able to develop strategies for the effective and remote execution of this project.

In this work, we look for ways to develop the teaching and meaningful learning of Physics, focusing on concepts related to planetology and habitability in high school. According to Moreira (2012), himself based on Ausubel's approach (AUSUBEL, NOVAK, HANESIAN, 1968), for learning to take place in a meaningful way, the student must be pre-disposed to learn. In the author's words, "the learner must want to relate new knowledge, in a non-arbitrary and non-literal way, to their previous knowledge" (MOREIRA, 2012 p.8). Thus, we believe, learning and teaching physics happens with a higher degree of achievement when the concepts are of interest to the student. In this way, the theme of "planetology and habitability" is a powerful context in which a teacher can expose concepts related to pressure, density, temperature, physical states of matter; among other numerous concepts that can be worked using this theme. Thus, we adopted as a research question "Can the remote teaching of concepts related to planetology and habitability in high school occur in a significant way?". That is a provocative but interesting question, because remote teaching during the year of 2020 happened – due to the sanitary precautions imposed by the reality of COVID-19 – almost totally online, without warning, with bare to no preparation from the teachers and the students and most importantly – breaking the didactic contract made with the students that the classes would happen in a school and live environment, among colleagues to interact.

In order to answer our research question, we stipulate the following objectives: to develop a didactic guide, which instructs students through the exploration of new concepts using mathematical operations that are compatible with their previous knowledge; understand the supposed conditions for the development of life; provide real data so that students can accurately determine whether or not a planet is habitable; analyze the students' arguments and what information they used to validate their inferences.

We see that this research is of considerable important for the didacticization of the theme in order to bring it to classrooms, whether virtual or live. Analyzing the current base in the BASE NACIONAL COMUM CURRICULAR (BNCC) (Common National Curriculum Base) (BRASIL, 2017), a document that standardizes and guides formal education at primary and secondary levels in Brazil; it is possible to identify that the theme proves to be very interesting. Among the 23 skills to be developed in science classes in high school, it is possible to contemplate up to 6 of them with the study of concepts related to planetology and habitability; being them:

> **(EM13CNT201)** Analyze and discuss models, theories and laws proposed in different times and cultures to compare different explanations about the emergence and evolution of Life, Earth and the Universe with currently accepted scientific theories. (**BRASIL, 2014, p. 557,** our translation)[1]
>
> **(EM13CNT203)** Evaluate and predict the effects of interventions on ecosystems, and their impacts on living beings and the human body, based on life maintenance mechanisms, matter cycles and energy transformations and transfers, using representations and simulations of such factors, with or without the use of digital

[1] (EM13CNT201) Analisar e discutir modelos, teorias e leis propostos em diferentes épocas e culturas para comparar distintas explicações sobre o surgimento e a evolução da Vida, da Terra e do Universo com as teorias científicas aceitas atualmente.

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devices and applications (such as simulation and virtual reality software, among others). (**BRASIL, 2014, p. 557,** our translation)[2]

(EM13CNT204) Elaborate explanations, predictions and calculations regarding the movements of objects on Earth, in the Solar System and in the Universe based on the analysis of gravitational interactions, with or without the use of digital devices and applications (such as simulation and virtual reality software, among others others). (**BRASIL, 2014, p. 557,** our translation)[3]

(EM13CNT205) Interpret results and make predictions about experimental activities, natural phenomena and technological processes, based on the notions of probability and uncertainty, recognizing the explanatory limits of science.(**BRASIL, 2014, p. 557,** our translation)[4]

(EM13CNT209) Analyze stellar evolution by associating it with models of origin and distribution of chemical elements in the Universe, understanding their relationships with the conditions necessary for the emergence of solar and planetary systems, their structures and compositions and the possibilities for the existence of life, using representations and simulations, with or without the use of digital devices and applications (such as simulation and virtual reality software, among others). (**BRASIL, 2014, p. 557,** our translation)[5]

(EM13CNT301) Build questions, elaborate hypotheses, forecasts and estimates, employ measurement instruments and represent and interpret explanatory models, data and/or experimental results to build, evaluate and justify conclusions in dealing with problem-situations under a scientific perspective. (**BRASIL, 2014, p.559,** our translation)[6]

In addition to the skills to be developed within the chosen theme, we also count on the theme's high media impact. According to Amato (2016) we rarely spend more than a week without viewing or receiving any news that is related to some astronomical discovery in the media, specially, nowadays, of the discovery of new planets that could bear life. This factor indicates the growth of the field and its attractive media power. This surely contributes to arouse students' curiosity.

According to Costa et al. (2018), in recent decades there has been a great increase in the number of published research on, as well as in the scientific dissemination of

[2] **(EM13CNT203)** Avaliar e prever efeitos de intervenções nos ecossistemas, e seus impactos nos seres vivos e no corpo humano, com base nos mecanismos de manutenção da vida, nos ciclos da matéria e nas transformações e transferências de energia, utilizando representações e simulações sobre tais fatores, com ou sem o uso de dispositivos e aplicativos digitais (como softwares de simulação e de realidade virtual, entre outros).

[3] **(EM13CNT204)** Elaborar explicações, previsões e cálculos a respeito dos movimentos de objetos na Terra, no Sistema Solar e no Universo com base na análise das interações gravitacionais, com ou sem o uso de dispositivos e aplicativos digitais (como softwares de simulação e de realidade virtual, entre outros).

[4] **(EM13CNT205)** Interpretar resultados e realizar previsões sobre atividades experimentais, fenômenos naturais e processos tecnológicos, com base nas noções de probabilidade e incerteza, reconhecendo os limites explicativos das ciências.

[5] **(EM13CNT209)** Analisar a evolução estelar associando-a aos modelos de origem e distribuição dos elementos químicos no Universo, compreendendo suas relações com as condições necessárias ao surgimento de sistemas solares e planetários, suas estruturas e composições e as possibilidades de existência de vida, utilizando representações e simulações, com ou sem o uso de dispositivos e aplicativos digitais (como softwares de simulação e de realidade virtual, entre outros).

[6] **(EM13CNT301)** Construir questões, elaborar hipóteses, previsões e estimativas, empregar instrumentos de medição e representar e interpretar modelos explicativos, dados e/ou resultados experimentais para construir, avaliar e justificar conclusões no enfrentamento de situações-problema sob uma perspectiva científica.

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astronomy. These factors contribute to the theme's popularity. Analyzing recent technological changes, according to Silva (2017), the main source of information and entertainment used by young people is the internet. Therefore, when we seek to develop classes using a theme that is frequently disseminated and presents information in accessible language and easily accessible by the student, we have the necessary components to foster the acquisition of knowledge in a meaningful way. To teach in an effective and lasting way, we will use David Ausubel's theory of meaningful learning. In this learning theory, broadly disseminated by Moreira (2012), we consider the concepts that the student already knows. The new knowledge will use previously established concepts as a cognitive basis. It is also possible to use the "previous organizers", these are described by the author as a quick and succinct way to prepare the student, prior to the class, to receive the new, cognoscible knowledge.

To analyze the answers presented by the students, we will use Bardin's (2016) content analysis. Through this sequential arrangement of procedures, we hope to visualize evidence of meaningful learning. The interpretation of data and categorization will make it possible to determine the meaning attributed in the student's speeches.

In the following sections the reader will find a description of the online teaching method; then, we will expose the theoretical framework that supports this research, meaningful learning and applied content analysis will be presented in the methodology subsection. These two theories guided the development of the material, for carrying out the activity and also analyzing the data collected. Last but not least, we present an analysis of our results and conclusions.

Online teaching

Just like the face-to-face modality, we see that the online modality also has advantages and disadvantages. According to Buntnaru et al. (2021) the lack of social interaction; as well as technical problems with internet connection and incompatibility of some equipment are factors that can negatively impact learning. On the other hand, online teaching presents a series of advantages that make teaching more flexible and provide new learning opportunities. These are, according to the authors, easy access to experts, greater exposure to educational environments and the possibility of joining study groups or communities.

In a study carried out by Maqableh and Alia (2021), the degree of student satisfaction with online education during the period of social isolation was evaluated in view of the Covid-19 pandemic. The work by Maqableh and Alia (2021) found that, in the short term, there was an increase in trust, participation, and the convenience of online studies. At the same time, the results show that there were students who noticed themselves more distracted, overloaded and suffering with connection problems.

While the study by Maqableh and Alia (2021) assessed online teaching in a general context, the work by Cheung (2021) assesses the effectiveness of using synchronous online classes. According to the author, in this modality the interaction between teacher and student takes place in real time, usually through a video conference. The author believes that this is the most beneficial modality for students as it is more like face-to-face classroom interaction. In another study by Cheung (2016), 16 recorded synchronous classes where teachers asked students questions were analyzed. According to the author during the sessions, many of the students choose to turn off their cameras

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and microphones. In this way there was no evidence of student interaction, although it was a synchronous encounter. The author recognizes that a case study, such as the one reported, cannot serve as a basis for analyzing synchronous teaching itself. Naturally, the teacher's methodology and the use of educational technologies can drastically influence student interaction (Li apud Cheung, 2021).

Taking note of the current research scenario, regarding the theme “online teaching”, we realized that the best way to carry out this research would be to carry out synchronous meetings with students. We also paid due attention to the amount of school work developed, to avoid overloading students. In addition, we opted to carry out the whole study in a few sessions, so that in the short term, according to Maqableh and Alia (2021), there was an increase in the participants' confidence. In the next session, the methodological procedures used to carry out this project will be presented.

Methodology

This project was designed to be carried out with students who were between the second and third year of high school at a public school in the city of Novo Hamburgo. A literature review carried out by the authors, on the selected topic, took into account works published in the period (2011 to 2020) using as keywords: “exoplanet”, “extra solar planet”, “teaching”, “learning”, “instruction” and “education”. After the literature review, it was possible to document that the subject of planetology and habitability, being already scarce, is even less covered in high school, since most of the work was aimed at students who were already at the undergraduate level. Thus, we started to idealize the didactic transposition so that high school students could experience such concepts. In addition to having contact with the concepts linked to the theme, we developed our activities using real data collected directly from the NASA Exoplanet Archive database (HAN, et al, 2014).

After the literature review stage, we started to build a didactic guide. This had, above all, the objective of guiding the student through the processes to be carried out. The guide made use of several previous organizers during the activities to activate their subsumers related to the topic at hand. Based on the literature review carried out, it was possible to develop a guide, that would allow the student to analyze real data from an exoplanet and infer, at the end of the process, whether this is an exoplanet or not and which planet could be habitable. This inference would be developed on the basis of the previous organizers presented by the guide. In them were presented factors that provide the development of life as well as possibilities for life to develop in extreme cases. The student should therefore reflect upon the real data obtained from the NASA Exoplanet archive database and using scientific argumentation, judge by themself whether the data revealed the existence of an exoplanet first and then if such exoplanet would be habitable or not.

In the subsections below, there are brief descriptions of each of the 5 steps used during the didact stage of this study.

1st Step: Contextualization

At this stage, students had their first contact with the concepts of habitability and habitable zone. To understand these concepts, it was ideal for students to be at least in the third year of high school. Thus, the probability that they have already had contact with such concepts is very high. Previous organizers are therefore very useful in activating existent subsumers needed for the task at hand.

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2nd Step: Estimation

At this stage each of the students was given a single Exoplanet and a table with information about it. In the following steps, these data provided to the students served as a basis so that, by applying physical concepts, reasoning and also mathematical calculation, they could identify characteristics relevant to the identification of the possibility of life, such as the mass of the planet, the density of the planet, the distance at which the habitable zone was located, and the temperature of the planet.

3rd Step: Classification

Using the data estimated in the second step and following the classification tables presented in the guide, the students were able to determine whether or not the studied planet was similar to planet Earth. Pertinent factors that allow a quick comparison with other planets in the Solar System were also used.

4th Step: Contextualization of Extreme Possibilities (outside the habitable zone)

In this session, students had contact with the concepts linked to the possibilities of habitability in the vicinity of the habitable zone. One of them is the possibility of a high light reflection index, which would allow a slight reduction in the planet's temperature. And the second is the possibility of a super dense sphere in a not very cold zone, allowing an increase in the planet's internal temperature.

5th Step: Argumentation

In this part the students had to argue, using the data obtained algebraically and classified to determine whether the exoplanet they studied could or could not be considered by them as a possibly habitable planet. Students were asked to use both the conditions presented and the possibilities to substantiate the inference.

Data collecting

To fully monitor the evolution of the students in the construction of concepts during this project we chose to carry out 4 processes divided into 2 stages of data collection. Each of the students would take a pre-test, the didactic guide, post-test and an interview. The interviews were conducted following Trevisan's “Report Aloud” (2019) protocol. This point idealized by Trevisan (2017) aims to identify the cognitive processes the student performed while answering the questions. Thus, in an interview that follows the “Report Aloud” protocol, the student reports everything he was thinking while answering a certain question.

The first stage of data collection was called “pilot test”, in which 2 students from the third year of high school performed the activity present in the didactic guide, as well as the post-test test and interview. The execution of a pilot test proved to be essential for the improvement of the teaching material before the effective data collection. The pilot test was carried out over a period of two weeks, with 4 virtual meetings with students through the Google Meet platform.

In the actual data collection, it took place within a period of 1 month, initially with 20 students attending the third year of high school. There was only one dropout throughout the process, so all 19 remaining students completed the planned activities. A

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total of 3 virtual meetings were held with each of the 19 students, using the Google Meet platform. In the first of them, students performed the pre-test and half of the activities present in the didactic guide. In the second virtual meeting, students performed the second half of the guide and responded to the post-test. The materials made available to students were sent to them in ".doc" format, so that they could be easily filled with a text editor.

The first two sessions took place in small groups, optimizing the time for data collection and encouraging communication between the students present in the sessions. The third virtual meeting took place only between researcher and each individual student to carry out the interview. Following the "Report Aloud" protocols, we seek to identify which cognitive processes were important for constructing their answer; that is, what insights took him from the question to the final answer. This is during the guide's most expressive activity, argumentation.

Data analysis

With the data collection completed, we move on to the treatment and analysis of these data. As previously mentioned, we used Bardin's (2016) content analysis theory, thus analyzing in a textual way what the students wrote in their arguments and also the transcripts of the interviews, upon when students reported what they were thinking when they responded and/or formulated the argument. During the floating reading, we did the scanning of the text , then it was defined that our categories would be made a posteriori, that is, based on the initial interpretations of the material. We adopted the objective of this analysis to identify whether the students inferred were able to correctly determine whether the studied exoplanet was habitable or not; based on which conditions and possibilities the students based their answers. To categorize one of the arguments presented by the students, we opted for the registration unit by themes; which we believe is the most appropriate for this case.

Results

When analyzing the students' assertiveness in inferring the habitability of the exoplanets studied, we were impressed with the result of 100% assertiveness. All students correctly assessed the exoplanet habitability based on the actual, present, world data provided to them.

We then proceed with the structural analysis of argumentation, where we seek to identify which conditions and possibilities the students considered when building their argument. There were three conditions presented in the guide that could support the students' point of view during the inference. Knowing this, we define the degree of the strength of the argumentation in terms of the number of conditions used by students in their speech. In this way, students who expressed only one of the three conditions in their answer were categorized as having a "low" degree of grounding. Students who related two of the three conditions were categorized with an "average" degree of grounding. And in turn, students who used all three conditions were qualified with a "high" degree of grounding. In Graph 1 we can see the number of students who were classified in each of the categories.

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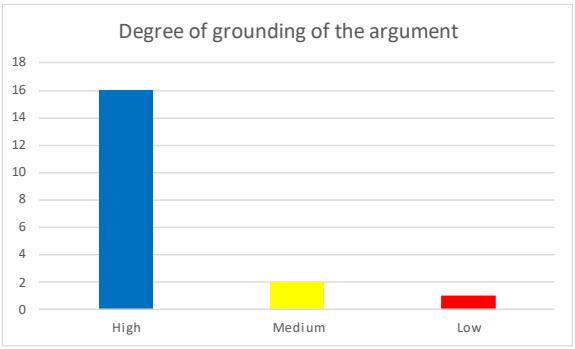
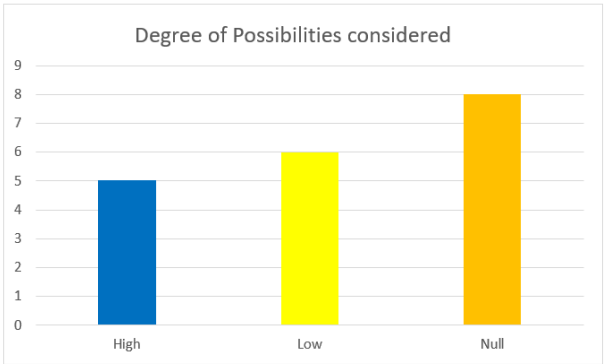


Graphic 1- Number of students in each of the categories developed to analyze the use of conditions.

Analyzing the conditions that were most used to support the students' arguments, we noticed that mass and density stand out. This condition was used by all students. Next, we have 'distance and habitable zone' in equal numbers with temperature, both conditions appearing in 17 of the 19 works.

In the argument, students were asked to consider the two possibilities of habitability in extreme cases. Analyzing the students' arguments, we classified them according to the degree of possibilities considered, cited or explained correctly in the answer. Students who considered both possibilities were classified as having a "high" degree of consideration for the possibilities. While students who used only one of the two possibilities were qualified with the "average" grade. Students who did not mention any of the possibilities were categorized with the "null" degree of consideration of the possibilities. In Graph 2 we can see the number of students who were included in each of the categories created to consider the possibilities.



Graphic 2- Number of students in each of the categories developed to analyze the use of extreme possibilities.

Analyzing the number of times each of the possibilities was presented, we see that 9 out of 19 students argued about the possibility of a dense atmosphere and only 7 out of 19 students spoke about the possibility of a high rate of reflection.

Discussion of results

Initially, we noticed the effectiveness in using the method, since all students could or were able to assertively infer their arguments. According to Moreira (2012), the assessment of meaningful learning occurs with a focus on capturing meanings and on the student's ability to transfer knowledge to unknown situations. The data demonstrate the

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students' success in facing a new problem situation, based on real-world data by using concepts that are rarely worked on in the classroom. We noticed that 16 of the 19 students showed a high degree of consideration of the usual conditions and that 11 of the 19 students related at least one of the possibilities in their argumentation. The use of both the conditions and the possibilities in the midst of argumentation is evidence that suggests that meaningful learning has occurred with most of these students.

Conclusion

Based on the data collected and on the literature that supports this article, we conclude that the study of planetology and habitability, through online platforms, resulting in meaningful learning is entirely feasible. Using previous organizers as facilitators and preferably by carrying out group work, thus encouraging communication even in online environments are factors that the authors consider cornerstones for the success of this study.

We ended this research very pleased, yet cautious, with the results obtained. We believe that new comparisons can be made between these results, one of them being the assertiveness of students in relation to the number of participants in each of the work groups. Because according to Roper (2007) group communication is important to increase the degree of understanding of concepts during the learning process. We also believe that the answers can be analyzed through the degree of detail of the explanations which will undoubtedly require more time from these researchers. But we believe that pertinent results can emerge from a more elaborate analysis.

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