

## DEVELOPMENT OF A CUBESAT KIT FOR ACADEMIC PURPOSES: DESIGN, CONSTRUCTION, AND APPLICATIONS

## DESENVOLVIMENTO DE UM KIT DE CUBESAT PARA FINS ACADÊMICOS: PROJETO, CONSTRUÇÃO E APLICAÇÕES

## DESARROLLO DE UN KIT DE CUBESAT PARA FINES ACADÉMICOS: PROYECTO, CONSTRUCCIÓN Y APLICACIONES



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### ABSTRACT

The disconnection between theory learned at school and the practical application of concepts in objects, items, or ideas that are apparently not tangible, such as a satellite, presents itself as a difficulty in the Brazilian educational system, aiming to bridge the gap between theory and the practical objective of science and technology education, while also seeking to spark curiosity and interest among teachers for technological development. This article begins with a bibliographic review to explore concepts and practices related to CubeSat kits for academic use. The practical part of the project involves building a CubeSat prototype that can be easily replicated and used by students with various levels of knowledge. By providing a complete and efficient CubeSat Kit, using PBL (Problem Based Learning) techniques, train a new generation of scientists and engineers, both developing technical skills and essential soft skills for the job market, such as teamwork, leadership ability, presentation skills, as well as to explore space and conduct innovative experiments.

**Keywords:** Cubesat. Skills Development. Technology. Education.

### RESUMO

A desconexão da teoria aprendida na escola, com a aplicação prática dos conceitos, em objetos, itens ou ideias que, aparentemente não são palpáveis, como um satélite por exemplo, apresenta-se como uma dificuldade no sistema de ensino brasileiro, visando aproximar a teoria com o objetivo prático do ensino de ciências e tecnologia, buscando também despertar a curiosidade e o interesse dos docentes para o desenvolvimento tecnológico. O presente artigo se inicia com um levantamento bibliográfico para explorar conceitos e práticas relacionados aos kits de CubeSat para uso acadêmico. A parte prática do projeto envolve a construção de um protótipo de CubeSat, de forma a ser facilmente replicado e utilizado por alunos de diversos níveis de conhecimento. Ao disponibilizar um Kit de CubeSat completo e eficiente, utilizando das técnicas de PBL (Problem Based Learning), capacitar uma nova geração de cientistas e engenheiros, tanto desenvolvendo habilidades técnicas e soft-skills imprescindíveis para o mercado de trabalho, como trabalho em equipe,

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capacidade de liderança, desenvoltura em apresentações, como para explorar o espaço e realizar experimentos inovadores.

**Palavras-chave:** Cubesat. Desenvolvimento de Competências. Tecnologia. Educação.

## **RESUMEN**

La desconexión entre la teoría aprendida en la escuela y la aplicación práctica de los conceptos en objetos, elementos o ideas que aparentemente no son palpables, como un satélite, por ejemplo, se presenta como una dificultad en el sistema educativo brasileño. Con el fin de acercar la teoría al objetivo práctico de la enseñanza de las ciencias y la tecnología, se busca también despertar la curiosidad y el interés de los docentes por el desarrollo tecnológico. El presente artículo comienza con una revisión bibliográfica para explorar conceptos y prácticas relacionados con los kits de CubeSat para uso académico. La parte práctica del proyecto implica la construcción de un prototipo de CubeSat, de modo que sea fácilmente replicable y utilizado por estudiantes de diversos niveles de conocimiento. Al poner a disposición un kit de CubeSat completo y eficiente, utilizando técnicas de PBL (Problem Based Learning), se pretende capacitar a una nueva generación de científicos e ingenieros, desarrollando tanto habilidades técnicas como soft skills imprescindibles para el mercado laboral, tales como trabajo en equipo, capacidad de liderazgo y desenvolvimiento en presentaciones, así como fomentar la exploración del espacio y la realización de experimentos innovadores.

**Palabras clave:** CubeSat. Desarrollo de Competencias. Tecnología. Educación.

## 1 INTRODUCTION

In recent years, the space industry has witnessed a remarkable increase in interest and demand for small satellites, especially due to their potential to democratize access to space. Among these small satellites, the CubeSat has stood out for being a standardized and modular platform, allowing the rapid, economical and flexible development of space missions. However, the availability of a comprehensive and efficient kit, capable of providing resources for the creation of a CubeSat, in a way that is accessible to the academic environment, and that stimulates curiosity and learning and new technologies in colleges, vocational schools and high schools is still a need that is not fully met. (Brazil, 2023).

In this context, the motivation of this work arises: to develop a complete and accessible CubeSat Kit, which can be used by students and researchers to design, build and develop theoretical learning. Like the example of elementary school students from Ubatuba who actively participated in the development of UbatubaSat (Ministry of Education, 2018).

Given the motivation presented, the general objective is how to develop an inclusive and efficient CubeSat Kit, providing the necessary resources and covering the main steps necessary for the creation of a satellite on this platform, from design, construction and operation in a standardized and modular system.

To achieve the overall objective, the following specific objectives have been established:

- I - Research and analyze the main components and technologies used in CubeSats, such as structure, electronics, energy, communication and sensors.
- II - Design and develop the essential components of the CubeSat Kit, considering the restrictions of size, weight and energy. Considering using ready-made and consolidated modules and systems in the market, such as Arduino®, Raspberry®.
- III - Integrate the components in a modular structure, allowing the customization and expansion of the kit according to the user's needs.
- IV - Develop documentation and instructions to facilitate the use of the kit, from assembly to simulated operation in orbit.
- V - Test and validate the CubeSat Kit under simulated conditions, verifying its functionality and reliability.

The importance of this work lies in the democratization of access to the development of new technologies, practical application of theoretical knowledge in various technological areas, such as sensing, design, systems development, programming, telemetry, providing students and researchers with a complete and accessible tool for the development of their skills. By providing a viable and efficient CubeSat Kit, accompanied by documentation and

instructions, it is hoped to empower and inspire a new generation of scientists and engineers to explore space and carry out innovative experiments (Brazilian Space Agency, 2022).

This work is organized into five sections, according to the following structure:

- Section 1: Introduction: presentation of motivation, research question, general and specific objectives, justification and structure of the work.
- Section 2: Theoretical Foundation: review of the main concepts and technologies related to CubeSats, addressing their origin, characteristics, applications and challenges.
- Section 3: Methodology: Detailed description of the procedures used in the development of the CubeSat Kit.
- Section 4: Development of the CubeSat Kit: presentation of the main components and functionalities of the kit, including its physical structure, electronics, power supply and management, communication and sensors.
- Section 5: Results and Conclusions: analysis of the results obtained with the implementation of the CubeSat Kit, followed by conclusions and recommendations for future work.

With this structure, it is intended to provide a comprehensive and detailed view of the development of the CubeSat Kit, from its conception to final validation.

## **2 CUBESATS: ORIGIN, COMPONENTS, ADVANTAGES AND DISADVANTAGES.**

CubeSats are miniaturized satellites, based on a standardized cube platform, usually with dimensions multiples of 10 cm x 10 cm x 10 cm, and 2 kg, defined as 1 unit, or 1U, being a scalable model, can be designed in 1U, 2U, even 12U. They were developed as a low-cost, reduced-time development alternative for space missions. The concept of CubeSat was first proposed in 1999 by Jordi Puig-Suari and Bob Twiggs, with the aim of allowing students and small organizations to conduct space experiments. (Cds, 2022).

Since then, CubeSats have evolved and gained popularity, driven by technological advancements and the growing demand for access to space. The standardization of CubeSats has facilitated integration and collaboration between different institutions and countries, resulting in a wide range of applications such as Earth observation, space science, communications, and technology demonstration (Raffa, 2021).

### **2.1 ADVANTAGES AND LIMITATIONS OF CUBESATS**

CubeSats have several advantages over conventional satellites. Its modular and standardized construction allows for faster and more economical development, with

commercially available prefabricated components and technologies already known and widely used. In addition, they can be launched as secondary payloads on larger rockets, taking advantage of existing launch opportunities (David, 2004).

However, CubeSats also have some limitations. Due to its small size, the payload capacity and available energy are limited. Stability and orbital accuracy can also be affected, resulting in a shorter lifetime in orbit. Additionally, communication with CubeSats can be challenging, due to antenna size constraints and limited power. (Ministry of Science, Technology and Innovation, 2022).

## 2.2 COMPONENTS OF A CUBESAT KIT

According to Silva and Lopes (2020); Cappelletti, Battistini and Malphrus (2020), a CubeSat kit usually consists of a variety of essential components that enable the construction and operation of the satellite, which have been separated in the following structured way.

- **Structure:** The structure is responsible for providing physical support and protection for the internal components of the CubeSat. It is usually constructed of lightweight materials such as aluminum or carbon fiber to keep the weight down. It is also important in the thermal load of the satellite.
- **Electronics:** The electronics of the CubeSat include the motherboard (PCB), which houses the essential electronic circuits and devices such as processors, memory, sensors, actuators. Thermal control systems and payload interface units can also be included.
- **Energy management and supply system:** CubeSats typically have limited energy systems, such as solar panels for solar energy capture and batteries for storage. These systems are responsible for providing power for the CubeSat's operation during orbit.
- **Communication:** Communication systems allow data exchange between the CubeSat and ground stations. Generally, low-gain antennas are used for data transmission and reception, while high-gain antennas can be used for longer-range communications.
- **Sensors:** Sensors allow the CubeSat to collect data from the space environment and perform its specific tasks. They can include orientation and control sensors, such as magnetometers and gyroscopes, and sensors for scientific or Earth observation applications, such as cameras or spectrometers.

## 2.3 IMPORTANCE AND APPLICATIONS OF CUBESAT KITS FOR ACADEMIC USE

CubeSat kits for academic use play a key role in training students and promoting research and development in space technology. They provide a practical and accessible platform for students to learn about the principles of space engineering, acquire relevant technical skills, and conduct scientific experiments (Silva, 2020).

By exploring the theoretical foundation of CubeSat kits for academic use, we seek to understand the concepts, definitions and fundamental characteristics of these platforms. This exploration will allow a clear understanding of the existing base and will assist in the development of the research project, contributing to the advancement of technological and spatial education (Meller, 2021).

In a study, observing the development of some skills, Straub and Whalen (2014) were able to qualitatively measure the development of comfort and the ability to present to the public, teamwork, leadership and technical development during the development of small satellites.

## 3 METHODOLOGY

The methodology adopted involves the realization of an applied research, with a qualitative approach and exploratory and descriptive objectives. In addition, technical procedures of bibliographic and documentary research will be used to support the development of the project.

### 3.1 STAGES OF THE RESEARCH

The stages of the research will be structured to comprehensively investigate the CubeSat, for the making of the kit and its use in the academic context. Starting with a bibliographic survey, several sources such as books, articles and documents will be used to explore concepts, practices and challenges related to the kits, feeding the creation of the theoretical basis for the analysis and systematization of the data collected. With the theoretical basis, a prototype will be defined and built for demonstration. The conclusion will address gaps and contributions of the project, solidifying a useful reference for the development of the project and guiding researchers interested in expanding knowledge in this constantly growing field.

#### 3.1.1 Bibliographic survey

Conducting a systematic bibliographic research, exploring several relevant sources of information about the academic use of CubeSat. Books, scientific articles and documents will

be selected that address the concepts and applications of CubeSat kits, as well as the best practices and challenges related to their academic implementation.

The kit to be proposed does not necessarily need to follow the guidelines of the CDS (*CubeSat Design Specification*), however, it must be known to the users, because in case of interest in the launch, the CubeSat must follow the technical specifications contained in the document.

### **3.1.2 Analysis and systematization of data**

The data obtained through the bibliographic survey will be analyzed and systematized in order to identify concepts, characteristics and trends related to CubeSat kits for academic use. Notes, syntheses and categorizations of the main relevant points found in the sources consulted will be made.

### **3.1.3 Elaboration of the theoretical foundation**

Based on the analysis of the data obtained, the theoretical foundation of the work will be elaborated, which will address the concepts, definitions and fundamental characteristics of the CubeSat kits for academic use. The main information and knowledge based on the scientific literature will be presented, relating them to the general objective of the project.

### **3.1.4 Prototype construction**

With the data collected, together with the theoretical foundation, a basic prototype will be elaborated, to demonstrate in a physical and visual way the feasibility, ease and use of the kit for the construction and development of knowledge in assembly and technology. The following materials will be used to build the prototype:

- **Structure:** The structure will be built based on 3D printing, as the satellite is academic, and it will not be launched, it is not necessary to meet the specifications of mechanical strength and thermal load.
- **Electronics:** As it is a scalable system, easy to access, plan and program, the Arduino® will be used, together with a "Shield" board, for signal inputs and outputs.
- **Energy management and supply system:** The best option for electricity supply is solar, so solar panels, batteries to store energy where the orbit does not allow sunlight, battery charge management and protection board, DC-DC converters to adjust voltage levels, protection system and monitoring of consumption data and available energy (Tessari-zampieri et. al 2021).

- **Communication:** Due to the limitations of power consumption and distance, a low-power and long-range technology must be chosen, because the LoRa system uses a license-free frequency band, it will be the technology used. Anatel allows, in Brazil, the free use of the 915Mhz band. (Navarro and Rodrigues, 2022).
- **Sensors:** Humidity, pressure, temperature, GPS sensors will be used for geolocation and orbit monitoring. Additionally, for more specific missions, other sensors can be used, this is defined in the satellite design phase due to the mission to be accomplished.

### 3.1.5 Final considerations

At the end of the research, final considerations will be made based on the results obtained. A critical analysis of the main aspects addressed in the theoretical foundation will be made, highlighting the knowledge gaps identified and the possible contributions of the project to the advancement of the area of CubeSat kits for academic use.

The proposed methodology will allow an in-depth understanding of the concepts and characteristics of CubeSat kits for academic use, providing a solid foundation for the development of the project. In addition, the methodology adopted also allows other researchers to repeat the study, following the same instructions and contributing to the expansion of knowledge in this area.

## 4 RESULTS AND DISCUSSIONS

The current education system needs several improvements, to train not only professionals, but also conscious and questioning citizens, because there is always something to learn and what to teach. An excellent way to fix the theory, bring questions and develop knowledge and sharpen curiosity is to develop, in practice, the theory that may seem very abstract.

In this context, the idea of peaks and nanosatellites emerged, especially CubeSats, as these have become a paradigm shift, since something that was previously very distant from the reality of technology students, is becoming increasingly closer to students at various academic levels, from masters and doctors, to elementary school students.

A 1U CubeSat (Unit) is a specific category of CubeSat, which adheres to a set of size and weight guidelines defined by the *CubeSat Design Specification* (CDS). CDS was developed to standardize CubeSats and make them more accessible and cost-effective to build and launch.

Main features and specifications of a 1U CubeSat:

- **Standard Dimensions:** A 1U CubeSat has dimensions of approximately 10 centimeters x 10 centimeters x 10 centimeters. This equates to 1 liter in volume and is the smallest category of CubeSat.
- **Limited Weight:** A 1U CubeSat has a weight limit of about 1 kg. This weight restriction is one of the reasons why CubeSats are called "miniaturized."
- **Docking Pattern:** CubeSats are designed to fit into a standard 3U (three-unit) payload launcher, which is common in launch rockets. Therefore, a 1U CubeSat is often mounted on a docking frame that is compliant with launch standards. For the prototype and the kit will not be taken into consideration, but should be known to the assembly team.
- **Structure:** The structure of a 1U CubeSat is usually made of lightweight materials, such as aluminum or carbon fiber, to keep the weight within limits. This structure provides physical support and protection for the internal components. For the prototype and the kit, the structure will be made on the 3D printer, in PLA, due to the ease of modularization and customization and the reduced cost.
- **Electronics:** The electronics of the CubeSat 1U include a motherboard (PCB) that houses the essential electronic circuitry and devices, such as processors, memory, sensors, and control systems.
- **Energy Management System:** CubeSats often use solar panels to capture solar energy and batteries to store energy when not in direct sunlight. These power management systems are designed to provide power for all satellite operations.
- **Communication:** Communication systems allow the CubeSat to exchange data with ground stations. Due to size and power limitations, low-gain antennas are common for data transmission and reception, while high-gain antennas can be used for longer-range communications.
- **Sensors:** CubeSats can be equipped with various sensors, such as orientation and control sensors, magnetometers, gyroscopes, and sensors for scientific or Earth observation applications, such as cameras or spectrometers, depending on the specific mission.
- **Limited Power:** Due to the small size, the payload capacity and available power are limited in 1U CubeSats. This can affect the lifespan in orbit and the ability to carry out certain types of missions.

To design the satellite, it is necessary to follow the following steps:

- **Determination of the mission to be accomplished,** that is, what purpose the satellite has in its useful life. For this specific case, the mission will be simple, the measurement

of some variables in low Earth orbit that comprises the distance between 350 and 1400km above the Earth's surface, the lower orbits are unstable due to atmospheric drag. The variables to be measured are: humidity, pressure, temperature and geolocation to monitor the orbit, as it is an educational kit, the objective is the development and contact with technology.

- **Determination of Specifications:** Based on the mission, determine the specifications of the CubeSat, including size (e.g., 1U, 2U, 3U), sensor types, and instrumentation. It is possible to estimate the weight and energy consumption at this stage, but without much precision, as it is necessary to select all the components, make approximate calculations of weight and energy consumption, so the weight, energy consumption and energy management system will be specified together with the selection of components. For the kit, the cubesat will be of the 1U standard, weighing up to 1kg, and the sensors will be for humidity, pressure, temperature and GPS.
- **Component Selection:** Choose the components that will be used in the CubeSat, such as sensors, electronics, solar panels, batteries, and antennas. Make sure these components meet the mission specifications. The electronics are listed below, as well as the average power consumption, which is crucial for the design of the power management system.

**Table 1**

*Bill of Materials*

Item	Qty.	System	Description	Pot. mW	Price	Weight (g)
1	1	PCB	Arduino UNO	600	R\$ 50,00	58
2	1	PCB	Sensor ShieldV5.0	240	R\$ 15,00	26
3	1	PCB	High Precision Temperature and Humidity Sensor - AHT10	70	R\$ 15,00	13
4	1	PCB	Barometric Pressure Sensor BMP180	50	R\$ 15,00	12
5	1	PCB	GPS	250	R\$ 55,00	25
6	1	Com.	SX1276 LoRa 915Mhz RF + 4Km Antenna	300	R\$ 65,00	25
7	6	SGE	6V Solar Panels	-2160	R\$ 125,00	138
8	1	SGE	Battery 12v 5000mah	-	R\$ 120,00	200
9	1	SGE	MPPT Charge Controller	-	R\$ 50,00	200
10	1	Structural	Frame Mounting Kit	-	R\$ 200,00	200
11	1	Structural	Kit of screws, nuts, washers, cables and connectors for assembly.	-	R\$ 100,00	150

Estimated total	R\$810,00	822
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Source: Prepared by the author based on price surveys in the year 2024.

- Construction: The prototype will be carefully built based on the items raised earlier.

**Figure 1**

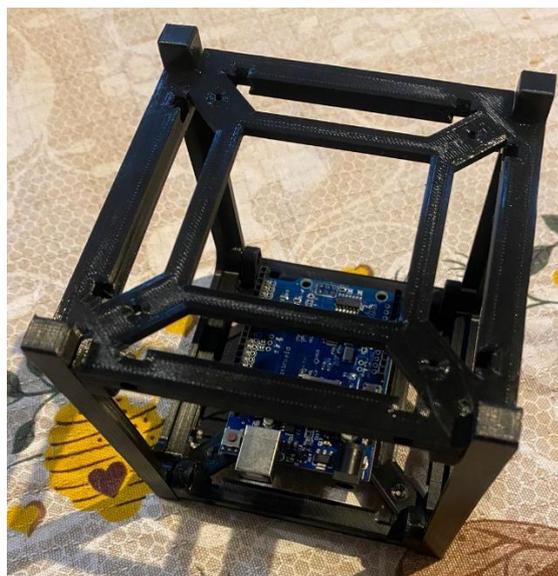
*Cubesat frames and mounting*



Source: The author.

**Figure 2**

*Cubesat in assembly*



Source: The author.

- Ground Testing: Conducting ground testing to ensure that the CubeSat works properly. This includes electronics, communication, and structural integrity testing.

- Preparation for launch and launch: These steps are not relevant to the design of the kit, but are indispensable knowledge for the design team, as thermal and mechanical tests are required on the satellite before launch.
- Mission in orbit: After launch, the CubeSat enters orbit and begins the mission. This involves collecting data, transmitting information to Earth, and conducting planned experiments.
- Monitoring and control: Monitor the CubeSat in orbit to ensure that it performs as intended. This may involve software updates and trajectory adjustments.
- Data collection: Utilize the data collected by CubeSat to meet mission objectives. This can include analyzing scientific data, observing the Earth, or conducting experiments.
- End of mission: When the CubeSat mission is complete, plan for shutdown and safe re-entry into the atmosphere if necessary. A growing concern is that of space junk, the European Space Agency (ESA) estimates that there are about 900,000 useless objects in orbit, whose size varies between 1 and 10 cm.

## 5 FINAL CONSIDERATIONS

### 5.1 CONSIDERATIONS ABOUT THE STUDY CARRIED OUT

The prototype CubeSat kit, conceived as a tool of remarkable versatility and accessibility, offers a low-cost solution that proves to be extremely useful in educational environments of various levels. Its ease of assembly and programming makes it accessible to a wide spectrum of audiences, from elementary school students to undergraduates. For younger students, who may need some programming guidance, the kit can provide a ready-made source code. This significantly simplifies the introduction of these students to the vast world of programming, encouraging the development of problem-solving skills, creativity and critical thinking.

Nevertheless, its comprehensive applicability is not limited to younger students, as this kit is equally suitable for undergraduate students and multidisciplinary projects. This prototype offers the opportunity to engage in interdisciplinary projects, which is vital for the promotion of teamwork skills, leadership and enhancement of public presentation skills. In addition, its affordability is particularly beneficial, making it possible for educational institutions with limited resources to access a valuable educational tool.

In the context of an increasingly technology- and innovation-driven world, this prototype CubeSat represents an invaluable educational resource, as it not only facilitates the acquisition of technological skills but also plays a key role in empowering students for the future. Thus, by providing an open platform for the exploration of space and space

technology, this kit not only enriches learning, but also promotes the development of crucial skills that will serve students throughout their lives, both personally and professionally.

Even in an adverse scenario, such as the Sars-Cov-2 pandemic, where it was necessary to maintain social isolation measures, there was a great acceptance, by teachers (80%), of the practical and integrated application of various disciplines in PBL (*Project-Based Learning*), the practical and integrated application in problem solving proved to be an effective method for, In addition to arousing curiosity and interest in technological learning, developing necessary and extremely important skills in academia and the job market.

## 5.2 LIMITATIONS OF THE RESEARCH

While the development of the CubeSat Kit has shown great potential for educational application, some important limitations should be considered:

- **Absence of validation in a real orbit environment:** The prototype was tested only in simulated ground conditions, without exposure to real factors such as microgravity, space radiation or extreme thermal variations, which are common in real space missions.
- **Exclusive focus on educational environments:** The project was conceived for didactic purposes, which excludes technical requirements required by space agencies for launch, such as certifications, vibration tests and mechanical resistance.
- **Limitations of technological resources:** As it is a low-cost kit, accessible and simplified components were used, which restricts the complexity of the missions that can be simulated.
- **Lack of longitudinal evaluation:** Studies have not yet been carried out to monitor the impact of the use of the kit over time on the formation of technical and behavioral skills of students.

## 5.3 RECOMMENDATIONS FOR FUTURE STUDIES

To expand the impact of the project in the academic context, it is recommended that future research consider:

- **Pedagogical evaluation:** Investigate, through educational methodologies, how the use of the kit contributes to the development of skills such as critical thinking, problem-solving, teamwork and creativity at different levels of education.
- **Curricular adaptation:** Study ways to integrate the CubeSat Kit into specific subjects of the school and university curriculum, promoting interdisciplinary approaches aligned with the National Common Curricular Base (BNCC).

- Inclusion and accessibility: Develop adapted versions of the kit for students with disabilities, ensuring that the practical experience is accessible to all audiences.
- Teacher training: Create training programs for teachers, focusing on the use of the kit as a didactic tool, including support materials and project-based teaching strategies.
- Expansion to remote teaching: Explore the use of the kit in hybrid or remote teaching environments, especially in contexts of low connectivity, using offline resources and complementary printed materials.

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