Review Article

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On the strategy of emphasizing disruptive computer-based approaches when teaching astronomy to promote related careers

Abstract

The knowledge attained in the last decades in space physics, and in particular in Astronomy, has attracted, in part due to its associated computational innovation components, the attention of young students all over the world. Thus, both teaching and the scientific dissemination of knowledge in these areas should seek to guide, based on this interdisciplinary characteristic, talented young people towards related careers. By introducing Space Physics and Astronomy as data-driven sciences, and with a high dependence on computer simulation and disruptive technologies, we make the research and development activities associated with them even more attractive. In this article we highlight the program called *Decolar Astronomia* (DA), an initiative carried out in the city of S.J. dos Campos, SP, Brazil. In the DA 2022 edition, eight activities were formulated with the aim of emphasizing the relevance of computational knowledge in space sciences with an emphasis on 21st century Astronomy. In addition to describing the activities that were applied under DA-2022, we present a more generalstrategy that can be applied by any other program. This strategy emphasizes computational aspects (such as data-driven science and disruptive technologies) related to Astronomy, in motivating teaching programs for young students. The expected result, after applying this strategy, is that the interest in Astronomy and related careersbecomes even greater.

Keywords: Education for careers, space physics, astronomy, data science, applied computing, disruptive technologies

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Introduction

The essential use of computers in space physics and astronomy has been consolidated for more than five decades.[1-4] In particular, research in Space Sciences as Astronomy, Astrophysics and Cosmology is currently based on cutting edge technology to automate large telescopes (whether on the ground or in space), to observe (and advance knowledge through) large volumes of data with high sensitivity and high temporal, spatial and spectral resolution. Furthermore, using data to feed sophisticated numerical models to advance theory within the knowledge cycle. However, there is a question arising from this scenario involving disruptive computer-based approaches, as for example, *data science* and *cloud computing*: how much of this sophisticated scientific and technological apparatus can and should feed space sciences teaching, as well as dissemination initiatives, for young beginners who are yet to choose the career to follow. Faced with this challenge, several initiatives have emerged in the field of elementary education, in which the participation of experienced researchers in space physics and astronomy has been requested. More recently, the need to show students how the choice of cosmological parameters impacts the evolution of the universe, confronting theoretical adjustments with observations motivated us to develop software with a high level of an interface that would allow such understandings without all the necessary mathematical background.[5] In this endeavor that flourishes all over the world, the Program called *Decolar Astronomia* (DA)[6] was born in Brazil.

The Decolar initiative[1] is a reproduction of the *Centro para Desenvolvimento do Potencial e Talento* [2] (CEDTE), a program conceived by Zenita Cunha Guenther that draws upon humanistic educational philosophies.[7]

The pilot undertaking represents a pioneering special education center initially established in Lavras, Minas Gerais, operating within the framework of educational supplementation and currently encompassing numerous facilities across Brazil. The Decolar Program in progress, is an initiative of the Department of Education and Citizenship of S.J. dos Campos (SJC)-SP-Brazil. It aims to identify, monitor and stimulate the knowledge and talent of students with high capacity for careers of their own choice. In this way, the Program acts both for dissemination and for teaching, bringing teachers and researchers, as volunteers, who act as instructors in each programmed activity. The Program started in 2007 in SJC-SP[6] and in 2022 it resumed its face-to-face activities after two years of remote work due to the COVID-19 pandemic.

The program activities encourages self-knowledge, so that the students discover their skills and face challenges that empower them, preparing them for the future, bringing reflections and learning about the career, dreams and paths they want to follow, in addition to the formation of a healthy personality. One of the strategic areas of the program is science, with an emphasis on pure and applied research, where students have the opportunity to broaden their world view and understand the importance of technological innovation. In this scope, Astronomy is a topic that always arouses the interest of students, and so that they can deepen their knowledge and participate in experiences to build capacities. Thus, each DA scheduled activity is carried out in partnership with professionals who work in Space Physics and Astronomy.

The main focus of the 2022 edition was to present Astronomy as a data driven science, always involving scientific computing, leading students to learn about technological and computational aspects inherent to Astronomy in the era of Big Data.[8] In this work, we describe the 8 activities that make up Decolar Astronomia 2022 (DA-2022), identifying in each one, in addition to the contents and materials, the challenges and results achieved within a strategically planned schedule to bring students closer to the multifaceted career of a professional who works and will work in Space Physics and Astronomy in the 21st century. Based on the experience gained in developing the DA-2022 program high-lighting the computational aspects of the career, we present here a generalization of this strategy as shown in Figure 1. This takes into account common points of knowledge transmission that appear both in teaching and in scientific dissemination when strengthened by the main computational aspects involved in Astronomy and related careers.

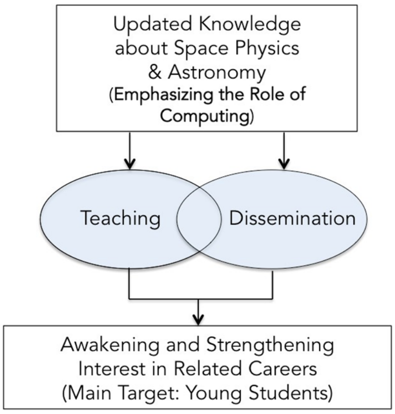

Figure 1 Outline of the strategy addressed in this work inspired by the activities developed during the Decolar-Astronomia program in 2022.The novelty in this edition was to emphatically highlight the current role of computing in research and development activities in Space Physics and Astronomy. In this sense, these careers are presented as data-driven sciences (data from observation and/or computational simulation).

The article is organized as follows: the Section 2 we presents the details of DA-2022 carried out with the participation of researchers from *INPE* and others institutions. In Section 3 we present a generalized strategy to promote careers for young students inspired by DA-2022. In the last section, we conclude the paper by discussing the importance and relevance of applying the teaching and dissemination strategy presented in Section 3.

The DA-2022 program in partnership with INPE

The Decolar program selects students from the municipal network to develop an individualized work plan after school hours, from the 6th to the 9th school period. They are students aged between 7 and 12 years. The program seeks to identify, monitor and encourage students considered enthusiastic and talented. Currently, Decolar has more than 200 students and offers activities in the main areas of Science, Research and Technology; Arts and Creativity, Skills and Expression; Gastronomy; Communication; Organization and Humanities. In general terms, the program selects students with high academic performance. These students choose, within the topics offered by the program, those that they identify as a possible career. Within this perspective, it is up to each team responsible for training (coordinators and teachers) to seek to maximize their influence in choosing that career. This creates an environment of healthy competition that will result in the adoption of excellence strategies capable of strengthening students' interest in that career.

For the period of 2.5 months (March to May 2022) around 15 students who choose, among others, Astronomy as a career were selected to participate in the activities of DA-2022 (a pilot sub-program with the potential to be reproduced in other coaching-initiatives and promotion of Astronomy as a career). The number of students was limited to 15 due to the following logistical factors involved: classroom size for online and hands-on activities, transferring students to field activities in a Van and number of instructors available in this edition.

The eight activities developed for the DA-2022 in partnership with the authors of this work are described below.

Activity A1

Topic: *On the Origin and Evolution of the Universe: What we already know and what we still need to understand based on big data.*

In this activity astronomy (in the framework of space sciences) was presented within the scope of Cosmology. Emphasis was placed on how models describing the Universe are confronted with inference and real data. Thus, astronomy can also be presented as a data-driven science also associated to others disruptive technological and scientific innovations.

The Data Science concept,[9] as shown in Figure 2, provides students with an overview of epistemology through Astronomy, starting from the first paradigm (pure empiricism), passing through the second paradigm (describing nature with mathematical models), and, of course, emphasizing the last two paradigms involving computing: the 3rd paradigm, that of computational simulation and the 4th paradigm, the current one that is science driven by data. In this scope, the concept of Big Data[9] also emerges, involving the famous four Vs (4Vs): data involving large **Volumes**, high data acquisition **Velocities**, high data **Variety** and their heterogeneous **Values** (mainly in the sense of data life cycle). With this knowledge in mind, we try to answer the question that defines this Activity (A1), starting from the early Universe (Big Bang conjecture) to the current Universe when z (the *Redshift*) equal to zero (This timeline is in its idealized form of topics in the left column of Figure 6). During this "cosmological journey", beyond the physical and astronomical concepts, we use advanced N-body simulations and highlight the main computational approaches used in each snapshot of cosmic evolution. Gravitation is also presented from the point of view of Space Physics, offering a hook to discuss simulations with the few bodies that make up our solar system.

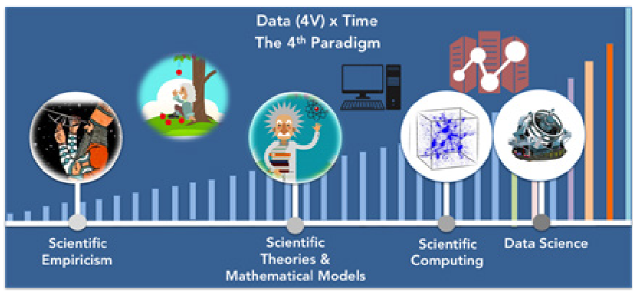

Figure 2 The main picture used in A01 to introduce students to Data Science as the 4th paradigm, with icons from space physics and astronomy.

In this activity A1 we also highlight that astronomical observatories, in relation to their place of operation, can be distinguished into four categories: space-based, airborne, ground-based, and underground-based. Each category seeks to meet the research demand in the different energy windows of astronomical observation: Radio, Infrared, Optics and High-Energy Astronomy. In this opportunity, some aspects of disruptive technologies (such as adaptive optics supervised by AI, for example) are mentioned to arouse the interest and curiosity of students. The workload for this activity was 2.6 hours with two 10-minute coffee breaks.

Activity A2

Topic: *Meeting with Space Science Workers: a narrative about each experience and the computational challenges in the career*

In this activity, we invite two workers in space sciences, a researcher and a data engineer, to talk about their professional life since their student days. During the interview, each one was encouraged to report their experience with computing, with emphasis on the use of cutting-edge technologies. More specifically, each of the Interviewees was induced, as previously agreed with the students, to comment on their experience with data science, cloud computing and IoT devices related to observation, simulation and data analysis in this era of disruptive innovations. For this, we use the tables shown in Figure 3.

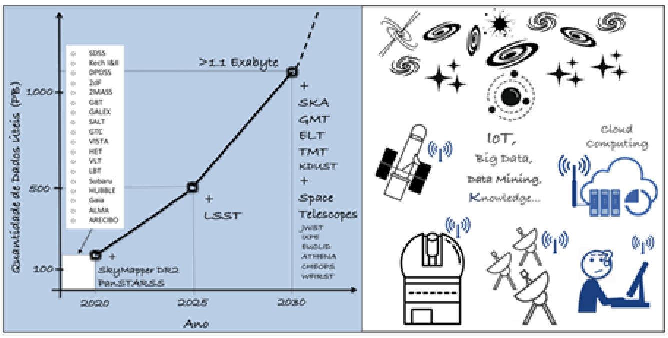

Figure 3 The main picture used in A2. Left: graph showing the forecast for the increase in the amount of useful astronomical data (in Petabytes) given the main observational missions. Right: a drawing made together with the students featuring how astronomers will face all of this.

The chat was held remotely and had the participation of Dr. Simone Daflon (from the National Observatory of Rio de Janeiro) and the Data Engineer, Dr. Felipe Madsen (from the National Radio Astronomy Observatory (NRAO), NM-USA). The workload for this activity was 2 hours with one 15-minute coffee break.

Activity A3

Topic: *Visiting the National Institute for Space Research (INPE) Facilities* in this activity, we schedule student visits to some facilities of the National Institute for Space Research: (a) LIT (Integration and Testing Laboratory) that build satellites,[10] (b) Brazilian Program for Studying and Monitoring Space Climate (EMBRACE);[11] (c) Astrophysics Division BINGO Project;[12] (d) Brazilian Decimetric Array (BDA)[13,14] and (e) CPTEC's Supercomputer.[15] In each of the visits, the students interacted with equipment and instruments, always trying to raise questions about IT for the professionals who received us.

The workload for this activity was 10 hours split into two visits (Figure 4).

Activity A4

Topic: *Interacting with a Modern Telescope for Solar Observation with emphasis on IT resources*

This activity was carried out on the facilities of the Interactive Science Museum (MIC) where we used a telescope with a switch and automatic guidance (Celestron NexStar 4SE). Students were introduced to the fully automated Go to assembly with a database of over 40,000 celestial objects to automatically locate and track objects. They also learned about Sky Align technology for telescope alignment from three bright objects. In this activity, however, carried out during the day, the observation of sunspots was explored (with the use of appropriate filters). As a hook, high-performance simulations of the solar dynamo model were shown, which explains the generation of sunspots from changes in the configuration of the solar magnetic field.[10,11] Spontaneous questions emerged about solar granules, convection and turbulence thus evolving the discussion towards the possibility of similar complex processes in the Earth's core and atmosphere.[12,13]

Figure 4 Above: students visiting, after visiting the control room, the antennas that make up the Brazilian Decimetric Array (BDA). Below: the same group visiting the CPTEC-INPE supercomputer.

Activity A5

Topic: *Simulating Space Travel to Learn Space Physics and Orbital Mechanics* In this activity, based on Kerbal Space Program (KSP),[14] we introduce students to the concepts of space travel from the perspective of physics and mechanics. Firstly, we introduced the concept of "Newton's cannon" from a dynamic activity in the classroom using a paper ball thrown with increasing speed until we reached the abstract idea of how to put an object in orbit. After introducing this concept, we discuss Kepler's [3] laws that define how to put an object into orbit. Then we introduce the software the KSP[3] where we simulate a manned mission in orbit and then back to Earth. It is worth noting that, at the time of re-entry, the simulation illustrates the very important aspect of a very well-planned space engineering project, as the mission can be compromised especially for re-entry into the atmosphere where the prototype needs a thermal shield due to the increase in temperature due to friction with the air. In a second moment, a new mission was developed with the objective of landing on the "Moon" and here we used a resource of the KSP of orbital maneuver that allows us to calculate and visualize the spacecraft's travel routes as Figure 5 illustrate.

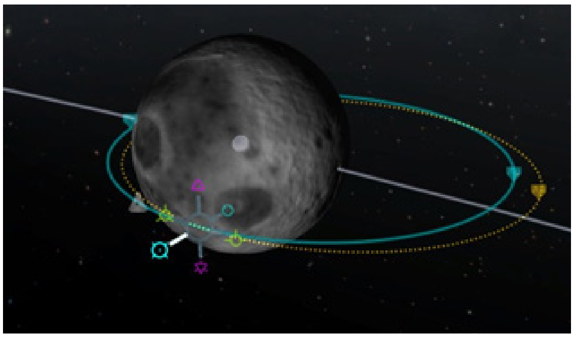

Figure 5 Radial orbital manuver plan using KSP. Figure extracetd from KSPWikiProgram.[15]

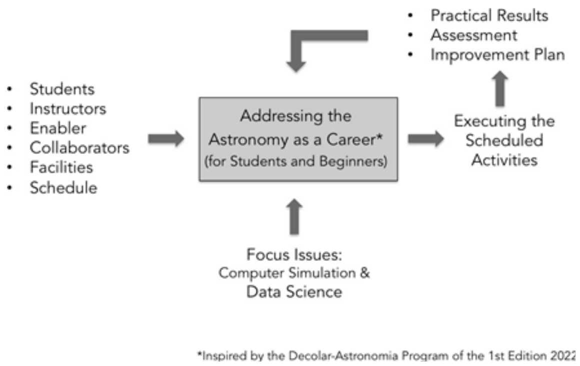

Figure 6 Bringing contemporary computer simulation and data science as focus issues intothe DA-2022 pipeline.

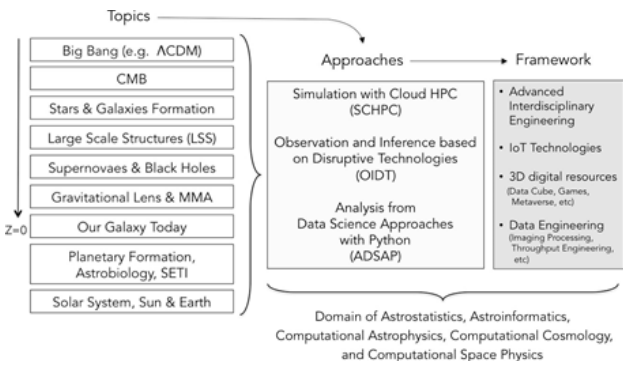

Figure 7 DA-2022 improvement and generalization strategy with identification of 3 main components (Topics, Approaches and Framework).

The students were invited to give ideas about the parts that would be used in the rockets and together we built the mission that would land on the moon. The enabler, who commanded the ship's controls, purposely caused the mission to fail. In this way, the students showed enormous enthusiasm in re-planning the rocket design, finding the failure, and retrying the mission. After these exercises, some provocative questions were posed, such as: what are the limiting logistical conditions and what is the amount of energy required for (i) interstellar and (ii) extragalactic travel? The workload for this activity was 2 hours with one 15-minute coffee break.

Activity A6

Topic: *Experiencing the Scales of the Universe from the Planetarium and Simulations in Python*

For this activity, carried out at the MIC Planetarium, we built a more realistic Sun-Earth prototype in relation to the scales involved in the distance between them (1 AU) and the diameters of each body. After this demonstration, we started a guided journey through the cosmos via sky simulations with the Zeiss SKYMASTER projector. We took the opportunity to bring students a discussion on Python programming for N-Body simulation with the nobody 0.0.4 package.[15] The workload for this activity was 2 hours with one 15-minutecoffee break.

Activity A7

Topic: *Is there extraterrestrial life? How is cutting-edge technology helping us answer astronomy's most thought-provoking question?*

In this activity, we brought the great questions of Astrobiology to the students. The presence of life in the universe depends on many different factors, especially the existence of biogenic elements (including, but not limited to, carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, and iron) and of planets where these elements can combine within on one, environment warm and stable enough to form life. In a cosmological context, the existence of hot planets requires the coexistence of stars and star-forming nebulae. The existence of these objects requires the existence of galaxies, until, ultimately, the existence of everything depends on the occurrence of the Big Bang, about 14 billion years ago. Thus, if one wishes to take a broad view of astrobiology, star formation and cosmology must be addressed.[16] We highlight the VPL project from Univ. Washington in partnership with NASA. The Virtual Planetary Laboratory (VPL) explores the possibility of detecting biomarkers (especially ozone) on planets around F, G, K and M type stars. The astronomical environment and the spectral characteristics and variability of the host star are consideredin these studies. We also highlight that, in a complementary way, the SETI Project (Search for Extraterrestrial Intelligence Institute) searches for intelligent biosignatures that is, signs of extraterrestrial technology. A very recent phenomenon related to the subject is the detection of Fast Radio Bursts (FRBs). The workload for this activity was 2 hours with one 15-minute coffee break.

Activity A8

Topic: *Astronomy and Computing: What are the biggest challenges for space scientists in the 21st century?*[17-19] Disruptive innovation based on Artificial Intelligence, increasingly widespread in all areas of research and technology, is becoming an essential tool for space sciences and astronomy. Advanced and intelligent instruments on Earth and in space will, in fact, become increasingly successful in the coming decades in making concatenated observations of different signals generated by the same cosmic phenomenon: electromagnetic waves of different frequencies from radio waves to powerful gamma-ray bursts, but also gravitational waves, neutrinos or high-energy cosmic rays. This is how we approach the challenge of multi-messenger astronomy with students, highlighting the new generations of intelligent gravitational antennas (such as the Einstein Telescope in Europe and the Cosmic Explorer in the USA) and electromagnetic telescopes (such as the CTA for gamma rays, KM3Net for neutrinos, the newly orbited Webb Telescope or the upcoming Vera Rubin Telescope (LSST)).

Such challenges also include other missions that bring a lot of interest to students, such as the development of the International

Space Station and the robotic exploration of other planets and celestial bodies, including the landing on a comet.[20] Therefore, technical challenges such as improving the performance of propulsion systems were also addressed. We also highlight Astrostatistics as a career that will grow quickly, because in the face of challenges related to astronomical Big Data, modern astronomy requires a wide range of sophisticated statistical and machine learning methods to characterize galaxy clusters and estimate the distances of galaxies to from photometric colors. Statistical concepts such as Bayesian inference were raised because they are central to link astronomical data to non-linear astrophysical models, address problems in solar physics, properties of star clusters and exoplanetary systems.[21] Detecting weak signals in complicated noise is needed to find periodic behaviors in stars and detect explosive gravitational wave events. The main open questions concern the characterization and prediction of extreme events from non-Gaussian approaches. While these concepts may seem advanced to the DA-2022 audience, the mention of such challenges caused a great deal of attention and excitement in most students. The workload for this activity was 2 hours with one 15-minute coffee break.

An integrated overview on the activities

All activities were carried out satisfactorily, with emphasis on activities A02, A03, A04, A05 and A06, which provided a unique experience for most students who opted for a career in Astronomy from an IT perspective. All participants (students and instructors) understood that the Space Physics and Astronomy that is and will continue to be practiced in the 21st century are carriers directly related to the 3rd and 4th paradigms of contemporary epistemology: a science that depends on simulations with HPC and is also driven by data as described in Activity A01. In this sense, we have drawn up an improvement plan aimed at achieving a level of excellence in this program.

It is also important to reinforce that the students, as they were previously interested in the subject, demonstrated a reasonable prior knowledge on the subject, bringing, in each activity, questions of scientific relevance to the state of the art in astronomy. Thus showing that, even though they were introduced to the topic, supposedly their curiosity for the area made them look for content in an “alternative” way. This experience endorses the fact that science dissemination materials must be prepared with great care and made availableas complementary material in these activities.[17,22]

A more general strategy after DA-2022

Based on a critical analysis of DA-2022, we prepared an improvement plan forthe next editions, which have resulted in a more general strategy to strengthen interest in careers related to Astronomy taking into account its interdisciplinary component provided by data science for Big Data and other disruptive approaches.[4]

The basic strategy of DA-2022 sought to add computational simulation and data science as focus issues in all activities. This strategy aimed to strengthen each student’s interest in careers in space sciences, with emphasis on Astronomy and Space Physics. On that occasion, we had the participation of students who opted for Astronomy in addition to other careers. We act as instructors and rely on the help of enablers, collaborating astronomers, adequate facilities and prior programming of activities approved by the administrative sector of Decolar Program. Figure 4 outlines the DA-2022 pipeline, highlighting the need to include, after the execution of all activities, a reflection on the practical results achieved, as well as an evaluation of the executed program to outline an improvement plan. By putting this dynamic into practice, we understand that the result was fully satisfactory (no dropouts were made and the reviews were all positive and motivating from all entry agents identified in the pipeline).

The improvement plan directed us to identify the main components of a more general strategy that considers adding disruptive approaches such as focus issues in all teaching and dissemination activities that aim to awaken or strengthen the interest of a young student in a given career. Thus, we identified 2 general components in this strategy, which are: *Approaches* and the background *Framework* that should support the third specific component that constitutes *Topics*. In Figure 5, this strategy is represented as an enhancement of DA-2022. However, in an application other than Astronomy, the same Approaches and Framework also remain valid within the strategy.

The logic is that once the topics are identified, each one is, as far as possible, discussed in a judicious way based on Simulation, Observation and Analysis approaches. If there is time, expertise and motivation, a Framework of disciplines for the approaches can also be presented, conceptually deepening the activity within the proposal of the basic strategy.

Going further, we specify in more detail all three components for the field of Astronomy. For each topic identified in Figure 5, three disruptive computer- based approaches are suggested: SCHPC (Simulation with Cloud HPC), OIDT (Observation and Inference based on Disruptive Technologies) and ADSAP (Analysis from Data Science approaches with Python). For each approach, the following disciplines can be searched in the Framework: Advanced Interdisciplinary Engineering (Electromechanics, Bioelectronics, etc.), Technologies for the Internet of Things (IoT), 3D Digital Resources (Data Cube, Games tech, Metaverse Mockups, etc). Details on each of the sub-components of the strategy will be detailed in an upcoming paper when considering some new future applications of the strategy already with characteristics of a new methodology. In the next section, we will finish the presentation of this teaching and dissemination experience by discussing some conclusive points within our perspective as participants in DA-2022. A very important complementary current issue to practice with young students, within the topic of disruptive computing that we recommend as strategic, is about the rules of good practice related to data governance[23] and responsible AI.[24] The main objective of this approach is critical reflection on the responsible use of resources offered by the internet (eg ChatGPT), cloud computing as a data repository, artificial intelligence for pattern recognition and augmented reality production, just to name a few. Everyone must respect rules of good practice and good policies in the use of new technologies and their application in scientific research, always seeking to collaborate to accelerate innovative research in Responsible and Equitable AI.[5] We therefore consider that this topic should be brought up, when possible, in all activities or, in a more elaborate way, constitute an extra activity within the methodology that is still being established.

Concluding remarks

Contemporary students, especially beginners, are undisputed users of technology, of course, through the intensive use of cell phones, tablets and laptops. Thus, any theme related to hardware (mini and super computers), software (programming in python and R, for example), Apps (games and EdTech), IoT and cloud computing immediately attract their interest. For this reason, whenever we have the chance to present a scientific subject to them, bringing out the disruptive computer-based approaches, when responsibly applicable, is an outstanding strategy. This is undoubtedly a characteristic of space sciences (but which can also be explored, for example, with computational biology within the scope of biological sciences).

The expected result from our first experience is that, based on the strategy discussed in this paper, young students become even more enthusiastic about their chosen career when they are stimulated by technological challenges involving computers and disruptive innovations. Therefore, it is imperative that coordinators and teachers always consider an inter and multidisciplinary approach, highlighting the area most common to the majority of young students, which are computing and communication technologies, especially those involving disruptive characteristics. This strategy, discussed in the previous section, brings details in its conception, thus indicating that it can be a prototype for a new methodology for teaching and promoting a career for beginning students who show preferences for a specific career. For this teaching and dissemination strategy to gain a methodological body, new applications must be carried out in a judicious and committed manner in their evaluation. Finally, from a general perspective, it is important for the young student to understand that Astronomy, like most sciences in the era of disruptive computer based approaches, is a career that requires interdisciplinary knowledge in relation to pure and applied computing. In practice, it is very difficult to complete undergraduate and graduate studies without solid computer knowledge and skills (programming, software and hardware resources). Career success will also depend heavily on these interdisciplinary components.

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Conflicts of Interest

None.

End Notes

1. The word “Decolar”, in Portuguese, refers to a plane taking off for a trip.
2. Center for the Development of Potential and Talent
3. Kerbal Space Program is a space simulation game where players manage a space program and develop skills to send crews of fictional creatures called Kerbals on space exploration missions a featuring realistic physics and challenges that require planning and engineering skills.
4. Disruptive technology or disruptive innovation is a term that describes technological innovation, product, or service, with “disruptive” characteristics, which cause a break with established standards, models or technologies. They often emerge to complement or replace tools and approaches that form well-established frameworks for research and development(RD).
5. “Equitable AI” refers to AI technologies that humans intentionally design, develop, and implement to result in equitable outcomes for everyone, including people with disabilities

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