Acta Astronautica 200 (2022) 562–573

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Use of space analog missions as an educational tool in primary schools

Chloé Carrière [a,*], Kevin Pahud [b], Volker Gass [a]

[a] Space Innovation, Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland
[b] EPFL Space Center (eSpace), Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland

ARTICLE INFO

Keywords:
Analog missions
Educational tool
Systems engineering
Primary school
Hands-on

ABSTRACT

Space exploration is a field that inspires a wide range of people, from children to university students, including the general public. With a return to the Moon planned for 2024 and the rapid expansion of the private industry, educating the next generation for this challenge becomes a priority. As many interdisciplinary programmes in universities are developed, the increasing interest in do-it-yourself projects can be observed. In addition, nothing inspires children more than the wish of becoming astronauts. By combining these two previously stated themes, space analog missions, simulations of life on another celestial body, were used as an educational tool for children, in our case in a primary school.

In the frame of an EPFL semester project, such a program was run at the Vivalys primary school in Switzerland. A class of 16 children between the age of 6 and 9 successfully designed and conducted a simulated Mars-based mission from September 2020 to March 2021, in spite of the difficult COVID situation. The Vivalys Mission has been entirely integrated to the school year's program by adapting the educational subjects (mathematics, sciences, geography, French, sports, history, and arts), attending workshops, and performing hands-on experiments. Systems engineering approaches were adopted allowing the class to acquire knowledge regarding stakeholder analysis, risk management and decision tools. The young team made mission design choices and presented them to experts during reviews. Leadership, teamwork and autonomy were demonstrated and practiced. This tool is innovative: a do-it-yourself approach combined with education and practical work.

The educational impact was studied using assessment strategies such as evaluations, rubrics and personal interviews. The progress and skills acquired, as well as their increasing will to work in the space field, were highlighted in the results. Following the success of this program, the local primary schools showed interest in running a similar project. Thanks to this first case study, lessons learned such as adapting the curriculum, organizing exterior activities, and enhancing the participation of adults, were collected.

This is the first step towards impacting different age groups, starting in pre-school right up to secondary education. The success of our study underlines the current need and enthusiasm for such projects and will be further developed in the upcoming years becoming easily accessible to schools across Switzerland and the world, also through the promotion at IAC.

1. Introduction

Educating and inspiring the next generations of the space workforce is becoming a priority with the upcoming challenges in the sector. Although space is usually of high interest for children ranging between 8 and 11, it is often not included in their school curriculum. By using space-related activities in and out of the classroom, interdisciplinary projects could be a way to foster a long-term interest for this next generation. Similar initiatives were run in the high-school context [1], but this study focuses on a younger target. In the frame of this project, analog missions were proposed as an engaging educational tool to be used in primary schools.

The objectives of this study were to design, perform and measure the educational impact of such a tool in a primary school named Ecole Vivalys [2]. In the end, the opportunities and lessons learned for the use of this project were discussed, allowing other organizations to run a similar initiative.

1.1. A. Analog missions

Analog missions have the goal to simulate life on another celestial

* Corresponding author.
E-mail address: chloe.carriere@epfl.ch (C. Carrière).

https://doi.org/10.1016/j.actaastro.2022.07.042
Received 23 March 2022; Received in revised form 18 May 2022; Accepted 24 July 2022
Available online 14 August 2022

Nomenclature

Acronyms/Abbreviations

BIOTESC	Biotechnology Space Support Center
CAVES	Cooperative Adventure for Valuing and Exercising human behaviour and performance Skills
CEAB	Canadian Engineering Accreditation Board
CDR	Critical Design Review
EPFL	Ecole Polytechnique Fédérale de Lausanne
ERT	EPFL Rocket Team
ESA	European Space Agency
EVA	Extravehicular Activity
FP	Flight Plan
HERA	Human Exploration Research Analog
ICE	Isolated and Confined Environment
ISS	International Space Station
MCC	Mission Control Center
PDR	Preliminary Design Review
QDR	Qualification Design Review
SE	Systems Engineering
SOP	Standard Operating Procedure
SWOT	Strength Weakness Opportunity Threat
S@yS	Space@yourService

body such as the Moon or Mars to prepare for real crewed space exploration. They play a significant role in testing protocols and technologies before flight as they represent a cheap and quick training compared to actual spaceflight. They are also a way to perform scientific experiments in situ [3].

These field test campaigns usually take place in a location similar to what would be expected in space, the Moon or Mars (underwater, polar regions, mountains, deserts) or isolated and confined environments (ICE).

1.2. B. State of the art

Different types of analog missions can be seen at the present. Although it is hard to have a complete overview of the current missions, Table 1 aims at exploring the different categories.

In this study, the focus was placed on non-profit analog missions used as a tool for education in primary schools: the Vivalys mission.

2. Concept

The Vivalys Mission was a test project organized by the Vivalys primary school in Ecublens, Switzerland, in partnership with the Space@yourService student association.

The project consisted in integrating certain aspects of a space mission in the school curriculum of a class of 7 to 8-year-old children. The class was composed of 16 children supervised by their teacher Mr. Roussel. The program concluded by a short adapted analog mission, or field trip, in March 2021 where the children were able to put their learning into practice. The association served as consultant for the project running the workshops and giving expertise and knowledge to design the analog mission.

Table 1
Types of analog missions.

Types	Space agency	Organization (short-term)	Organization (long-term)	Commercial
Example	HERA-NASA [4] CAVES-ESA [5]	Mars Society EuroMoon Mars	OewF	Astronaut Training

The Vivalys Mission had been entirely integrated to the school year's program. This was done by adapting the current school subjects (mathematics, sciences, geography, French, sports and finally history), performing experiments, and attending workshops. The kick-off of this project took place in August 2020.

The different topics that were identified, adapted and taught in class are listed in the table below. * show the subjects added in the frame of the analog:

The field test was the final part of the project during which the children applied all their recently acquired knowledge. The goal was to leave the children as project managers of their own mission, meaning the design choices were made by them and not the supervisors. The location chosen was a shelter in Sauvabelin, North of Lausanne. The 16 analog astronauts spent 3 days in isolation in their Martian base to reproduce life on Mars: dehydrated food, SOPs for cleaning, optimized hygiene, sports, and experiments were on the schedule. Due to COVID, they were unable to spend the nights but came home only to sleep (no meals nor showers there).

The two experiments performed were:

- Flying paper rockets outside.
- Growing plants in Martian soil.

One of the project's objectives was to leave the children as autonomous as possible, which could be challenging at that age. Therefore, the basics of team dynamics and teamwork were a central point of the mission preparation.

3. Project design

In this section, the design of the project was presented according to four different categories: structure, schedule and milestones, communication and risk analysis. Then, the System Engineering (SE) tools taught were explained to later finish with the different modules developed to successfully achieve the mission. The focus was set on the modules design and progress as they were used to measure the educational impact and learning of the children, later explained in Section 4.

3.1. Project management

For this project, a standard management procedure was applied using Gantt charts, risk driven decisions and specific gates or milestones.

3.1.1. Structure

The project was organized around four different entities: the school administration (represented by the principal of the school, Mr. Delamadeleine, and Mrs. Doyen, educational advisor), the teacher (Mr. Roussel), the children (who were given specific roles before the CDR), and Space@yourService (represented by Chloé Carrière) as shown in Fig. 2.

3.1.2. Schedule and milestones

A Gantt chart was created at the beginning of the year to explain the timeline to the different stakeholders. Continuous schedule updates had to be made to adapt to the sanitary situation. The main Gantt chart can be seen in Appendix A. Three main phases were implemented to achieve different milestones that are the Design Reviews (PDR, CDR, QDR). During each phase, a set of workshops (Table 2) was organized by Space@yourService. The details of workshops were presented in section 3.3.

3.1.3. Communication

Communication revolved around emails, shared Google drive and meetings. Weekly meetings were organized with the teacher for logistics and biweekly meetings took place with the administration for the

Fig. 1. Mission insignia.

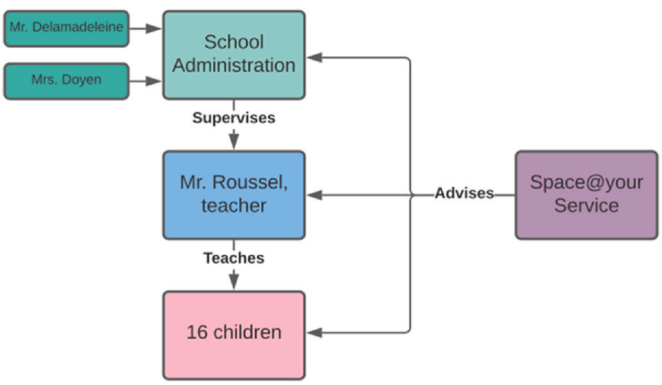


Fig. 2. Structure of the Vivalys team.

Table 2
Adapted and added topics to class.

Course	Content
Sciences	- Astronomy basics*: study of the solar system, optics, study of the constellations and the sky. - Biology introduction: plant culture (with and without soil), study of the surrounding environment. - Human physiology and psychology*: effect of microgravity on the body, psychology in isolation and confinement situations. - Electricity.
Mathematics	- Geometry: volumes, maps, rocket symmetry for flight stability*. - Logic/calculus: compute a budget*, meals requirements. - Large numbers: distances in the solar system*.
Geography/ Environment	- Geology: Martian soil*. - Cartography: design maps, field observation.
French	- Writing: prepare oral presentations, structure of Standard Operating Procedures (SOP)*, briefing and debriefing of missions. - Oral: Design Reviews*. - Reading: articles related to space.
Practical arts	- Design mission logo *(Fig. 1).
History	- History of the Cold War* - Space eras* - Hubble space telescope*
Sport	- Astronaut physical training*

preparation of design reviews. Communication in this project could have been drastically improved by fixing regular meetings to keep tracks of the project progress and children learning.

3.1.4. *Risk analysis*

The risk assessment of the project was supported by using the SWOT tool. SWOT is the acronym for Strengths, Weaknesses, Opportunities and Threats. This analysis is based on the identification of those different factors regarding a project or a company. Usually, they are identified by brainstorming and by answering specific questions, and then put in what is called the SWOT Matrix [6]. The four parameters are classified according to two criteria - whether they are helpful or harmful for the project (positive or negative), and whether they come from internal or external factors.

The SWOT analysis was done as part of the workshop on project management and systems engineering. The tool was first presented and then applied to a case study (Coca Cola). Finally, the children were asked to redo the exercise but with their specific project. Outcomes can be seen in Table 3. This table was meant to show the students' work and not to go in depth in the risk analysis of the project.

It is to be noted that SWOT analysis is only an identification of risks and not a complete analysis or mitigation. This part was tackled during design reviews towards the end of the project.

3.2. *Systems engineering tools*

Although a Systems Engineering (SE) model was not strictly followed, the team did used specific tools from the field of systems engineering to design their analog mission. This section presents the different tools of interest: stakeholder analysis, design reviews and decision tools.

3.2.1. *Stakeholder analysis*

Stakeholder analysis is the first step of the SE V-model, necessary to properly derive the high-level requirements for a project. A hub-and-spoke model was produced and is displayed in Fig. 3. This analysis was performed by the children themselves during the SE workshop. This work is meant to show the students' work and not go in depth in the stakeholder analysis itself.

3.2.2. *Design reviews*

As presented in Section 3.1.2, the project was managed according to a standard SE schedule being: Preliminary Design Review (PDR), Critical Design Review (CDR) and Qualification Design Review (QDR). Design Reviews are milestones where design is evaluated against its requirements to validate and move on to the next step. For each review, stakeholders were invited to the presentation and were asked to give feedback on the project. Children gave 30-min presentations, followed by 30 min of questions and answers. They were audited by members of Space Innovation, the EPFL Space Center, Space@yourService and the school administration, present online due to COVID. The goal was to give an overview of their mission and see if they could move onto the next phase. Feedback was focused on presentation skills, application of acquired knowledge in their project and the mission details. Based on

Table 3
Workshops (Alpha phase – purple, Beta phase – blue, Gamma phase – green, After mission - yellow).

Date	Workshop
30/08/2020	Project Kick-off
29/09/2020	Leadership and group dynamics
06/10/2020	Being an analog astronaut (Asclepios)
04/11/2020	Fundamentals of SE
20/11/2020	Paper rockets launches (ERT)
09/12/2020	Dress Rehearsal
01/03/2021	Plant growth in microgravity (BIOTESC)
28/04/2021	Build and program rovers (EPFL)
04/06/2021	Meeting with Claude Nicollier

Fig. 3. Vivalys hub-and-spoke model.

this feedback, children adapted their design and searched for the necessary knowledge to perform the mission after the QDR. The slides were done by the teacher, as the powerpoint software is to hard to be mastered at that age, but the presentation's content was decided by the children. Fig. 4 shows one of the children arguing a question during the PDR.

3.2.3. Decision tool

Different tools to select a final concept out of many possibilities are available in the SE literature [8]. The Pugh matrix being one of them. It consists in a simple way to compare concepts with a datum (the reference) and applied a scoring to help the final decision. This tool was presented in class to the children in mid-December by the education advisor (Mrs. Doyen). Altogether with the children, they applied it to some design choices for the mission, being sports selection, meals planning and supervision choices. An example of the Pugh matrix done for sports selection can be seen in Table 4, gymnastics being chosen as datum.

Fig. 4. Children's defense during the PDR [7].

Table 4
Vivalys SWOT.

	Positive	Negative
Internal	- Innovative and interesting project - Funding already confirmed - Support by Space@yourService	- Instability of measures due to COVID - Potential lack of time - Potential lack of skills
External	- Martian space missions = tomorrow's challenge - Inspiration for other students - Learning of new skills	- COVID Regulations - Loss of the base before the mission - Sick astronauts before launch

3.3. Modules

This section gave an overview of the different workshops performed in and out of the classroom by S@yS with the help of external experts.

Project kick-off: This module was the first encounter with the class. It aimed at introducing what they would be doing throughout the year but also get a first glimpse of what it's like to be in space. Experiments targeting senses like taste, touch or smell were used to have a full experience. These experiments were inspired from astronauts' lives onboard the ISS. The Galileo experiment was also performed.

Leadership and group dynamics: This workshop was given at the beginning of the semester and tackled the notion of teamwork and leadership definitions. Firstly, S@yS explained the meaning of the word "Team" in contrast to "Group". Then, the notion of leader was explored with little cartoons where children had to choose which one was displaying a successful leader. In addition, a rapid overview of the concept of design reviews was presented based on the example of building a car. Application of recent learning was done using Lego toys. Three teams were formed to which different instructions were given to build a Lego tower. A leader was elected and oversaw making sure that instructions were respected, implying efficient organization and communication. At the end of the workshop, written feedback was asked to the children on what they liked/disliked, what they've learned and what they would change. This workshop was a good exercise to emphasize on the complexity of managing people and acting as a team, and additional iterations should be planned in the future.

Being an analog astronaut: This workshop was given in collaboration with an Asclepios [9] analog astronaut, Sophie Lismore, and aimed at explaining what an analog mission is. The training and role of analog astronauts were presented by mentioning the flight plan and their survival own training. Following this presentation, the students were divided into three groups to perform three different activities in a row. The first activity was an introduction to SOPs by writing a procedure on how to clean their classroom. The second one was an outdoor sports training in which children were exposed to different thematic sessions: walking on the Moon or Mars, why astronauts should do 2 h of sports per day on the ISS, cardio training, and reinforcement exercises. The final activity was on the difficulty of manipulating tools using gloves like astronauts do on EVAs.

Fundamentals of SE: This workshop presented some notions of SE and management. Firstly, an introduction of complex systems in space exploration was presented including the V-model and the major design reviews, all supported by Lego toys. Then, the children focused more on the Vivalys mission: mission objectives, stakeholder analysis, requirements definition, and risk analysis using SWOT tool. Difficult notions were explained using movies, such as Ariel, the little mermaid, to illustrate the stakeholder requirements. During this workshop, a useful set of words and acronyms were taught to the children: PDR, CDR, QDR, EVA, MCC, SOP, ISS, Briefing, Debriefing, FP, and GO/NO GO. Well-received by the children, this workshop allowed them to get a sense of what was required for their upcoming PDR. With retrospection, this workshop should have been organized earlier to anticipate a better overview of their PDR.

Paper rockets launch: This activity was organized in collaboration with the Space Innovation and the EPFL Rocket Team (ERT). The workshop consisted in a remote presentation by ERT members on rocketry, including basics of symmetry and stability. Then, the children had to build their own paper rocket following an SOP. Finally, an outdoor launch session was organized to test their rockets. This experiment is one of the two that was performed again during their mission.

Dress Rehearsal: This workshop was an important milestone for the project. The Dress Rehearsal was a way to evaluate what the children had learned and to identify the points that still need some practice and learning before the mission. Mr. Roussel and S@yS supervisors were isolated in a separate room (simulating Ground Control), as it can be seen in Fig. 5. The class was divided into two groups to perform the two selected experiments for the mission: paper rockets and plant culture. Two sessions of 45 min were organized to perform each experiment once per team, in which there was a designated leader and someone communicating with the ground station, keeping Earth updated with experiments status or raising questions on SOPs. At the end of each session, a debrief was done by the leaders: did they achieve their objectives? how did it feel to work as a team? any difficulties regarding the SOPs?

During previous workshops, the class didn't seem very autonomous so one could expect this rehearsal would not be a success, but surprisingly against all odds, the two teams were well organized and focused on their experiment. The major feedback was that the 45 min allocated to the rocket experiment was too short, therefore the time was extended for the mission. Looking at the group dynamics, a bigger proportion of individual players were observed even if in some cases they were helping each other. The main feedback was then to systematically do things together at each step of the process, using the SOP. However, they successfully adapted to some issues. For instance, the zoom session shut down during the exercise and the person in charge of communication had to use a walkie-talkie as back-up solution.

In conclusion, the Dress Rehearsal was a good exercise for the class to get a first feeling on how it would be like during the real mission, but also for the supervisors to evaluate what the team of analog astronauts was able to do. The experiments were not yet mastered but more training session were run to prepare them for the field campaign.

Plant growth in microgravity: In collaboration with BIOTESC from Luzern, which was the Principal Investigator of the CERES experiment done by Thomas Pesquet in the ISS [10], this workshop was a unique experience for the children to follow plant growth in "micro-gravity". Indeed, the scientific method was introduced to them by monitoring the growth of seeds on Earth and on a Random Positioning Machine (Fig. 6), simulating micro-gravity. They were then able to compare these results with Thomas' at the end of the study, therefore concluding the best seed choice to go to space.

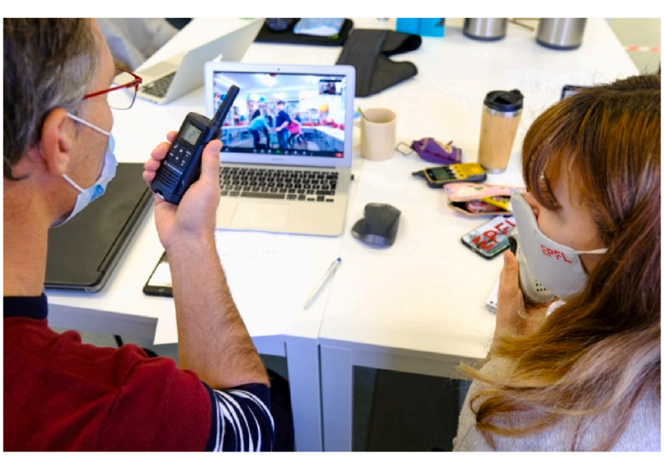


Fig. 5. Dress Rehearsal: the adults acting as Ground Support [7].

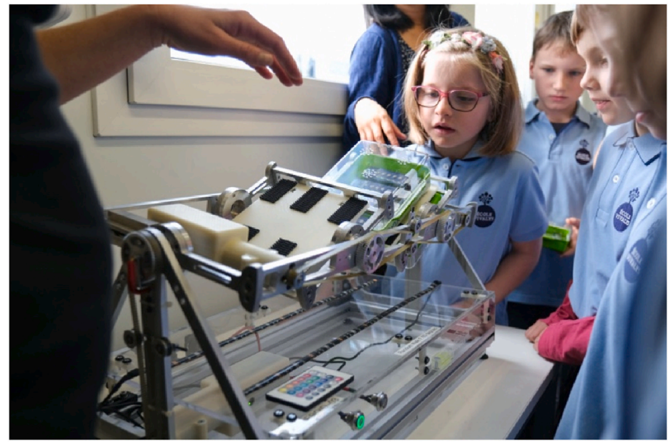


Fig. 6. Random positioning machine in vivalys [7].

Build and program rovers: This module was an extra activity planned post-mission. The goal was to introduce the class to programming and robotics. They had to build a small Mars rover and make it perform a short routine. This workshop was a great success and may be applied in the next mission.

Meeting with Claude Nicollier: At the end of the school year, the class had the opportunity to present their work to the Swiss Astronaut Claude Nicollier, who commented on their mission. He then presented his own experience as an astronaut.

3.4. The mission

The mission took place between the 17th and the 19th of March 2021. The class was staying in a relatively isolated shelter at the North of Lausanne. During their mission, they followed a strict Flight Plan, ate dehydrated food, didn't shower, and did sport sessions. They had three objectives:

- Flying paper rockets on EVA (wearing space suits and mask).
- Plant growth.
- Monitor the well-being and psychological behaviour of the crew.

To perform these objectives, they had SOPs to follow. While on EVAs, they were wearing space suits and masks as it can be seen in Fig. 7, to try to be as realistic as possible.

The mission was a success in the sense that the two scientific objectives were completed, and the children were aware of the importance of well-being. Nevertheless, the isolation criterium was not respected

Fig. 7. The children analog astronauts on Mars [7].

due to the presence of journalists [11]. Although they performed experiments autonomously, the teacher was always present in the base.

4. Educational impact

The case study now being described, its education impact can be raised. This section presented a way to analyze it. Measurements' methods were described, followed by results and possible openings on the future steps.

4.1. Experimental methods

To measure the educational impact of such projects, expected outcomes need to be defined first: "What do we want students to be able to do at the end?". Then, we should define criteria to evaluate those predefined outcomes: "How do we measure the outcome? How can we quantify the criterion?". Finally, we measure this impact through assessment methods such as validated rubrics, interviews, and surveys (Fig. 8). In our case, the teaching strategy would be the use of analog missions.

4.1.1. Learning outcomes

The learning outcomes were defined and classified into two categories: learning (objective measurement) and perception of learning (subjective measurement). Table 5 summarized them.

4.1.2. Assessment criteria

Rubrics (validated or not) are often used as assessment criteria. The process of validating rubrics being time-consuming and out of the scope of this study, choice was made to use already established ones. However, very few validated rubrics related to interdisciplinary projects could be found in literature. Therefore, non-validated rubrics were selected and applied, taken from the paper "*Rubrics for accreditation and outcomes assessment in Engineering capstone projects*" [12] written by Waterloo University. These rubrics assess the Canadian Engineering Accreditation Board (CEAB) graduate attributes of problem analysis, design, individual and teamwork, communication skills, economics, and project management. Details of these rubrics can be seen in Appendix B. Project Management skills, Interpersonal/social skills, and Specific Communication skills aspects were assessed based on the use of some of those specific rubrics. Concerning the Domain Knowledge aspect, criteria was established by the Vivalys school using tests in class. The tests were graded from 1 to 10 and the skill was considered acquired by the children if they obtained 7 or higher, while above 8 was satisfactory.

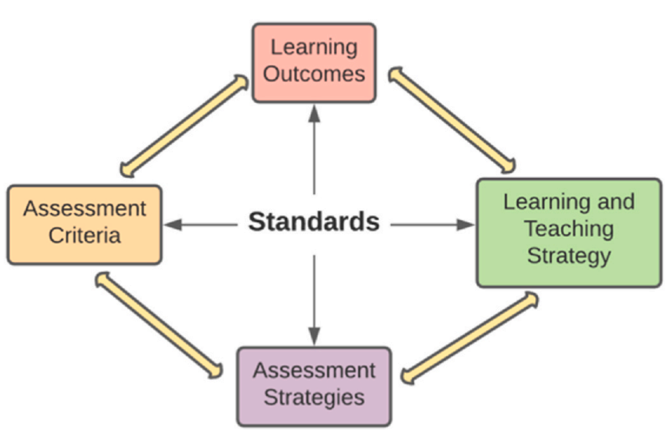


Fig. 8. Measure of an educational impact. Black arrows highlight the guidance given by standards and yellow arrows illustrate the iterative process. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 5
Vivalys Pugh matrix for sport selection.

Criteria	Running	Gymnastics	Reinforcement
Cost	–	0	0
Logistics	–	0	0
Completeness	–	0	–
Realism	+	0	+
# of +	1	0	1
# of -	3	0	1
Total	−2	0	0

4.1.3. Assessment strategies

For each aspect of learning outcomes, a different strategy was chosen. The main one was to track the progress by comparing the results of two or three different assessments made with a time interval in between.

- **Project Management/Interpersonal and Social Skills/Specific Communications**: measured using the selected rubrics at the main milestones.
- **Domain Knowledge**: evaluated with tests in class in mathematics (determine a budget), writing (rocket SOPs), reading (exploring the Moon, space missions, Mars …), history (Space race, ISS, etc.), arts (mission insignia), and sciences (plant growth, solar system). Examples can be seen in Appendix C.
- **Perception of Learning**: 5-min individual interviews were organized with each child. Discussion subjects were motivation to work for space in the future, motivation to go to class, creativity, ability to do a space mission, teamwork, etc. Two assessments were done: pre and post mission.

4.2. Results

This section featured the results of the previously described method to measure the educational impact of the tool. The section was divided according to the assessment strategy.

4.2.1. Project management/Interpersonal and Social Skills/Specific Communications

Rubrics were used and adapted to the age of the children. Based on the main milestones, the results can be seen in Table 6:

Table 6
Vivalys learning outcomes.

Project Management skills	1. Knowledge of project management vocabulary: PDR, CDR, QDR, objectives, criteria, etc.
	2. Understand and use standard operating procedures
	3. Evaluate and follow a budget
	4. Define and respect deadlines
	5. Perform risk analysis
Interpersonal/social skills	1. Work in a team
	2. Demonstrate acknowledgement of group dynamics (leadership)
Domain knowledge	1. Acquire general knowledge on space exploration: a. History
	b. Space agencies
	c. Future of space exploration
	d. Analog missions
	e. Solar system and astronomy
	f. Soilless culture in space
	h. Rockets
Specific communication skills	1. Be able to present in front of an audience
Perception of learning	1. Motivation to go to class
	2. Enthusiasm towards space missions
	3. Feeling of empowerment
	4. Increases creativity
	5. Increases autonomy
	6. Self-perception of ability to adapt in difficult situations

- **Teamwork:** This rubric's grade evolved from "Unsatisfactory" to "Satisfactory". The children were able to work together but sometimes their personal relationships took over. Nevertheless, progress was clearly observed during the Dress Rehearsal. When children were left alone, they were able to collaborate and meet their goals. During the mission's last day conflict arose, and the team was divided in two groups. This phenomenon was analyzed with the children post-mission. They were able to reach an understanding of team dynamics but still have trouble applying what they learn.
- **Communications:** This rubric's grade increased from "Unsatisfactory" to "Good". The children have been able to orally present by reading a paper during the PDR, then without from the CDR onwards. The first set of slides was of low-quality featuring sentences, images with no legends or non-related content. Improvements were seen through the CDR. The QDR was perfectly structured and proved that they were indeed able to perform the mission. Their ability to answer questions from the audience correctly had also drastically increased. At the project's beginning, they were sometimes not answering exactly the question or missing vocabulary. At the end, their tone and type of answers were appropriate to the situation.
- **Project management:** This rubric was initially graded "Unsatisfactory" and reached "Good" after the QDR. Tools like SWOT and stakeholder analysis, or leadership skills were understood but children were not ready to use them on their own after the PDR. However, SOPs were well-understood and used during the Dress Rehearsal. The risk analysis was better understood towards the end and the class was even able to propose mitigations. Planning and budgeting were also better known towards the end of the project. The children thought of running tests and therefore could demonstrate a critical thinking.

4.2.2. Domain Knowledge

Domain knowledge was evaluated with different tests, and results can be seen in Table 7. A grade above or equal to 7 out of 10 being considered as an acquired topic, many topics were assimilated by the children from the Domain Knowledge perspective. The Yuri Gagarin reading was the only one challenging to pass. In addition to tests performed in class, at the beginning the notion of analog mission seemed to not be fully understood especially looking at what can be simulated (food and EVAs) at what cannot (microgravity). Towards the QDR, this notion was fully acquired.

4.2.3. Perception of learning

Individual interviews with each child were performed twice: pre- and post-mission. Each statement was rated between 1 (not at all) to 5 (a lot). The means (N = 16) can be seen in Table 8 alongside standard deviations (see Table 9).

On one hand, certain feelings have increased with the experience of the mission like their ability to design a space mission, or to work in a team. Their passion for space has also bloomed.

On the other hand, other feelings have significantly decreased like their confidence in their knowledge for space, which may translate to their awareness of what they do not know. A conflict arose on the last day of isolation which explains the decrease in their feeling of being autonomous or being able to stay alone with their classmates. This phenomenon is not uncommon in analog space missions [13]. It is interesting that it could also be seen with children. In addition, motivation has also dropped on going to class and learning new things on space. This may be explained by wanting to discover other topics as the motivation to work on a project remains.

The results are always above average which indicates a positive trend confirming the positive impact of this project on the pupils. In addition, during the final interviews, the children mentioned that this experience brought them perseverance, courage, and a better ability to work in a team. Nonetheless, these results can only be interpreted in a qualitative way keeping in mind that sample size is low to significantly draw conclusions. It still gives good insights on the possibility of using analog missions to improve the perception of learning on a wide range of topics.

Finally, before the mission, 33% of the students wanted to work later in the space field and 60% were thinking about it. After the mission, the numbers rose to 46% each, demonstrating a clear impact of this project in their will to work in space sector.

Table 7
Results according to the milestone (UNS: Unsatisfactory, S: Satisfactory, G: Good).

Time	Teamwork	Communications	Project Management
PDR	UNS	UNS	UNS
CDR	S	S	S
QDR	S	G	G

Table 8
Domain Knowledge results.

Tests	% Pass
Sciences: solar system	100
Writing: the rocket	93.8
Reading: Yuri Gagarin	50
Reading: To the Moon	93.8
Reading: the Red planet	100
Economy	94.8
History: the space race	81.3
Conjugation: the verb	100

Table 9
Perception of learning results.

Feeling	Pre	Post
Able to design a space mission	4.4 ± 1.1	4.6 ± 0.7
Able to propose ideas helping the current space engineers	3.9 ± 1.3	3.9 ± 1.0
Able to work in the space field	4.1 ± 1.2	4.1 ± 1.3
Able to work in a team	4.3 ± 1.0	4.7 ± 0.5
Confident in my knowledge on the space field	4.6 ± 0.6	4.2 ± 0.8
Able to adapt to difficult conditions	3.9 ± 1.6	4 ± 1.0
More autonomous	4.1 ± 0.9	3.6 ± 1.4
Able to stay alone with my classmates	3.9 ± 1.1	2.7 ± 1.7
Motivated to work on a project	4.6 ± 0.8	4.7 ± 0.8
Motivated to participate in the final mission	4.3 ± 1.0	4.5 ± 0.8
Motivated to learn new things on space	4.8 ± 0.4	4.5 ± 0.8
More motivated to go to class than last year	4.6 ± 0.8	4.2 ± 1.1
More creative than last year	4.0 ± 1.0	3.4 ± 1.2
More passionate about space than last year	3.7 ± 1.4	4.4 ± 0.8

4.3. Future steps and discussion

As mentioned before, these results are insightful, but one cannot significantly conclude on the educational impact of this tool. Furthermore, this study can only be qualitative considering the number of participants involved. To improve the confidence in the results, more measurements could be done in other case studies, using the same formalism. It would be interesting to run broader research including much more schools and different age/education level intervals.

Indeed, having only one sample run on one specific class and one specific school does not allow to draw conclusions, but it however hints at the potential of such educational projects. In addition, the experiment was run in a developed country that is Switzerland, and in a private school. The authors believe that this tool could also prove to be impactful in the developing world. In fact, the budget and hardware needed are low, the motivation of the teacher and will to search for local experts are what matter.

5. Lessons learned

This project took place during the 2020 fall and spring semesters, marked by the second wave of the COVID pandemic making the design and organization of the case study even more challenging. Indeed, in mid-October, Space@yourService was no longer authorized to physically go in the Vivalys School to run the workshops and in addition EPFL announced that no associative activities were allowed until the end of January. The impact of these major changes had to be investigated and propagated onto the ongoing project:

- **Modules:** the modules were revised to be run only by one person in the Vivalys school. The Design Reviews were held online, adding complexity in the interactions with the class.
- **Mission:** Government Covid policies imposed that children could not spend the night during their mission. A new scenario was created, children only went back home to sleep with the constraints of no meals nor showers allowed. The monitoring of the sanitary situation was added in the class's task and risk analysis.

Although this situation could be seen as a constraint, it brought new opportunities and skills to the children involved who adapted to their environment.

Clarification of roles has been a challenge as there were many stakeholders: S@yS, EPFL, Space Innovation, Vivalys school. At the beginning of the Vivalys project, the role of Space@yourService was misunderstood by the school administration, being only a role of advisor and workshop organizer but not responsible for the progress of the project, the latter being under the frame of the school. After several meetings, the team achieved efficient dynamics by specifying more in details the role and tasks of the teacher, that were underestimated at first. An adaptation time was necessary for the teacher to understand the objectives and the new organization. This must be kept in mind for the next years of projects with other schools. Indeed, the formalism of SE was complex concepts for the teacher to understand, and this type of tools should be used being aware of the commitment to the children but also to the professor.

Concerning the study of the educational impact, it was difficult to find validated rubrics for interdisciplinary projects. In the field of education, it seems to have space for improvement, especially with the growing implementation of interdisciplinary projects in universities. This project allowed to acquire skills in measurement methods of educational impact and their influence on projects' design and management.

To conclude this section, the tool is currently being used once again with a different class of children in the Vivalys school. This time, the class was mandated by the Little Prince to exploit resources of a nearby asteroid. This shows there is possibility for a diversification in scenario using this educational tool. We encourage teachers, schools, and educators to feel free to use it.

6. Conclusions

Throughout this study, one could see how this tool was innovative in the field of education within primary schools. The case study was successfully conducted using many skills from Systems Engineering, Project Management and Domain Knowledge. The educational impact was derived but needs further study for significant conclusions, emphasized by the lack of specific data in the literature. More precise data and significant conclusions could be drawn as this tool is more and more used. Hopefully, these missions will become increasingly present to inspire the future generation and prepare the leaders of tomorrow.

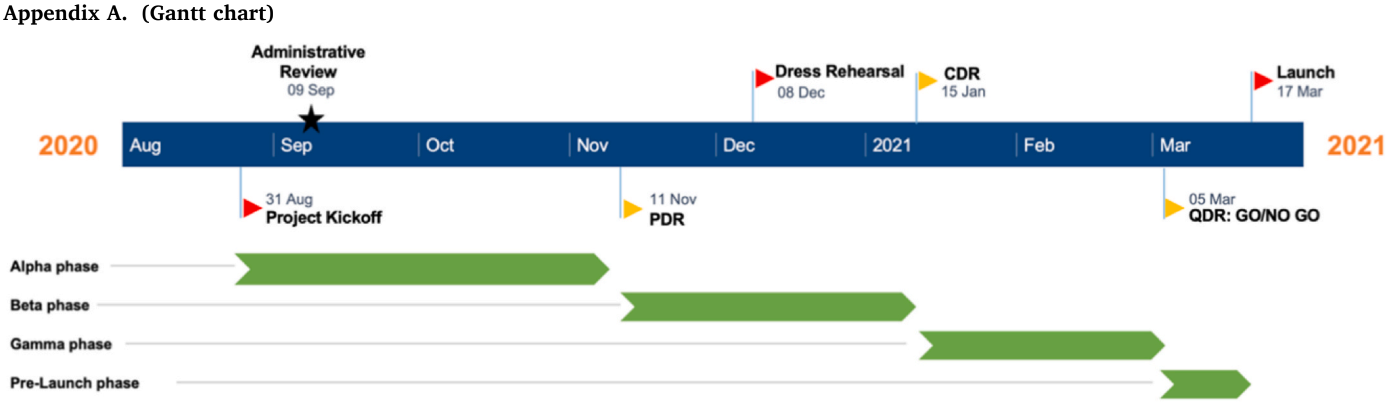
Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank the Vivalys school for their support in the context of the project. Mr. Roussel, the class's teacher has shown adaptability and novelty in our collaboration. This would not have been possible without the supervision of EPFL, Space Innovation, and eSpace, especially with the work of Prof. Volker Gass. Many thanks to Space@yourService members for their help in organizing the modules as well as the other external organizations (ERT, BIOTESC, Asclepios). Finally, we are thankful to the children who have shown courage, enthusiasm, and respect to our team. We hope to one day really see them on the surface of Mars!

Appendix A. (Gantt chart)



Appendix B. (Rubrics)

1. Specific Communication Skills [12].

Element	Assessment				
	Outstanding	Excellent	Good (Minimum Expected of a Practicing Engineer)	Satisfactory (Minimum Expected of a Graduating Student)	Unsatisfactory
Written Mechanics	Production quality that is compelling and engaging.	Production quality enhances communication.	Acceptable production quality: accurate spelling and grammar; appropriate choice of fonts and colours; appropriate use of language.	Marginal production quality: minor errors of spelling and grammar; irregular fonts and layouts.	Unreadable: illegible, unprofessional.
Oral Performance	Commands the attention of the audience throughout.	Voice, body posture, and handling of questions convey confidence and full knowledge of work being presented.	Professional tone and body language: loud and clear; oral performance compliments visual material; competent handling of questions.	Acceptable tone and body language; some nervousness may be notable; relies heavily on slides to communicate rather than using slides as supporting aids.	Unprepared; inaudible; nervous habits may be distracting; unable to answer reasonable questions.
Graphical Representations	Compelling and engaging; pictures worth “a thousand words”.	Graphics enhance communication; clearly present message and meaning.	Professional use of figures, tables and images that compliment the written/oral components: properly labelled, plotted, sized.	Acceptable use of figures and images: some minor problems with layout, sizing, legibility, colour.	Distracting, confusing, or inappropriate graphics that detract from the written or oral content.
Organization and Clarity	Leads audience towards scientific and technical insight.	Enhances delivery of technical content.	Professional layout and organization: appropriate division of sections, logical order helps audience understand problem and resolution in time/space limits.	Acceptable layout that uses basic outline or template for presenting information; may contain minor gaps in logical flow of information or adherence to time/space limits.	Information is disorganized making it difficult for audience to understand the content.
Content	Complete and inspiring technical story from start to finish.	Content presents an enhanced technical story that shows insight beyond the obvious.	Professional level of content: appropriate for audience; complete, accurate, and appropriate depth; conclusions/ recommendations are defensible based on information presented.	Acceptable coverage of technical content: all expected sections are clearly covered.	Expected content is sparse or missing; and/ or proper citations of sources are missing.

2. Teamwork Skills [12].

Element	Assessment				
	Outstanding	Excellent	Good (Minimum Expected of a Practicing Engineer)	Satisfactory (Minimum Expected of a Graduating Student)	Unsatisfactory
Individual contribution to the team	Always provides useful ideas when participating in the group discussion. Effort is above and beyond expectations.	Routinely provides useful ideas when participating in the group discussion. Always makes excellent effort to achieve task(s) on hand.	Usually provides useful ideas when participating in the group discussion. A strong group member who tries hard!	Sometimes provides useful ideas when participating in the group discussion. A satisfactory group member who does what is required.	Rarely provides useful ideas when participating in the group discussion. May refuse to participate.
Problem Solving	Identifies multiple solutions to problems and provides critical analysis.	Actively looks for and suggests solutions to problems.	Refines solutions suggested by others.	Willing to try out solutions suggested by others.	Lets others do the work.
Collaboration	Emphasizes the positive contributions of others. Looks for opportunities to enhance all tasks in the project.	Is never publicly critical of the project or the work of others. Always has a positive attitude about the task(s).	Is rarely publicly critical of the project or the work of others. Often has a positive attitude about the task(s).	Is occasionally publicly critical of the project or the work of other members of the group. Usually has a positive attitude about the task(s).	Is often publicly critical of the project or the work of other members of the group. Is often negative about the task(s).
Focus and Punctuality	Always focused and helps keep others on focus. Exceptional time management to complete task ahead of time.	Consistently stays focused on the task and what needs to be done. Very self-directed. Finishes tasks according to schedule.	Focuses on the task and what needs to be done most of the time. Other group members can count on this person. Tries very hard to finish tasks on time.	Focuses on the task and what needs to be done some of the time. Other group members must sometimes encourage this person to keep on task and to finish task on time.	Distracts others from focusing on task. Always late and may impede the progress of the team.
Communication	Always listens to, shares with, and supports the efforts of others.	Almost always listens to, shares with, and supports the efforts of others.	Usually listens to, shares, with, and supports the efforts of others.	Often listens to, shares with, and supports the efforts of others.	Rarely listens to, shares with, and supports the efforts of others.

3. Project Management Skills [12].

Element	Assessment				
	Outstanding	Excellent	Good (Minimum Expected of a Practicing Engineer)	Satisfactory (Minimum Expected of a Graduating Student)	Unsatisfactory
Goals identification	A realistic set of tangible goals were listed, organized, and prioritized. The effort is above and beyond expectations.	A realistic set of tangible goals were listed, organized, and prioritized.	A set of tangible goals were listed, organized, and prioritized. The goals set were not necessarily properly organized or prioritized.	A set of goals were listed, organized, and prioritized. The goals set may have been unrealistic and not properly prioritized.	A set of goals were listed, organized, and prioritized. The goals are unrealistic, poorly organized and improperly prioritized.
Task Breakdown	Realistic steps were identified and their interdependencies and completion dates were established. The effort is above and beyond expectations.	Realistic steps were identified and their interdependencies and completion dates were established.	Realistic steps were identified and their interdependencies and completion dates were established. Some of the articulated interdependencies did not reflect the interdependencies of the steps actually taken in the project.	Some steps were identified and their interdependencies and completion dates were established. Some of the articulated steps may have not reflected well the actual steps taken in the project.	Some steps were identified and their interdependencies and completion dates were established. The articulated steps poorly reflected the actual steps taken in the project
Schedule	A realistic and comprehensive schedule including all projected tasks and milestones is compiled. The timeline reflects the allocated hours for each step and resource. The effort is above and beyond expectations.	A realistic and comprehensive schedule including all projected tasks and milestones is compiled. The timeline reflects the allocated hours for each step and resource.	A realistic schedule including all projected tasks and milestones is compiled. The timeline adequately reflects the allocated hours for each step and resource.	A schedule including most projected tasks and milestones is compiled. The timeline is at times unrealistic w.r.t. the allocation of hours for each step and resource.	A schedule including a few tasks and milestones is compiled. The timeline is unrealistic w.r.t. the allocation of hours for each step and resource.
Resources (e.g., Human, Material, Financial, etc.)	Group members were effectively assigned to each task. Material and financial resources were identified in the plan and procured in a timely manner. The effort is above and beyond expectations.	Group members were effectively assigned to each task. Material and financial resources were appropriately identified in the plan: and procured in a timely manner.	Group members were adequately assigned to each task. Material and financial resources were identified in the plan. Few small delays in procurement did not affect the timely completion of tasks.	Group members were adequately assigned to each task. Some of the material and financial resources may have been misidentified in the plan and not procured in a timely manner.	Assignment of group members to tasks was inadequate. Material and financial resources were misidentified in the plan, resulting in the significantly delayed completion of many steps.
Budget	A budget reflecting the identified steps and resources was created and updated as necessary. The effort is above and beyond expectations.	A budget reflecting all the identified steps and resources was created and updated as necessary.	A budget reflecting most of the identified steps and resources was created and updated as necessary.	A budget reflecting crucial steps and resources was created. Updates were made whenever significant changes were incurred.	A budget that did not reflect some of the crucial steps and resources was created. Few, if any, updates were made.
Risks Management	All potential risks are correctly identified, mitigated and/or managed as appropriate. The team demonstrates a superior ability to re-scope and reanalyse the design whenever a new risk is identified.	All potential risks are correctly identified, mitigated and/or managed as appropriate. The team demonstrates some ability to re scope and reanalyse the design when a new risk is identified.	Most potential risks were correctly identified and managed.	Some evidence of risk identification and management. A few unidentified risks that materialize negatively affect the progress of the team at many stages of the design.	Very little evidence of risk Identification and management is present. Team was not able to cope when any potential risks materialized.

Appendix C. (Test examples)

History and math sample tests.

4) Quels sont les pays qui ont participé les premiers à « la course à l'espace » ?
Entoure la bonne proposition.

SUISSE et ALLEMAGNE.

U.S.A et U.R.S.S.S (la Russie maintenant).

U.S.A et Chine.

5) Quel fut le premier être vivant envoyé dans l'espace ?

____________________ .

6) Indique le nom de la navette spatiale qui a explosé en plein vol ?

C'est la navette spatiale ____________

Une combinaison de spationaute, un casque de respiration et des chaussons de protection coûtent 700 francs.

Si je donne ce billet, combien le marchand va-t-il me rendre ?

____ .

Une fusée à construire coûte 18 francs.

Si je donne ces 2 billets, combien le marchand va-t-il me rendre ?

____ .

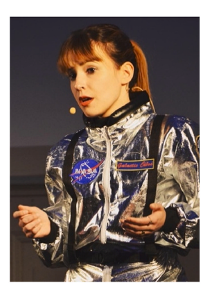
Un vélo coûte 250 francs.

Si je donne ces 3 billets, combien le marchand va-t-il me rendre ?

____ .

References

[1] Charles J. Camarda, Olivier de Weck, Sydney Do, Innovative conceptual engineering design (ICED): creativity and innovation in a CDIO-like curriculum, in: Proceedings of the 9th International CDIO Conference, 2013.
[2] Ecole Vivalys, Mission Vivalys, August 2020. https://www.vivalys.ch/lancement-de-la-mission-vivalys/. accessed 10/09/2021.
[3] NASA, About Analog Missions, 2019. https://www.nasa.gov/analogs/what-are-analog-missions. accessed 10/09/2021.
[4] NASA, HERA – Human Exploration Research Analog, 2019. https://www.nasa.gov/analogs/hera. accessed 10/09/2021.
[5] Loredana Bessone, Jo De Waele, Francesco Sauro, The ESA CAVES Astronaut Training Program: Speleology as an Analogue for Space Missions, 2018. https://www.hou.usra.edu/meetings/lpsc2018/pdf/1458.pdf. accessed 10/09/2021.
[6] Philippe Wieser, EPFL, Project Management and Risk Analysis (MGT-427), October 2020.
[7] Maxime Fayet, Vivalys Pictures, 2020/2021.
[8] Oliver de Weck, EPFL/MIT, Fundamentals of Systems Engineering, October 2020 (ENG-421).
[9] Asclepios Project, June 2019 asclepios.ch (accessed 30/09/2021).
[10] BIOTESC, EPO Pesquet. https://ntrs.nasa.gov/api/citations/20160011087/downloads/20160011087.pdf, July 2016 accessed 30/09/2021.
[11] RTS, Des écoliers Vaudois font une expérience de simulation de la vie sur Mars, March 2021. https://www.rts.ch/info/regions/vaud/12056592-des-ecoliers-vaudois-font-une-experience-de-simulation-de-vie-sur-mars.html. accessed 30/09/2021.
[12] William Bishop, Oscar Nespoli, Wayne Parker, Rubrics for Accreditation and Outcomes Assessment in Engineering Capstone Projects, 2012.
[13] Taber MacCallum, Jane Poynter, David Bearden, Lessons learned from Biosphere 2: when viewed as a ground simulation/analog for long duration human space exploration and settlement, SAE Trans. (2004) 1095–1104.



Chloé CARRIERE Chloé Carrière, also known as 'Galactic Chloé', is a Management of Technology and Entrepreneurship student at the Federal Institute of Technology Lausanne. *Besides her studies, she brings the science around space travel, astronomy and astrophysics to wider audiences though social media, youtube and live presentations. She is the founder of the association Space@yourService that launched several educational projects around space exploration. Chloé wishes to be one of the first women to step on the Moon and to contribute to the future of a sustainable use of outer space.*

Kevin PAHUD Kevin Pahud studies Energy Science and Technologies at EPFL, where he is busy combining his knowledge towards a more sustainable society and bringing science communication about space engineering and energy through various public events, social media, and research notes.

Parallel to his studies, he currently works as a research analyst at Zenon, a think tank aiming to achieve a sustainable future compatible with planetary boundaries by bringing the scientific method at the core of his work.

His interests include combining discussions around energy, resources, and space to help broaden the debate about humanity's grand challenges.

Volker GASS After completing his master's degree in Microtechnology at the Ecole Polytechnique Fédérale de Lausanne (EPFL) in 1989 he worked in the aerospace industry sector for 22 years, during that interval also completing a PhD in Science in the field of applied Micro-Systems Technologies at the University of Neuchâtel, Switzerland in 1994. Since October 2011, Volker Gass is nominated Director of the Swiss Space Center (now call ed Space Innovation) EPFL. In September 2021, he was appointed visiting Professor at MIT AeroAstro, working on System Engineering and the New Space Economy.