Engineering Notebook

for

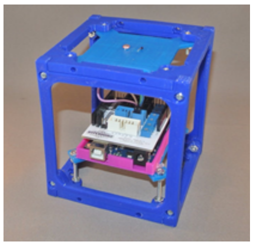
Carthage-1 CubeSat Mission

By: LabLabi Labs in the First Skills Club
Written By: Eya Lahiani
Date: 7th - 11th of July
Place: Kerkennah Hostel Headquarters

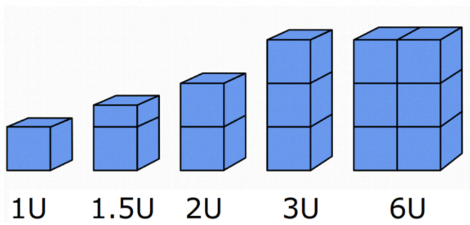
0. Table of Contents:

1. Introduction:

What's a CubeSat?



A CubeSat, short for Cube Satellite, is a type of miniaturised satellite that is built using standard dimensions and components. CubeSats were first developed as an educational tool to provide students and researchers with a low-cost platform for space exploration and experimentation. However, they have gained popularity due to their small size, low cost, and ease of deployment.
CubeSats are typically cube-shaped and have standardised dimensions of 10 centimetres (about 4 inches) per side. They are often referred to by their "U" value, which represents the number of these 10 cm cubes they occupy. For example, a 1U CubeSat is a single cube, while a 3U CubeSat is three cubes stacked together.

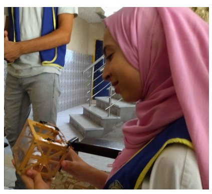


Units measuring volume of CubeSats.

These satellites are designed to perform a wide range of missions, including scientific research, technology demonstration, Earth observation, communication experiments, and more. While they are smaller and less capable than traditional satellites, CubeSats provide an accessible platform for many innovative ideas and experiments.
CubeSats are commonly launched as secondary payloads, hitching a ride on larger rockets that are primarily carrying larger satellites or payloads. This approach allows for cost-effective access to space for CubeSat developers. Once in orbit, CubeSats operate independently, performing their designated mission objectives.
Due to their small size and limited resources, CubeSats face several challenges, such as power constraints, limited communication capabilities, and shorter lifespans compared to larger satellites. However, advancements in technology continue to improve their capabilities, making CubeSats a valuable tool for various applications in space exploration and research.

Who Are We?

We, LabLabi Labs are a group of 5 teenaged tunisian high school students of ages ranging between 14 to 17. Our passion for space engineering and eagerness to improve our knowledge about it has brought us together to work on the Carthage-1 CubeSat mission.

Member:	Picture:
Kmar Zammit, 14 1st Grader Coach Assistant in VEX V5 at the First Skills Club Builder (*)	

Youseef Ben Jmeaa, 14 9th Grader Mentee at the First Skills Club Programmer (*)	
Eya Lahiani, 16 3rd Grader, Math Section Competitive Programming Coach at the First Skills Club. Engineering Notebook Writer, Website Developer (*)	
Ibrahim Chabchoub, 16 3rd Grader, Math Section Python and AI Coach at the First Skills Club. Programmer (*)	
Mohamed Ben Haj, 17 3rd Grader, Technology Section VEX V5 Coach at the First Skills Club. 3D Designer (*)	

(*) Note that all these roles are not fixed to a certain member alone but interchangeable. These were only put to specify who worked most on each part.

Our CubeSat Mission Overview

Our CubeSat is a 1U (10cm x 10cm x 10cm) cube-shaped Satellite fully made out of organic material. Its mission is to track and monitor various aspects of inner and outer space, which will be discussed in more depth throughout the Engineering Notebook.
The purpose of the Engineering Notebook of our CubeSat mission is to document the process of its creation following each step we made and give credit where it is due.

2. Mission Concept:

Our CubeSat will be deployed to monitor various aspects of inner space as its first mission, outer space as its second and its final mission being the beginning of its end.
- The outer space mission (which will be primary) is mainly about the tracking of space debris which will help in improving space situational awareness and contribute to space debris mitigation efforts.
- When there is about 15% of remaining battery life, the microcontroller will send an order to stop all operating sensors and activate the thrusters. These thrusters will direct the cubesat flying in the direction of the atmosphere either to continue its secondary mission (and recharge its batteries there) or to perform its final mission.
- The inner space mission (which will be secondary) will be about providing a study of the Earth's atmosphere by measuring parameters such as air composition, temperature, pressure, or pollution levels. This can contribute to climate research, weather forecasting, and environmental monitoring.

- The final mission and the last achievement in the life of the CubeSat where instead of thrusting in the atmosphere to perform the secondary mission, the CubeSat will do that with an immense force to try and burn in the atmosphere of the planet becoming mere ash and leaving no trace of its existence, unlike the other polluting space crafts.

3. Our Journey

Our journey starts on the 7th of July, 2023 when the CubeSat Summer Camp begins.
On day one, we met at the port by 7.30AM and made our departure to kerkennah not long after by 8. We arrived at the hostel by 10am after taking a bus.
We then started setting our luggage and picking our beds in the bedroom. Later, we had breakfast around 11am. After that, the camp really started with our first encounter with the topic through an introduction done by our coach Alaa Ben Ameur.

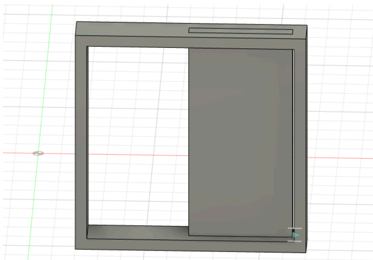
Day 1:

- A general introduction to CubeSats
- Quiz about CubeSats (We won it)
- Brainstorming session:
    - Team & Project Name.
    - Mission and Objectives.
    - Design Research and Discussion.

Day 1 ended with fun and games right after coming back from the beach most people slept by 3 to 4 am and then woke up by 8am which marked the real start of day2.

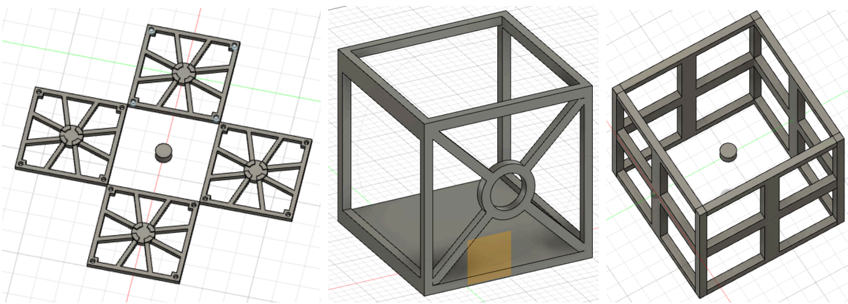
Day 2:

- 3D Design Workshop:
    - Modelling & Rendering
    - Animation Making (we made a sliding window using Joints)



A still frame of the moving window

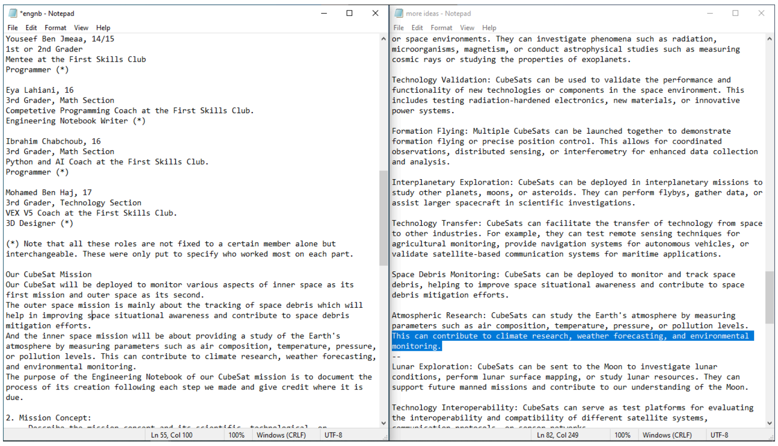
    - Sample Cubesat Shell Design



Pictures of the shell designs we made

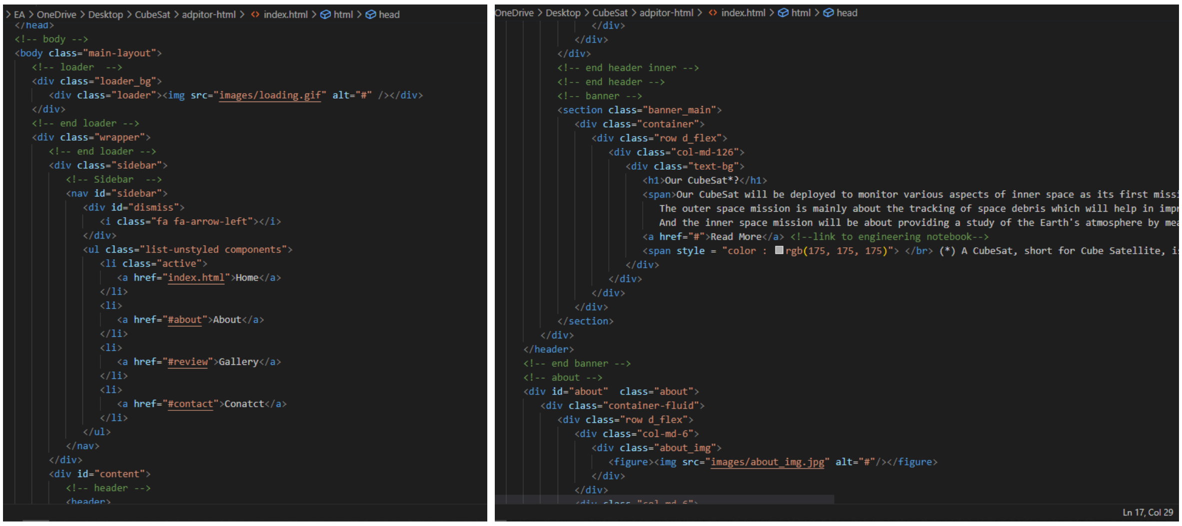
- Voice Recordings & Videos Collection

- Logo Making
- 3D Design progress
- Engineering Notebook Progress



A snippet of the primary work on the engineering notebook

- Website Making



Snippets of the code behind the website

Day 2 ended quickly after going to the beach and having some fun during the night, most people slept by 4 am and woke up by 8am. With that started day3.

Day 3:

- Basics of Wireless Communication:
    - What is Wireless Communication?
    - Types of Wireless Communication.
    - How does Wireless Communication work?
- Arduino Communication Protocols:
    - Synchronous and Asynchronous transmission.
    - UART, SPI, SSI and I2C.
    - NFR24L01: how it works and how we can work with it.
    - Building activity.

```
*camp day3 - Notepad
File  Edit  Format  View  Help
synchronous & asynchronous transmission
clock sign (sclk)
chronogram de signal d'horloge (a logic gate)
H        ^
1>       |  ____
         |  |   |
0>       |__|---|____-------->
                 \/
-> this is a sychronous transmission it has a rythm (i9a3),
the chronogram will be giving us a "tableau de verité"
universal serial bus (usb)
```

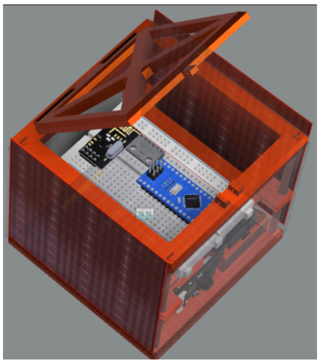
```
UART= Universal Asychronous Receiver-Transmitter
-> for a device to device serial communication (for example arduino uno (master) has
tx pin always goes to rx pin and vice-versa
--> can have multiple master devices

SPI= Serial Peripheral Interfacer
when you have only one master and multiple slave devices --> only one master
MOSI master output slave input (tx) --> MISO master input slave output (rx)

SSI gives the address of each slave device (define the slave device where we can get

I2C (TWI) --> Inter-Integrated Communication / Two Wire Interface
When you have multiple master devie as well apart from multiple slave devices
has 2 bus cables
has 2 resistors --> it has polirisation, it minimizes error and enhances precision

NRF24L01
1/ Why?
it's easy, there's esp32 (easy, close up range), LoRa (high level) as alternatives
it's got some problems such as being a linear type of wireless communication
```

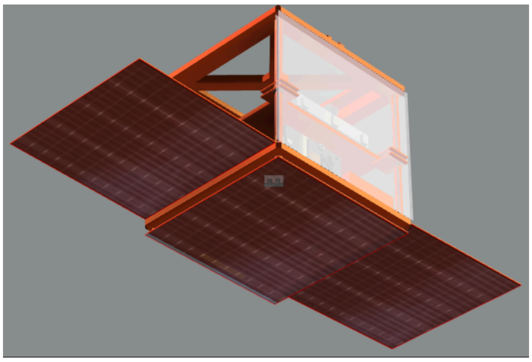
Snippets of Eya's notes during the session

By the end of the day we:

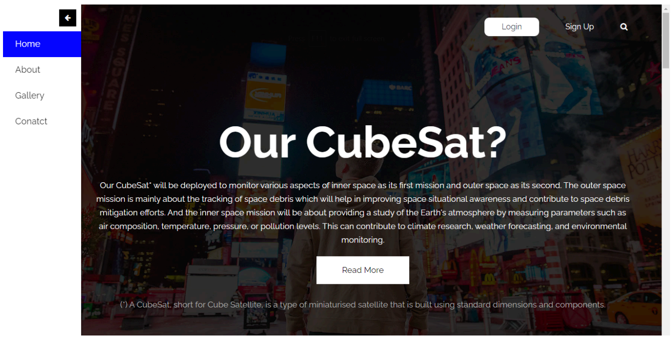
- finished working on the 3d design
- finished the website
- finished the assembly of the cubesat prototype (electronics part)
- finished the teaser video

Here are some pictures documenting our work for the day:





Pictures of the finished 3D Design and CubeSat Prototype.



Pictures of the finished website and Ibrahim working on the teaser video

Day 4:

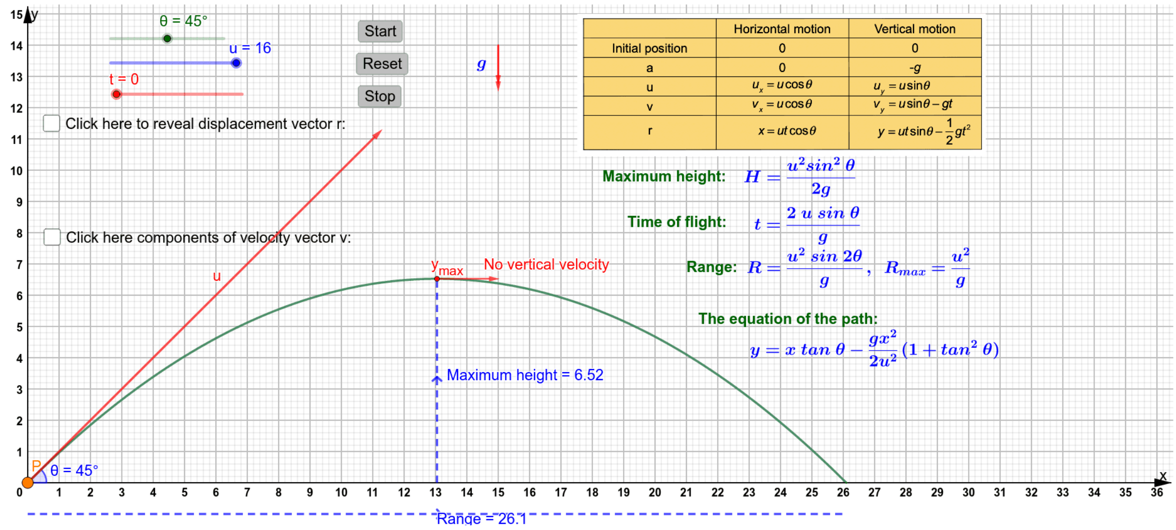
We stayed up very late during day 3 finishing up our CubeSat prototype assembly (shell part), presentation and engineering notebook.

Here are some pictures from that night:

Our team members working on their tasks

Pictures of our Cubemates and us from the night of the 4th Day

And then we had our long awaited… ENTERTAINMENT/REST DAY!
We worked on the AI Powered Strategy of Object Detection and determining the trajectory of the space debris.
Law of projectile motion:



https://www.geogebra.org/m/g6cnzbns

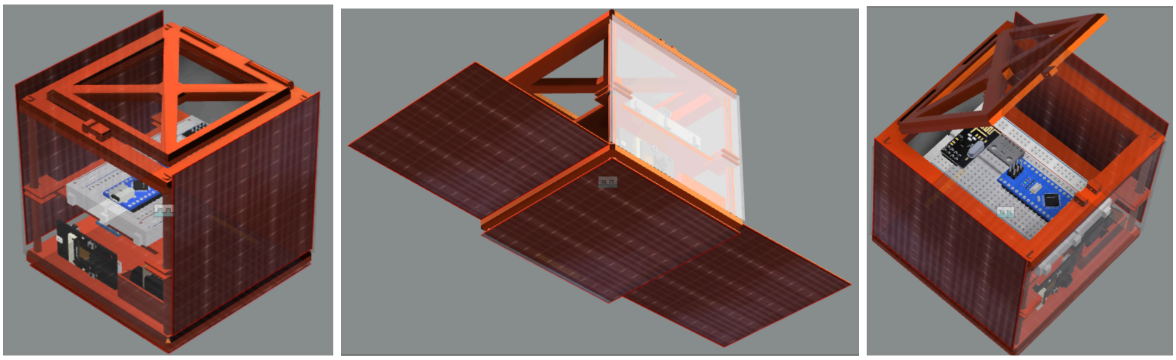
Day 5:

This day has been our presentations and judgement day.

4. Design and Development:

Overview:

This is an overview of the CubeSat's design, including the overall architecture and subsystems.



Rendered images of the final 3D Design

Design Process:

How?

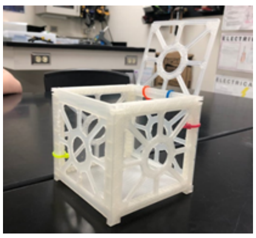
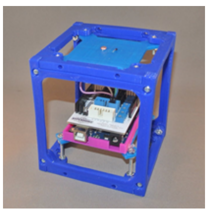
We used Autodesk Fusion 360 to design our CubeSat.

We had an introduction to Fusion 360 during the second day of the camp by Coach Alaa Ben Ameur. It was enough to make us able to communicate our ideas with our main designer, Mohamed Ben Haj and find interest in this new field to most of our members.

Since part of our mission is for the CubeSat to be launched back into the atmosphere of the earth after being thrown out of it, we had to study the basics of derivatives and the laws of projectile motion from the internet.

Why?

Concerning the design of our Cubesat, we came across these popular designs and got inspiration from them to design our own:

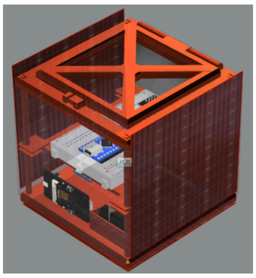
Reference	Strengths	Weaknesses
	1. Stable and protected structure. 2. Visually Appealing.	1. Over-consumption of Material. 2. Zip ties for sealing aren't practical for maintenance. 3. Using glue can be impractical if looking for more room for updates. 4. Need a lot of printing time since each side (6 faces in total) is printed separate from the other. 4. Less room for energy storage.
	1. Light weight 2. Screws are reliable and practical 3. Room for energy storing.	1. Electronics are fairly exposed to hazards, but when solar panels are added the insides get covered. 2. Visually lacking in appeal. 3. Needs less printing time than the first but still a relatively big amount because although it doesn't print each face, it still prints 4 faces, which isn't an optimal solution.

We chose to design something close to the 2nd design but with more modifications to have an optimal balance between printing time, beauty and purpose. So, instead of print more sides like the 2 discussed designs, we will print less, specifically 2 and then adding VEX

IQ-like bars to connect the whole thing together. This structure is proven to be more robust as well and allows for more space for solar panels and energy storage.

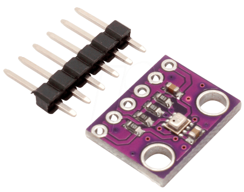
We chose to have solar panels exactly on 3 adjacent faces of the CubeSat only, because those will be the exact sides that the sun will reach during the CubeSat's mission time. Any additional solar panel on any other side will not be able to add much energy as much as it will consume in its manoeuvre of being directed to the sun.

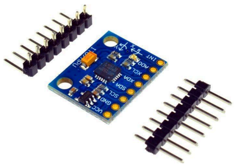
As the CubeSat is launched into the outer layers of the atmosphere, the face that is symmetrical to the door will be facing the sun as the others open to join this face in the collection of solar energy. This decision matrix is why we chose it over all the other designs:

	1. Very robust structure. 2. Room for solar panels. 3. Relatively lightweight. 4. Adjustable and ready for modifications even after assembly. 5. Less printing time. 6. Resource efficiency. 7. Visually appealing. 8. All electronics are sealed behind a protective transparent layer.

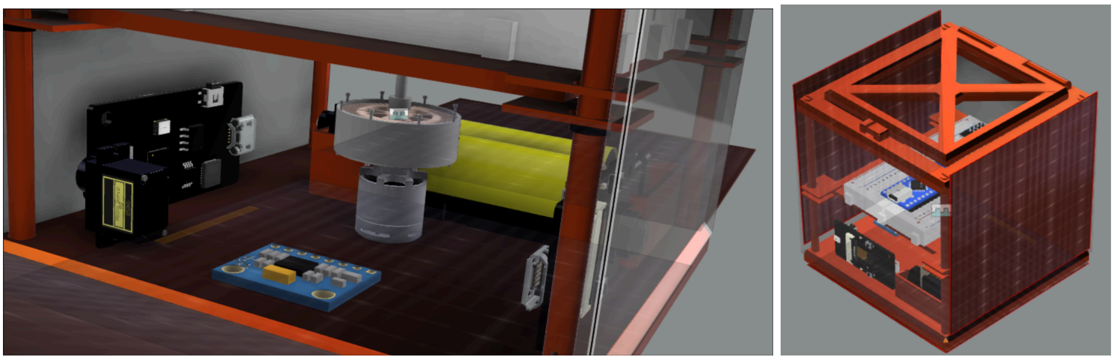
5. Component Selection and Integration:

We didn't have much of a choice regarding the picking of the inside components in the building process. But we got the opportunity to be as creative as we wanted in the 3D Designing process.
Here is the list of the components that were provided to us (*):

Name	Picture	Description
NRF24L01		NRF24L01 is a radio transceiver module (SPI protocol) used to send and receive data at ISM operating frequency from 2.4 to 2.5 GHz. This transceiver module is composed of a frequency generator, beat controller, power amplifier, crystal oscillator modulator, and demodulator.
NRF24L01 Shield		It uses the I2C (TWI) communication protocol to communicate with other controllers such as the Arduino thus to simplify the NRF24L01 communication.
BME280		The BME280 is a humidity sensor especially developed for mobile applications and wearables where size and low power consumption are key design parameters. The unit combines high linearity and high accuracy sensors and is perfectly feasible for low current consumption, long-term stability and high EMC robustness.

MPU6050		The MPU6050 is a Micro-Electro-Mechanical Systems (MEMS) that consists of a 3-axis Accelerometer and 3-axis Gyroscope inside it. This helps us to measure acceleration, velocity, orientation, displacement and many other motion-related parameters of a system or object.

The component choices were made based on performance, size, weight, power, and compatibility with the microprocessor we are using (Arduino Nano). Our 3D Design Advisor gave us resources to use since we had limited or more suitably no internet connection.



This is the rendered final product.

6. Testing and Verification:

Testing our CubeSat prototype was the most exciting part of our 5-day-long journey. Our Mentor, Mr. Rabah and one of our team members went outside and tested the telemetry for our CubeSat. All the while, Tijani Kallel, our Wireless Communications Coach and Ibrahim Chabchoub, our main programmer were phoning the transmitting team and telling them when the signal was received or not by the receiving antenna. All in all, the range was discovered to be around 800 metres, right next to the beach. It was really a phenomenal moment.

Pictures from the testing and verification process.

7. Launch and Deployment:

Currently, we aren't able to launch our CubeSat, because it is after all still a prototype and a work in progress.
We look forward to the launch and deployment of Carthage-1 using a helium or di-hydrogen balloon, a drone… Or perhaps even it can be launched as a secondary payload on a big rocket or so.
We are looking forward to the opportunities that are yet to come. Let us dare to dream and venture looking upon those opportunities that are probably not so beyond our horizons anymore.

8. Future Plans:

We are looking forward to implementing more of our fields of expertise such as an **AI/AR camera** that detects space debris.
We are planning to add a personalised network for very specific use and communications, maybe apply our knowledge of **CyberSecurity** to enhance protection to these networks or something of that sort.
We also wish to implement **Quantum Technologies/Computing** into this project, maybe use quantum entanglement as a tool for wireless communication in order to fasten the transmission and receiving process, doing it in mere instants. Moreover, we can implement high-level quantum algorithms such as quantum image recognition to further enhance the abilities of our CubeSat.
Last but certainly not least, we are hoping to **launch** our finalized CubeSat Carthage-1 and see it perform its missions like intended.

9. Lessons Learned:

We learned a lot during this 5-day-long summer camp, about everything there is to know about CubeSats. We studied 3D Design, practised and got feedback on our work and improved it. The lectures about the principles of Wireless communication were so eye-opening to our members. It was very informative and condensed and highly inspirational. We also had the opportunity to understand the code behind our CubeSat prototype. We tested and verified the range and abilities of the Carthage-1 CubeSat.

10. Reflections and Conclusion:

Though we faced some challenges along the way (such as almost burning up some electronics due to a misconnected wire, or the slowness of our designer's computer and the very limited time frame…), we still had a lot of fun, successes, and lessons learned throughout the CubeSat project.
We are very thankful for this opportunity as it was highly educational, competitive in a good and healthy environment and most of all well balanced (between fun and hard work), we can't hope for a better experience.
As of today, the Carthage-1 stands as a 1U LabLabi Labs CubeSat, its mission being to track and monitor various aspects of inner and outer space.

11. Appendices:

In this last section, we wanted to include relevant supporting materials, such as detailed calculations, softwares used, references and special thanks.

Component Selection:
https://www.elecrow.com/nrf24l
https://www.bosch-sensortec.com
https://invensense.tdk.com/products/motion-tracking/6-axis/mpu-6050/
3D Design: Autodesk Fusion 360
Programming & Telemetry: Arduino IDE
AI Powered Strategy: Open CV

Special thanks go to:
Our mentors for giving us this opportunity and making everything possible.
Our coaches for giving us the information and never backing down from helping us whenever we need.
Youssef Samet and Ahmed Amin Jallouli for his help with the teaser.
Mohamed Rayen Guidara for giving us the idea of making a database tracking the debris.

- Thank you for reading our Engineering Notebook. -