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# On the Challenges of Reaching Pupils with Spacetech-related Extracurricular Activities

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## ABSTRACT

Today's rapid progress in space exploration leads to a high impact on our society. Especially young people are highly affected by this fascination. Despite this large pool of curious pupils, it remains challenging to find entry points into space and aeronautic-related careers for them. Often, these topics seem to be out of reach for most pupils. Educational programs like AstroPi (offered by ESA) or High School Aerospace Scholars (offered by NASA) target this issue. However, those projects never get into contact with actual outer space and remain mostly theoretical. The goal of the mission "SpaceTeamSat1" and the CubeSat with the same name, is to provide an entry point to pupils, by giving them the opportunity to participate in a space mission.

With SpaceTeamSat1, the TU Wien Space Team develops a 1U CubeSat platform from scratch and operates it in low earth orbit at an approximate altitude of 500 km. It shall allow pupils of secondary schools, aged between 15 and 19 to run their own code on a Raspberry Pi payload in space. The mentioned payload offers a variety of sensors and cameras, which allows the execution of a broad range of experiments. Participating pupils and teams formed from them will be supervised by their teachers on a regular basis. In order to teach common industry practices and maximize the chances of a successful mission, the TU Wien Space Team will offer additional guidance in the form of documentation, reviews, and get-togethers. The highlight of the mission will be a coding challenge, where teams of pupils will compete against each other over the most successful in-orbit experiment according to inventiveness, project management, and code quality. These tasks are divided into different levels, beginning at entry-level tasks, such as calculating the rotation rate or investigating the thermal behavior of the CubeSat. More advanced tasks may include taking pictures of the Earth or Moon.

At the moment, "SpaceTeamSat1" is in its prototyping phase and is planned to be launched in 2024. Complementary to that, a preliminary school outreach has begun, and a hand-selected group of secondary-level schools has been accepted to join as pilot participants. This allows for fine-tuning of the offered educational program and reveals drawbacks that can be targeted before the official start of the CubeSat mission. Additionally, the educational mission is evaluated and developed in cooperation with ESERO Austria. To our knowledge, the TU Wien Space Team is the only organization that offers such a mission so far. Since the know-how and technology that is produced in the course of the "SpaceTeamSat1" mission is supposed to be open source, we are able to share insights on the difficulties that have been faced – or are expected – when proposing extracurricular activities to schools and pupils.

### Acronyms

**COBC** communication and onboard computer

**EDU** educational unit

**EPS** electric power system

**HAT** hardware attached on top

**IC** integrated circuit

**PCB** printed circuit board

**RF** radio frequency

**RTOS** real time operating system

**STS1** SpaceTeamSat1

**TUST** TU Wien Space Team

**UART** universal asynchronous receive and transmit

**UV** ultra violet

### Introduction

Since the first launch in 2003,[1] CubeSats have contributed vastly to the democratization of space. Their relatively low technical complexity, manageable financial risk, and quick availability transformed space into an approachable frontier for entities besides the usual big players. Many domains discovered the benefits CubeSats can have for their enterprise. Academic institutions are provided with affordable platforms for their experiments. For instance, the Firebird II mission[2] consisted of two identical 1.5u CubeSat, which investigated electron bursts in Earth's atmosphere. The data generated by the satellites enabled scientists to establish a minimum scale size for individual electron microbursts. Another example would be BioSentinel,[3] which investigates the reaction of biological organisms to deep space radiation.

On the other hand, the industry is interested in the scaling potential of CubeSat networks. Ororatech,[4] for example, has announced to scale its CubeSat constellation, in order to speed up its wildfire detection algorithms.

It took until 2018, for the first 1000 CubeSat to be launched.[5] Four years later, in 2022, the 2000th CubeSat reached space. Market studies suggest, that the CubeSat market is still continuing this progressive trend. 835 CubeSats are expected to launch in 2023. This number is supposed to grow to 880 by 2030.[6] Statistics from open databases[7] fortify these forecasts (see fig. 1 for reference).

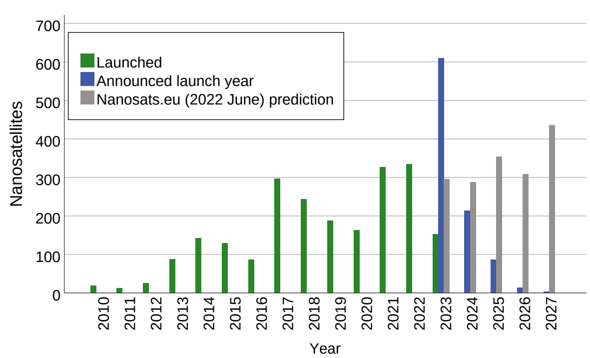


**Figure 1: Previous and predicted CubeSat launches. Recreated from data provided by Kulu E.[7]**

This trend suggests, that there will be an increasing need of CubeSat developers. However, there is no educational path to becoming a "CubeSat engineer" or even an engineer for conventional satellites. Education and knowledge transfer, therefore, have to be carried out in the form of extracurricular activities. There have been efforts from various public entities to establish such programs. Programs like AstroPi[8] and High School Aerospace Scholar[9] allow pupils of varying levels to gather first experience with space-related programs, or to reinforce already gathered skills. However, none of these activities include parts that will actually be operated in space. Hence, the delivered experiences of such programs mainly remain theoretical. In addition to that, such programs are often limited to a restricted quantity of pupils. This circumstance disables access to a broad mass of pupils and raises a mental barrier. In order to tackle this issue and to generate more interest, the TU Wien Space Team (TUST)[10] proposed the SpaceTeamSat1 (STS1) mission in 2019 and started the development of the 1U CubeSat (see Figure 2) of the same name.

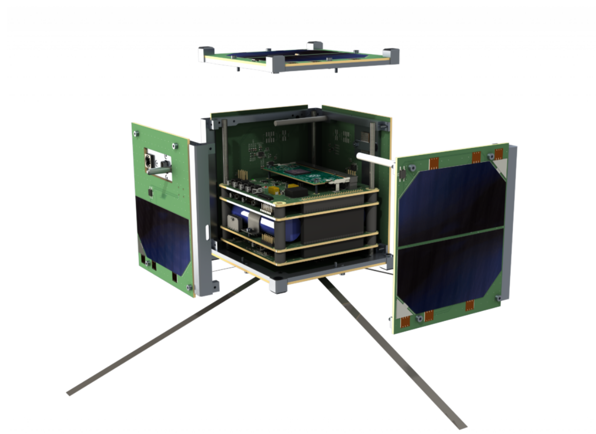

**Figure 2: A rendering of STS1.**

In this paper, the mission and the satellite architecture is presented shortly in section 1. After that, the main educational challenges are identified, and solutions, that are implemented by the STS1 mission, are proposed in section 2. Section 3 gives insight into the currently running pilot project. Eventually, section 4 sums up the presented information.

## 1 Mission Architecture

The STS1 mission tries to develop, operate, and provide a "lab in space" to pupils of varying levels of education. This includes the preparation of educational resources. The centerpiece of the mission is the 1U CubeSat STS1. Its payload will consist of a Raspberry Pi 3+, which has access to a variety of sensors and two cameras. Pupils will be encouraged to develop Python code for this payload in order to run their self-defined experiments. Examples of such experiments may include the determination of the sun vector, based on the solar cell voltages, or the estimation of the forestation degree of a patch of land beneath the CubeSat. Once the STS1 has been successfully launched, pupils will be granted computation time on the Raspberry Pi unit, so they can execute their experiments. Python code can be uploaded to the payload from the ground station at any time. This enables pupils to do bug fixes in their experiments or lets them add additional features. Communication between CubeSat and the ground station is done via the 433 MHz band. Uplink is operated exclusively by the TUST via its ground station. In order to achieve a greater receive time window, the SatNOGS[11] network and database are leveraged.

### *1.1 CubeSat Overview*

STS1 is a 1U CubeSat whose main features are the two Raspberry Pi cameras and the Raspberry Pi 3+ computing module. All printed circuit boards (PCBs) (besides the Raspberry compute module) are designed by the TUST. Figure 3 shows an overview of the CubeSat architecture.

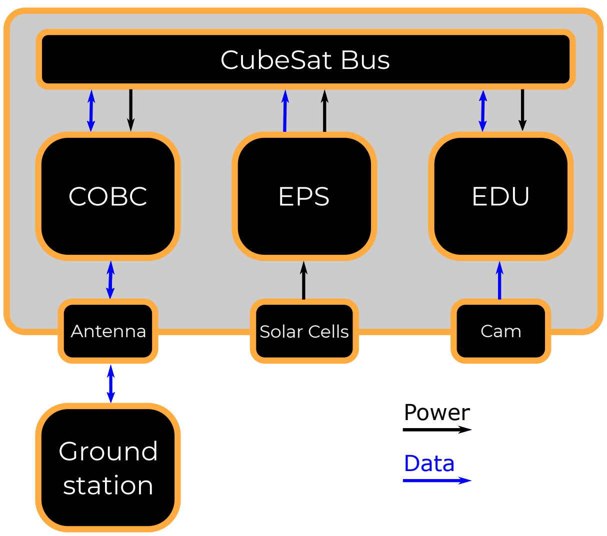


**Figure 3: Satellite architecture.**

STS1 is divided into the following sub-modules:

**COBC** The communication and onboard computer (COBC) is responsible for the distribution of data packages to the other submodules of the CubeSat. It also feeds and reads the radio frequency (RF) module. Additionally, the COBC is the master of the payload, meaning that it enables and disables the educational unit (EDU) according to a computing time scheduler and the current power availability. Due to the little amount of expected data traffic, the roles of the communication module and onboard computer have been merged into the COBC. The main part of the COBC is an STM32F411RE, which runs the real time operating system (RTOS) Rodos.

**EPS** The electric power system (EPS) is responsible for the generation, storage, and provision of electric energy. Eight triple-junction solar cells produce an average of 2 W. The generated electricity is stored in a 20 W h LiFePo battery pack. In order to ensure maximum reliability, a minimalistic design approach is followed. This means, that the EPS will not contain any microcontrollers. All logic functions are achieved either through specialized integrated circuits (ICs) or through discrete circuitry. Additionally, a distributed approach is followed. This means that the EPS core module only provides a single unregulated voltage to the other submodules. The submodules implement their own voltage converters. Since these distributed voltage converters can be optimized to the needs of the respective submodule, an overall higher electric efficiency can be achieved.

**EDU** The EDU consists of the Raspberry Pi 3+ compute module, a range of sensors, and two cameras, which are mounted on opposite sides of the CubeSat's exterior. On request of the COBC, the EDU sends data packages via universal asynchronous receive and transmit (UART) to the COBC. These data packages may contain the results of the experiments, or control data. The EDU has access to the following sensors:

- An experimental dosimeter by Seibersdorf Laboratories
- Accelerometer
- Temperature sensor
- Gas sensor
- UV sensor
- Various on-board voltages, currents, and temperatures (housekeeping data)

## 2 Educational Challenges

In order to come up with an educational concept for the mission first, three dimensions of challenges shall be explored: time, money, and complexity. Eventually, a concept is proposed, that shall address these pain points and shall promise a successful education experience.

**Time** This is of twofold nature. Firstly, it describes the timely effort pupils have to put into the program. As the contribution to STS1 is meant to be an extracurricular activity, participation can not exclude ordinary school visits. Hence, the tasks for the pupils must be manageable within a certain time period. Secondly, the specific time point of pupil participation is important. The CubeSat will only be in orbit for a certain amount of time. Pupils who wish to conduct an experiment on the CubeSat will have to be able to finish their experiment within this time frame. It is possible that pupils will participate in the program as part of their final thesis. Hence, they have to present results at the end of the school year.

**Money** In order to address as many pupils as possible, the financial investment for participation has to be low. The main cost points would be programming environments (i.e. PCs, software, hardware), electronics equipment, and additional educational material (books, tutorials, etc.). Using well-known hardware (i.e. Raspberry Pi or Arduino) for the EDU may reduce the financial overhead that pupils will experience, as most schools anyhow own such hardware or have a specific budget to obtain it. Such hardware often comes in pre-assembled form, which relaxes the requirements on the electronics equipment.

**Complexity** This refers to the difficulty of the tasks, that the pupils have to work on. The obvious challenge, that has to be considered here, is that tasks can not be too demanding. Otherwise, pupils might get overburdened, will lose motivation, and may even lose interest in the field. Similar outcomes are to be expected, if the tasks are trivial. With the added downside, that no educational gain may occur in that case. Task complexity also has a cross-dependency to the time dimensions, as more difficult tasks take longer to finish.

More subtle nuances that have to be considered, are for example the various school types. Pupils of technical-oriented schools may already possess the fundamentals in order to participate in a technical task. Pupils of more scientifically inclined facilities possibly will not. The situation would reverse for a scientific task. As pupils spend much of their time with their teachers, they will be the pupil's first person of contact if any technical or scientific questions arise, with regard to the task. Hence, it is important to choose a topic that also teachers are familiar with.

### *2.1 The Concept*

As a first step, the target has been set to focus the educational objective on pupils of secondary-level schools (aged 15 to 19). Pupils younger than that, most likely will not have the basic skill set, required to work on a time-sensitive scientific or technical task. In order to tackle all the previously stated different challenges, a monolithic educational concept will not suffice. A modular approach has to be chosen, in order to address as much of the target audience as possible. This will be realized, by defining a core educational mission goal and splitting it into three modules: scientific, software, and hardware. Figure 4 shows an overview of this proposal.

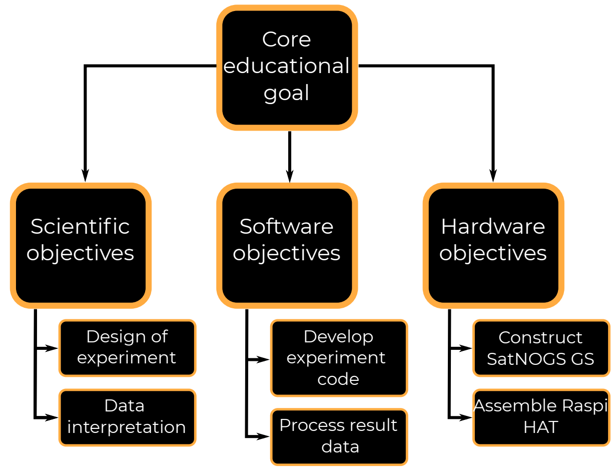


**Figure 4: Educational modules**

Modules are self-sufficient tasks, that can be completed without the immediate necessity of the other modules. Pupils may choose how many of the modules they want to participate in. This allows them to more granularly choose tasks that fit their field of expertise, and to fine-tune the challenge to their level of comfort.

The core educational mission goal is to design an experiment that will run on the CubeSat, set up hardware to receive the data on the ground and to interpret it. Pupils that choose the scientific path will be tasked with the formulation of a sound scientific question and defining their approach to answering it. This will most likely include a form of interaction with STS1. They shall motivate the relevance of their studies and present their findings in a report. If the experiment depends on data gathered by STS1, or requires a specific program to be run on the EDU, TUST will provide that for the pupils. As STS1 will be using the SatNOGS network, the pupils will not need to set up their own ground station. They can extract the downlink data from open-source databases.

Groups that want to pursue a software-centric competition, will be presented with a coding challenge. This challenge will be the same for each participating team and will revolve around a generic CubeSat use case (e.g. detecting the cloudiness of the area beneath the CubeSat from pictures taken by the satellite), or the recreation of a historically important satellite mission. It will be necessary to develop the experiment code, that will run on the CubeSat and the software that interprets the data on the ground. The TUST will be responsible for the execution of the experiment code on the satellite and for the handover of the generated data to the teams.

Hardware-inclined teams will construct their own SatNOGS ground station according to resources available online.[12] They may include improvements to the design, by adding an antenna rotator or more specialized antenna types. Additionally, they will have to assemble a Raspberry hardware attached on top (HAT). In conjunction with a Raspberry Pi, this will allow them to simulate the STS1 CubeSat on their premises. The ultimate goal for these groups of pupils will be to receive beacons from STS1 and other satellites and inject the data into the SatNOGS database.

Care was taken to ensure that all of these challenges can be decoupled from the actual satellite launch. In case of an unsuccessful launch, or the satellite not operating properly in orbit, the educational goals can still be achieved, as the pupils can test their work efforts on mockup hardware on the ground.

In order to encourage friendly competition among the pupils, the final results will be graded according to a yet-to-be-defined scheme.

## 3 Discussion

Parts of the educational concept are currently being tested with the help of partners (like the Vienna Museum of Science and Technology[13]) and pilot schools. Some issues could already be identified, which are discussed briefly:

**Chip shortage** The enduring global chip shortage also affects the proposed educational mission for the foreseeable future. Mainly, this circumstance affects the availability of the Raspberry Pi modules. Until today (June 2023) most distributors are unable to deliver the single board computer. As pupils will test their software and hardware on these modules, they are an integral part of the educational concept. In order to mitigate this issue, the STS1 HATs are designed to also fit other versions of the Raspberry Pi computer.

**Mostly final-year pupils are interested** The current participants mainly consist of pupils who are in their final year. As they have to deal with their final thesis, their time during the school year is quite limited. The modular approach accommodates this, by breaking down the workload into more manageable pieces. The final grading scheme will encourage careful choosing of the number of modules that are worked on by the pupils. For instance, by applying a penalty, when certain goals of a module are not achieved. This shall motivate pupils to focus on a single module.

**Hardware assembly** The raspberry pi HAT, that shall simulate the behavior of STS1, is custom hardware. Therefore, manual assembly is required. The schools participating in the pilot test were either not equipped for this task, or did not want to assemble the hardware themselves. Hence, TUST assembled it for them. As this is quite time consuming, a different approach has to be found. For instance, the teams that choose the hardware path might be tasked with assembling the hardware for other teams as well. Alternatively, a sponsor company has to be found, that assembles the hardware.

None of these points seem to be a show-stopper for the proposed concept. The participants in the pilot test gave mostly positive feedback, which fortifies the decision to continue in this direction.

## 4 Conclusion

The STS1 mission and the accompanying CubeSat have been presented briefly. The major challenges for the educational goal have been identified, and a concept has been proposed, that aims to accommodate all of them. Tests with pilot schools allowed to present preliminary insights into the feasibility of the presented concept and showed to be promising.

## Acknowledgments

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## References

[1] Elizabeth Howell. Cubesats: Tiny payloads, huge benefits for space research. https://www.space.com/34324-cubesats.html, 2021.

[2] Arlo T. Johnson, John Sample, David Klumpar, Harlan Spence, Ivan Linscott, David Lauben, and Umran Inan. The FIREBIRD-II CubeSat mission. In *2021 USNC-URSI Radio Science Meeting (USCN-URSI RSM)*. IEEE, August 2021.

[3] Sofia Massaro Tieze, Lauren C. Liddell, Sergio R. Santa Maria, and Sharmila Bhattacharya. BioSentinel: A biological CubeSat for deep space exploration. *Astrobiology*, 23(6):631–636, June 2023.

[4] L Geismayra, F Schummera, M Langer, M Binder, and G Schlick. Thermo-mechanical design and analysis of a multispectral imaging payload using phase change material. In *International Astronautical Congress (IAC)–The CyberSpace Edition, 12-14 October 2020.*, 2020.

[5] Thyrso Villela, Cesar A. Costa, Alessandra M. Brandão, Fernando T. Bueno, and Rodrigo Leonardi. Towards the thousandth CubeSat: A statistical overview. *International Journal of Aerospace Engineering*, 2019:1–13, January 2019.

[6] Frank A. Robert, Maxime Puteaux, and Alexandre Najjar. Small satellites market growth patterns and related technologies. In *Handbook of Small Satellites*, pages 1–41. Springer International Publishing, 2020.

[7] Erik Kulu. Nanosats database. https://www.nanosats.eu/.

[8] ESA. AstroPi web presence. https://astro-pi.org/.

[9] NASA. High School Aerospace Scholars web presence. https://www.nasa.gov/centers/johnson/stem/High_School_Aerospace_Scholars.html.

[10] TU Wien Space Team. TU Wien Space Team web presence. https://spaceteam.at/?lang=en.

[11] Daniel J White, Ioannis Giannelos, Agisilaos Zissimatos, Eleytherios Kosmas, Dimitrios Papadeas, Pierros Papadeas, Matthaios Papamathaiou, Nikolaos Roussos, Vasileios Tsiligiannis, and Ioannis Charitopoulos. Satnogs: satellite networked open ground station. 2015.

[12] SatNOGS. SatNOGS groundstation build instructions. https://wiki.satnogs.org/Build.

[13] Vienna Museum of Science and Technology. Vienna Museum of Science and Technology web presence. https://www.technischesmuseum.at/en.