The Greenhouse in Space (GHIS) as STEM Educational Experience

In 2011, the section Human Spaceflight (HSF) of the European Space Agency (ESA) proposed the instructional project Greenhouse in Space (GHIS). Addressed to young teens (ages 12 to 14), the GHIS aimed at comparing the growth of the Arabidopsis thaliana on Earth, at different latitudes and without sunlight, and in space (micro-g environment). The plants were seeded contemporarily, in standard miniature greenhouses, by around eight-hundred European schoolers, by the crew of the isolation experiment Mars500 (Moscow), and by the Italian astronaut Paolo Nespoli within the MagISStra mission on the International Space Station (ISS). Despite a potentially hazardous accident occurring on the ISS, the GHIS became a successful STEM experience, enthusiastically accomplished in sundry schools. Its heritage about microgravity plant research was formidable also outside Europe, notably in the US National Aeronautics and Space Administration (NASA). We illustrate how GHIS was implemented in numerous hands-on laboratories via learning-by-doing, and how such massive participation persuaded the space agencies to pursue further educational ventures and partnerships. We focus on the GHIS activity of 25 Italian pupils from the Scientific High School "Giovanni Battista Grassi" in Latina (seat of the Planetarium "Livio Gratton"). The key reference is a talk delivered in the 98th annual congress of the Italian Physical Society at the University of Naples (September 17–21, 2012) together with a poster presentation in the international conference GIREP-EPEC 2011 at the University of Jyväskylä in Finland (August 1–5, 2011).

Keywords: *GHIS, ISS, ESA, HSF, EPO, NASA, ASI, STEM, HOL, ESD, ICT, SEND, TRL, secondary school, educational project, learning by doing, citizen science.*

Introduction

In 2009, under the innovative management of the Italian astrophysicist *Simonetta Di Pippo*[1], the ESA's Directorate of Human Spaceflight devised the Greenhouse in Space (acronym GHIS) as both an inspiring scientific experiment and a valid educational opportunity and launched the preparatory campaign "Feeding our Future: Nutrition on Earth and in Space" by spreading multi-language lesson notes via DVDs targeted to European secondary schools. The *GHIS* was inaugurated in February 2011 (Figure 1) by the European Space Agency – Human Spaceflight (ESA–HSF for brevity) and summarized as follows: "The Greenhouse in Space is an educational project by ESA involving schoolchildren aged between 12 and 14 and ESA astronaut Paolo Nespoli at the International Space Station growing the same plants in similar small greenhouses

[1] https://bit.ly/494CHis.

for several months. The project started on 17 February 2011 with an event in four locations in Europe:

- Cité de l’espace in Toulouse France;
- ESA European Astronaut Centre, Cologne, Germany;
- ESA ESRIN, Frascati, Italy;
- Ciência Viva in Lisbon Portugal.

The students were connected to each other and to the ISS to speak with Paolo Nespoli, who planted and watered the first seeds live. Paolo is now using his specially-developed greenhouse in space to grow plants and make observations of the life cycle of a flowering plant. The schoolchildren are able to follow this with their own experiment on the ground, using a similar greenhouse and the same species of plant." (from ESA website[2]).

Figure 1. *The 2011 official logo of the Greenhouse in Space*

Source: https://bit.ly/3B6Tymb.

Approximately 800 European schoolers, including pupils with Special Education Needs and Disabilities (SEND), joined the *GHIS* through STEM instructional projects based on Hands-On Laboratory (HOL) which reinforced the Education for Sustainable Development (ESD) for the critical role of plants in any ecosystems. The *GHIS* also fostered the Information & Communication Technologies (ICT) because students and teachers attended a live in-flight call with Paolo Nespoli[3], and they were invited to send their photos and talk to each

[2] https://bit.ly/3TLHixl.
[3] https://bit.ly/44ichaD.

other on a Facebook page as well as by emailing the Human Spaceflight education team (Gras-Velázquez 2016). Here we give a synopsis of the initiative, from the first announcement (February 3, 2011) to the closing event (May 25, 2011), with mentions to the pioneering programme "Feeding our Future" and to the ESA missions *MagISStra* and *Mars500*. Later we describe the contribution from the Scientific High School "G.B. Grassi" of Latina (Italy), famous for its Planetarium (Bonacci 2011a), whose pupils seeded, watered and observed an *Arabidopsis thaliana* growing in the mini greenhouse (Fig. 2) supplied by the well-established[4] Education Payload Operations (EPO). Most of the material about that trailblazing STEM activity comes from a topical talk (Bonacci 2012) and a poster presentation (Bonacci 2011b). The legal framework and up-to-date literature are retrieved from current institutional and sectorial websites.

Figure 2. *The 2011 ESA education kit for the greenhouse in space by EPO*

Source: https://bit.ly/4eFltcz.

[4] https://bit.ly/4jBridA.

The forerunner ESA programme "Feeding our Future"

In 2009, the European Space Agency – Human Spaceflight launched the preparatory campaign "Feeding our Future: Nutrition on Earth and in Space", examining food as a vital part of life on Earth and in space. In the ESA's explanatory page[5], the HSF clarified that the programme, available in 13 languages (namely: Český, Dansk, Deutsch, English, Español, Ελληνικά, Français, Italiano, Nederlands, Norsk, Português, Suomi, Svenska) and presented by ESA Life Scientist *Nicole Sentse*, "shows why we need food in the first place and what it represents in our culture and daily living. The video illustrates how our bodies process food as a source of energy and building materials. It looks at the importance of good nutrition for a healthy life and what can happen without it, whether here on Earth or in space. The programme also looks at research for preserving and growing food for long flights, as well as valuable technology for future food supplies on Earth, where climate change and population growth are global challenges. New techniques developed for space missions can help to feed hungry people on our planet. The DVD has a duration of 35 minutes and can be downloaded as a high-resolution movie (417 MB). A Teacher's Guide and a User's Guide are also available for download." In addition, the ESA–HSF's Director *Simonetta Di Pippo* expounded that: "Food and nutrition are a fundamental part of our daily lives, not only because we need energy and nutrients to stay alive, but also because they are the basis of our culture and way of life. The ancient Romans used to say 'mens sana in corpore sano' (healthy mind in a healthy body), a saying that is even more meaningful nowadays as it emphasises the importance of food and nutrition for a healthy life style – especially for the younger generation. I am therefore pleased to introduce to European educators and students, the programme 'Feeding our Future – Nutrition on Earth and in Space'. The programme deals with the topic of nutrition from an inspirational perspective – space travel. Astronauts on board the International Space Station must stay healthy to be able to cope with the demands of life in space. Long term space exploration requires advanced technologies in several different fields, including life support systems for astronauts. Europe contributes a great deal to the life support system research effort and food technology is an important focus. So one of the next big questions is 'what will be for dinner on the Moon?' Space – like nutrition – is an interdisciplinary topic because of its scientific, technological, cultural and emotional values. It is therefore an ideal and inspirational subject to engage and provide curriculum related material for European students. One of the missions of the ESA Directorate of Human Spaceflight is to bring the fascination of human spaceflight and exploration to our youth. Education is part of the intangible benefits of our programme that contribute greatly to the establishment of a knowledge-based society in Europe. I wish all teachers and students a pleasant view and work in the classroom." (from ESA website[6]).

[5]https://bit.ly/45ppQVF.
[6]https://bit.ly/4q6xAUU.

The two ESA missions committed with GHIS

The *GHIS* was tested in the microgravity of an orbiting laboratory and in absence of sunlight. Such extreme environments were provided, respectively, by two pivotal 2010–2011 ESA missions:

- *MagISStra*, 159 days on the International Space Station (Fig. 3);
- *Mars500*, 520 days in an isolation chamber in Moscow.

Ground-based drop facilities and any other experimental setup for domestic microgravity, alternative to the International Space Station, were excluded for the long duration of the plants' growth.

Figure 3. *Astronaut Paolo Nespoli and ISS crew in December 2010*

Source: https://bit.ly/4erdZbB.

The ESA–ISS mission MagISStra (December 15, 2010 – May 24, 2011)

Let us recall the mission MagISStra (Fig. 4): "ESA astronaut Paolo Nespoli was launched to the International Space Station for a long-duration mission on 15 December, serving as flight engineer for Expeditions 26 and 27. This was the third six-month mission by a European astronaut on the Station. From December 2010 to May 2011, Paolo, ESA's Italian astronaut, carried out an intensive programme of experiments, ranging from radiation monitoring to measurements that could improve oil recovery in petroleum reservoirs. His duties aboard the Space Station included participating in docking operations to receive two cargo spacecraft: Europe’s second Automated Transfer Vehicle (ATV) *Johannes Kepler*, and the second Japanese HII Transfer Vehicle (HTV). Both are unmanned spacecraft used to resupply the International Space Station. Nespoli was the prime operator for berthing the HTV to the Station after the free-flying vehicle was captured by his crewmate Catherine Coleman. In May, Nespoli received a new Italian crewmate for five days. ESA astronaut Roberto Vittori, assigned to Space Shuttle mission STS-134, flew to the Station on a flight opportunity provided by the Italian space agency, ASI. The Space Shuttle also delivered the Alpha Magnetic Spectrometer (AMS-02) to the Station. With more than 30 experiments during this mission, European space science is, as usual, driven by the quest to improve life on our planet. The mission scientific programme covered human research, fluid physics, radiation, biology and technology demonstrations. Paolo not only carried out experiments for ESA, but also for the US, Japanese and Canadian space agencies. As part of his educational programme, children had the chance to follow an international initiative built around health, well-being and nutrition (Mission X: Train Like an Astronaut), as well as a special greenhouse activity in space. From his privileged viewpoint in space, Nespoli used ESA’s novel 3D camera to show unprecedented images of the Station." (from ESA website[7]).

Figure 4. *The 2010 official logo of the mission MagISStra*

Source: https://bit.ly/3MNbAwa.

[7]https://bit.ly/40vhYiT.

The ESA–IBMP mission Mars500 (June 3, 2010 – November 5, 2011)

Let us recall the *Mars500* study (Fig. 5): "Human exploration of our Solar System is an important focus for ESA. The Agency has started on the path to making this a reality. Making sure that our astronauts are prepared mentally and physically for the demands of long exploration missions is imperative to a mission's success. In light of this, ESA undertook a cooperative project with the Russian Institute for Biomedical Problems (IBMP) in Moscow, called Mars500. ESA's Directorate of Human Spaceflight has a long tradition of conducting research on the physiological and psychological aspects of spaceflight. ESA's bedrest studies, in particular, are at the forefront of scientific research to understand how the human body reacts under weightless conditions, in order to devise effective countermeasures and enable humans to undertake long missions in space effectively. Mars500 is part of these scientific efforts to prepare for human exploration missions. When preparing for long space missions beyond the six-month range undertaken by Expedition crews on the International Space Station (ISS), medical and psychological aspects become an issue of major importance. When contemplating missions beyond Low Earth Orbit, such as to the Moon and Mars, daily crew life and operational capabilities may be affected by the hazardous space environment, the need for full autonomy and resourcefulness, the isolation, the interaction with fellow crewmembers and other aspects. A better understanding of these aspects is essential for development of the elements necessary for an exploration mission. Whereas research onboard the ISS is essential for answering questions concerning the possible impact of weightlessness, radiation and other space-specific factors, other aspects such as the effect of long-term isolation and confinement can be more appropriately addressed via ground-based simulations. The purpose of the Mars500 study is to gather data, knowledge and experience to help prepare for a real mission to Mars. Obviously there has not been effect of weightlessness, but the study is helping to determine key psychological and physiological effects of being in such an enclosed environment for such an extended period of time. The participants act as subjects in scientific investigations to assess the effect that isolation has on various psychological and physiological aspects, such as stress, hormone regulation and immunity, sleep quality, mood and the effectiveness of dietary supplements. The knowledge gained during the study is invaluable in providing the basis for the potential development of countermeasures to deal with any unwanted side effects of such a mission, and also to help in astronaut selection procedures, and at a modest expense. On the European side, the Mars500 programme was financed from the European Programme for Life and Physical Sciences in Space (ELIPS) and involves scientists from across Europe. <u>Life in the isolation chamber</u> – In order to simulate a mission to Mars, six candidates (three Russian, two European and one Chinese) were sealed in an isolation chamber in June 2010. This group was chosen to encompass working experience in many fields, including medicine, engineering, biology and computer engineering. Part of the chamber simulated the spacecraft that would transport them on their journey to and from Mars and another part simulated the landing module that would transfer them to and from the martian surface. Following the completion of an initial 105-day isolation period in 2009, a full 520-day study was started in June 2010. Candidates for this test began their mission training in February 2010 and the end of the isolation period was 4 November 2011. Sealed in the chamber, the candidates had only personal contact with each other plus voice contact with a simulated control centre and family and friends as would normally happen in a human spaceflight mission. A 20-minute delay was built into communications with the control centre to simulate an interplanetary mission and the crew was given almost an identical diet to that used for the International Space Station. As with a human spaceflight mission, the crew was free to take certain personal items, and they were supplied with books, films, personal laptops and can occupy themselves with physical exercise or their own studies. During the isolation period the candidates simulated all elements of the Mars mission, travelling to Mars, orbiting the planet, landing and return to Earth. The crew was responsible for monitoring and maintaining the health and psychological states of themselves and each other as well as monitoring and controlling and maintaining systems, including life support, control resource consumption. During the mission the crew carried out standard and non-standard cleaning and maintenance, as well as fulfilling scientific investigations. A 7-day week was put in place with two days off and a rotational system was put in place for night shifts. Non-standard and emergency situations were simulated to determine the effect of a decrease in work capability, sickness, and also failures of the onboard systems and equipment. During 'Mars surface operations' the crew was divided into two groups of three people each. Once the first group 'descended' to the martian surface, the hatch between the martian simulation module and the rest of the facility was closed by the second group and was opened again only when the Mars surface stay simulation ended." (from ESA website[8])

Figure 5. *The 2010 official logo of the isolation experiment Mars500*

Source: https://bit.ly/44tRorH.

[8]https://bit.ly/4kgoWiO.

The ESA–HSF educational project "Greenhouse in space"

Paolo Nespoli performs a preliminary greenhouse test (December 26, 2010)

Onboard the ISS module Columbus, Paolo Nespoli performed an illumination test[9] within the EPO's operation "Greenhouse", supported by the Norwegian USOC (Basit 2012), on December 26, 2010.

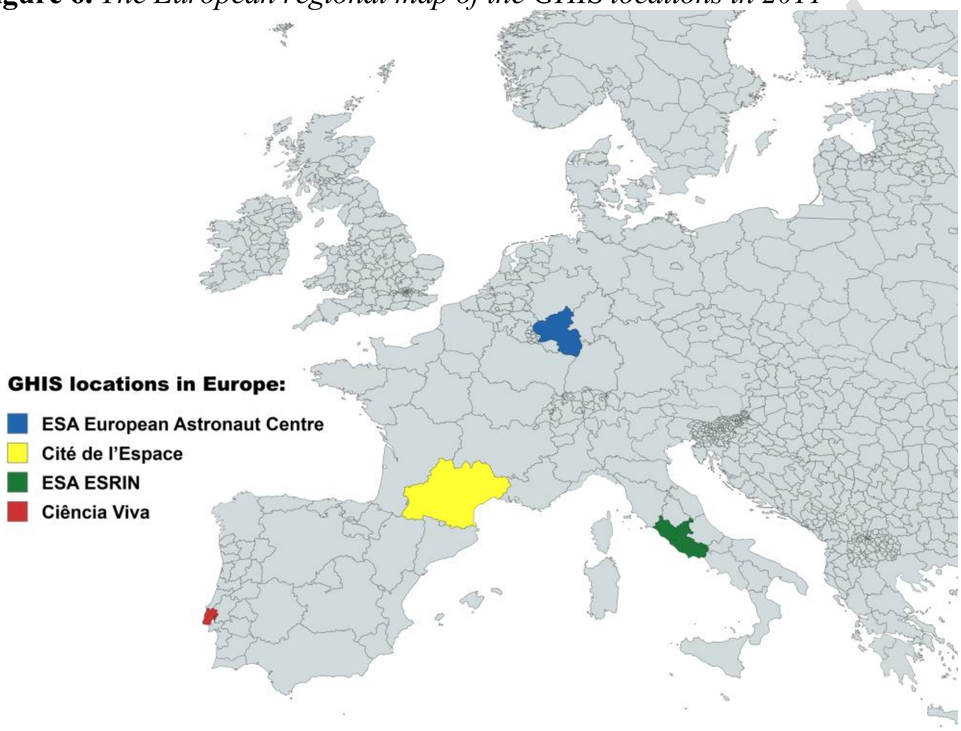
ESA-HSF announces the GHIS educational project (February 3, 2011)

On February 3, 2011, the European Space Agency – Human Spaceflight Education (ESA–HSF for short) announced the project Greenhouse in Space (GHIS) as follows[10]: "It's a small greenhouse for space voyagers – and for you. Paolo Nespoli has a special greenhouse with him at the International Space Station and he's inviting young science enthusiasts to conduct an experiment with him. *Instructions are now online!* Growing plants in space will be crucial for the astronauts of the future. When flying to Mars or even further, it will be necessary to produce fresh food onboard and become partially self-sufficient. Setting up greenhouses on the Moon, Mars or other planetary bodies will also be an important part of future exploration missions. Greenhouses also provide oxygen and bring some life to the bleakness of space. Caring for plants is a good way to maintain memories of Earth and an enjoyable way to pass time during the long and possibly boring interplanetary cruise. Plants aboard the ISS – There is no danger of boredom during Paolo's MagISStra mission, as it will be packed with activity and science. The 'Greenhouse in space' project, proposed and conceived by ESA's Directorate of Human Spaceflight, is not only a scientific experiment but also an educational opportunity for schoolchildren aged between 12 and 14. Paolo will use a specially-developed greenhouse in space to grow plants and make observations of the life cycle of a flowering plant. The schoolchildren will be able to follow this with their own experiment on the ground, using a similar greenhouse and the same species of plant. The experiment starts with watering of some thale cress (*Arabidopsis thaliana*) set up in the International Space Station's Columbus laboratory. The children will start their own ground experiments at the same time. Paolo will take still images of the growth cycle and video recordings of key steps in the germination of the plants and post them on the MagISStra website. The participating children will be able to compare the space experiment with their ground experiment. The young scientists on the ground and Paolo in orbit will follow the growth cycle of their flowering plants for about 10 weeks. The children will be encouraged to exchange their observations with each other over this period, creating a Europe-wide network that enables one experiment to link young scientists together in a special way. Schools who wish to participate in this experiment can order their mini greenhouse ground kits from the ESA's Human Spaceflight education website, where there are limited numbers available. […] The children will be invited to send their end results and observations to the ESA

[9]https://bit.ly/3L1DBDc.
[10]https://bit.ly/4ipZ0kB.

Human Space Flight education team, who will create a final lesson online for download by other schools and teachers. The experiment will be launched on 17 February 2011 with a live event linking together nearly 750 children in four locations in Europe: the European Astronaut Centre in Cologne, Germany[11]; ESRIN in Frascati, Italy[12]; Cité de l'Espace in Toulouse, France[13]; and Ciência Viva – Agência Nacional para a Cultura Científica e Tecnológica in Lisbon, Portugal[14]. Paolo will of course participate in the event from the Space station which will have its own miniature greenhouse." Let us notice how the *GHIS* project was accomplished in different European microclimates (Fig. 6).

Figure 6. *The European regional map of the GHIS locations in 2011*



Source: https://bit.ly/3YFX9jE.

ESA-HSF inaugurates the GHIS educational project (February 17, 2011)

On February 17, 2011, *GHIS* started with circa eight hundred gardeners on Earth (above the initial estimate of 750) and one in space: "ESA's 'Greenhouse in Space' educational project began yesterday in four locations throughout Europe and on the International Space Station. This unique undertaking involves schoolchildren and ESA astronaut Paolo Nespoli growing the same plants in similar small greenhouses for several months. Growing plants is essential for us all. They not only provide food, but they are also beautiful and relaxing. And they

[11]https://bit.ly/3IafwIq.
[12]https://bit.ly/4q7CHV1.
[13]https://bit.ly/3YoxdJe.
[14]https://bit.ly/3N60ZzV.

can be educational: the Greenhouse in Space project offers European children aged 10–16 the chance to compare plants grown on Earth with those in space. More than 800 children are now space gardeners, asking burning questions such as 'How do plants know where up and down is in microgravity?' and 'How difficult is it to sow seeds in space?' Together with Paolo Nespoli, ESA's astronaut on the International Space Station, they will now discover the answers to these questions with their own experiments. Thursday was seeding day – The project was launched yesterday in France, Germany, Italy and Portugal, along with Paolo on the Station. The children and teachers linked up via video, learning how to assemble their own greenhouses and plant the Arabidospis seeds. Sowing was not easy because of the minuscule seeds, but the choice of plant was far from random. Arabidopsis has already proved itself to be a hardy grower in space and, even more importantly, it self-pollinates – essential in the absence of pollinating insects in space! The students in Cologne were also treated to an impromptu appearance by Alexander Gerst, one of ESA's newest astronauts. And in Italy, there was a special space connection: part of the audience were students from Paolo's old school. Message from Space – Paolo joined the children in the afternoon by video for a 20-minute call from space, showing us his space-qualified greenhouse and watering the seeds. He demonstrated that simple procedures on Earth such as watering is extremely complex and possibly dangerous in weightlessness. Paolo kindly answered several questions from children in the different countries in a rare opportunity – it's not every day you get to speak to an astronaut in space. Now the children and Paolo are eagerly following the growing plants in this 15-week experiment. The results will be posted as an online lesson in ESA's web pages once the data from the 800 greenhouses on Earth have been compared to Paolo's experiment." (from ESA website[15]).

Mixed news from the ESA's missions (March 17, 2011)

In March 2011, the mission MagISStra interrupted the *GHIS* for the presence of a dangerous fungus, whereas the *Arabidopsis* plants kept growing well at *Mars500*. ESA clarified that: "Gardens are always a source of surprises. After three weeks of steady growth in space under the watchful eye of the ESA astronaut Paolo Nespoli, the baby space plants of the Greenhouse in Space project have found a new – and unexpected – travelling companion: fungus. The International Space Station (ISS) ecosystem is a particularly delicate one. Whereas some fungus does not cause much harm to earthly plants or humans, the balance of the closed systems in the Station could be compromised. It is known that spaceflight reduces the crew's immune systems, their ability to fight off infections, and once safety experts had confirmed that a fungus was growing in the greenhouse, the unavoidable decision was made to carefully remove the greenhouse from the ISS, thus avoiding any probability of causing any harm to the astronauts. The *Arabidopsis* plants, already having proved themselves as a hardy growers in space, seemed to grow very well despite the uninvited hitch-hiker on board. Paolo was

[15]https://bit.ly/4iNbxyr.

the first one to remark that simple procedures on Earth are extremely complex and possibly dangerous in weightlessness. 'Part of the experiment was indeed a success: we were able to grow the plants and observe them.' Even though some experiments can go wrong, Paolo said, 'This is a lesson to be learned that we can leave to the future astronauts. I'm sure they will get even better at it.' From real Space Station to virtual Mars spacecraft – The Greenhouse in Space education project moves on and encourages participating students throughout Europe to continue their experiments and monitor their plants even more closely. Now it is time to compare their greenhouses with the martian ones, as the crew of Mars500 found four of these little greenhouses packed in their lander module with all other cargo. Now they are carefully growing the same plants in their spacecraft-like modules and the results are coming in." (from ESA website[16]).

The GHIS closing event (May 25, 2011)

On May 25, 2011, the *GHIS* closing event was celebrated as follows: "Harvest time for the little greenhouses – ESA's high-flying 'Greenhouse in Space' educational venture began in February with a live link to the Space Station and four events around Europe. Now, after three months, the project has finished in Lisbon – and aboard a virtual Mars spacecraft. More than 800 children around Europe took part in the Greenhouse in Space project with varying results: some of the *Arabidopsis* seeds in the miniature greenhouses grew well, but some did not. Most importantly, *Arabidopsis* proved itself to be a hardy grower in space. Its short life cycle from seed to seed, small size and ability to self-pollinate make *Arabidopsis* an ideal plant to grow in space. The greenhouse aboard the International Space Station unfortunately developed a potentially hazardous fungus. Since the Station's ecosystem is particularly delicate, it was decided to dispose of it. Whereas some fungi are quite harmless to earthly plants and humans, the balance of the 'closed' systems in the Station could not be risked. The crew of the Mars500 simulated mission to the Red Planet began their greenhouse experiment at the same time as ESA astronaut Paolo Nespoli started his on the Station. They set up three greenhouses and the results were very encouraging: some plants completed the full cycle. […] Thank you, Lisbon! – The project's closing event was held in Lisbon, Portugal, at the Ciencia Viva science centre. Ciencia Viva invited 173 children and 20 teachers from eight schools from all over Portugal to present their findings on 12 May. Duarte Lopes elementary school in Benavente and Abel Salazar secondary school probed deeper by investigating how well Arabidopsis grows in different soils. Students even tried growing their seeds in gelatine – and the seeds germinated. Marcelino Champagnat school in Lisbon kept two greenhouses under the same conditions but withheld fertiliser from one. The school was awarded the first prize for their presentation and were given a Space Garden kit to try out some of their new ideas. Students from Duarte Lopes elementary school suggested using larger seeds and plants that are less sensitive to wide temperature changes. They concluded that such experiments are important

[16]https://bit.ly/4iIA5sm.

for gaining knowledge for space missions. They found that one experience leads to many others, and that learning is a continuous process." (from ESA website[17]).

The aftermath

The ESA invited all the other European participants to submit their findings by the end of June 2011. The Italian secondary schools respond to local administrations (regional or provincial, depending on their curricula) and the Province of Latina[18] (manufacturing hub in southern Lazio[19]) was represented in the *GHIS* by the Scientific High School "G.B. Grassi" whose students sent their "Greenhouse results" on May 27, 2011. Anyway, the *GHIS* did not conclude in May 2011 but lasted util the end of the *Mars500* mission, whose crew were able to grow their seeds to maturity as well as harvesting new seeds. Their results were summarized by Romain Charles – one of the crew members: "We started the Greenhouse in Space experiment with 4 small greenhouses on the 17th of February 2011. We sowed a total of 36 seeds. After one month, only 5 sprouts appeared in 2 of the greenhouses. Then I took the decision to prepare the 2 other greenhouses with a new soil and 16 new seeds. After a few weeks, we had a total of 7 different plants but some of them were already dying. After 12 weeks (3 months), the pods of the only surviving plant opened and I could harvest its seeds. I prepared a new greenhouse (new soil) for the seeds newly produced to check if our production was sustainable. Unfortunately, after 3 weeks, no sprout appeared." (from ESA website[20]).

Scientific impact

After the *GHIS* experience, ESA dedicated a specific webpage[21] to the research in space, and on parabolic flights, about the *Arabidopsis thaliana* acknowledging that "Growing plants for food in space and on other planets will be necessary for exploration of our Universe". The *GHIS* paved the way to modern microgravity plant research also outside Europe, especially by the National Aeronautics and Space Administration (NASA). In fact, on April 18, 2014, NASA launched the "Vegetable Production System" (Veggie) as "a space garden residing on the space station. Veggie’s purpose is to help NASA study plant growth in microgravity, while adding fresh food to the astronauts’ diet and enhancing happiness and well-being on the orbiting laboratory." (from NASA website[22]). Analogously, on April 18, 2017, NASA launched the "Advanced Plant Habitat" (APH) as "the largest, fully automated plant growth research facility that is used to conduct plant bioscience research on the International Space Station (ISS). It occupies the lower half of the EXpedite the PRocessing of Experiments to Space

[17]https://bit.ly/3DFpsrq.
[18]https://bit.ly/4spx0mN.
[19]https://bit.ly/4js9tO2.
[20]ttps://bit.ly/41Qp6pY.
[21]https://bit.ly/44f9YVG.
[22]https://bit.ly/44X0gHn.

Station (EXPRESS) Rack and one powered International Sub-rack Interface Standard (ISIS) drawer, providing a fully enclosed, closed-loop plant life support system with an environmentally controlled growth chamber designed for conducting both fundamental and applied plant research during experiments extending up to 135 days. The system requires minimal crew involvement to install the science, add water, and other maintenance activities. Why is APH Important? – In order to thrive in deep space, there is a need for new technologies in space crop production and food safety which will supplement the space diet with fresh, nutritious crops during space station, cislunar, lunar and eventually Mars missions. Currently, spaceflight plant research is conducted in plant chambers designed to operate in microgravity. Previous plant growth systems were limited by small growth areas available for crop production. In order to overcome remaining challenges in spaceflight plant research, larger plant growth systems were required. NASA developed two new plant research facilities, Veggie and the APH, for conducting spaceflight plant research on station as recommended by the National Research Council Decadal Survey Study 'Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era.' Both these facilities have larger plant growth areas and are designed for studying crop production, plant-to-plant interactions, and human-plant-microbial ecosystems using large plants in microgravity. Future plant research conducted in these research facilities will help enable exploration by improving our understanding of how plants, and the associated microbiomes in leaves and roots, grow in the spaceflight environment. This knowledge is essential for developing suitable countermeasures to mitigate potential problems of crop production, water recycling and atmosphere revitalization needed for supporting sustainable and long-term human colonies in space. Space Applications – APH seeks to further our understanding of plant biology and crop growth in space. The variety of experiments flown use the APH facility test the genetic and epigenetic effects of spaceflight, plant metabolism, factors leading to crop flavor, and the effectiveness of APH hardware to grow plants for human consumption in space. Experience gained cultivating crops with APH will inform deep space missions requiring more sustainable and nutritional food sources. Earth Applications – The primary purpose of APH is to improve our understanding of plant growth in space. However, the findings from these investigations could provide better understanding of plant biology with relevance to generating increased agricultural yields, enhanced flavor, or more stable and easily cultivated crops." (from NASA website[23]). The enduring echo of *GHIS* induced ESA to launch, in April 2017, the *AstroPlant* as "a citizen science initiative that aims to inspire home-gardeners, schools, urban farmers and enthusiasts to nourish seeds selected by the MELiSSA[24] team. Data recorded via a smartphone app will be sent to ESA for processing." (from ESA website[25]).

[23]https://bit.ly/49pQmQ4.
[24]https://bit.ly/4leb0am.
[25]https://bit.ly/3IcYGss.

Educational impact

We define *GHIS* as a STEM activity for involving three different subjects (Kelley & Knowles 2016): Astronomy, Biology, and Science. Although missing one of its highest goals, i.e., a full comparison with the ISS experiment, the *GHIS* strongly opposed the low attractiveness of STEM studies (Nistor et al. 2018), with a passionate response from eight hundred students, with various SEND pupils (Ianes et al. 2020), and dozens of teachers. As highlighted by the organizers[26], *GHIS* encouraged children's interest in science at an early age; the teacher *Paulo Fonseca* (Escola Básica D. Duarte, Viseu) exclaimed: "This was a unique occasion to talk to an astronaut and stimulate the appetite for science of our kids". Even the unexpected mold onboard the ISS turned into an instructional opportunity, letting the pupils realize that laboratory tests can be affected by accidents that virtual simulations often neglect (Bonacci 2025). The *GHIS* projects were implemented via *learning by doing* (Dewey 1916) in traditional laboratories (technology level TRL 4), triggering the emotional intelligence (Parker et al. 2004), and corroborating both the ICT (Gras-Velázquez 2017) and the ESD (Gras-Velázquez & Fronza 2020). The *GHIS* contribution from "G.B. Grassi" of Latina, the scientific high school hosting the Planetarium "Livio Gratton" (Bonacci 2013), was fairly appreciated in the Section "Didactics of Physics" of the 98th Congress of the Italian Physical Society (September 17–21, 2012) at the University of Naples (Bonacci 2012) and in the Poster Session of the international conference GIREP-EPEC 2011 (August 1–5, 2011) at the University of Jyväskylä in Finland (Bonacci 2011b). The latter projected the young city of Latina[27] on an international stage, so that the cosmonaut Walter Villadei went there in person to sponsor the school contest "Space for Your Future. The ISS: Innovatio, Scientia, Sapientia" in 2016 (Bonacci 2023). In conjunction with the start of the *GHIS* campaign, ESA potentiated the European Space Education Resource Office (ESERO[28]); opened in 2006[29], such project has become the foremost path of supporting early years, primary and secondary education community in Europe. On the footprint of the *GHIS*, the Italian Space Agency (ASI) promoted other instructional initiatives with the endorsement of astronauts as science ambassador (McNamee 2025), like the competition "YiSS – Youth ISS Science" publicized by Paolo Nespoli[30]. In Spain, instead, the "Ignacio da Riva" University Microgravity Institute[31] supported the "Europe to Space" program (EU2Space[32]), a challenge addressed to the university students from any major (Roibas-Millan et al. 2023) to "plan, design, solve, and put your hands on a real satellite that will fly to space" (from UARX website[33]).

[26]https://bit.ly/4iNbxyr.
[27]https://bit.ly/4mKNJhg.
[28]https://bit.ly/3HBG8lP.
[29]https://bit.ly/4lO6Mpp.
[30]https://bit.ly/47XKf6a.
[31]https://bit.ly/4qISWYZ.
[32]https://bit.ly/4pHy2ru.
[33]https://bit.ly/49qgHyB.

The GHIS educational project by the "G.B. Grassi" high school

We focus on the educational project "A greenhouse in space" by which the Scientific High School "Giovanni Battista Grassi" of Latina[34] joined the *GHIS* proposed by ESA in 2011. Hosting the Planetarium "Livio Gratton", a mighty driver of STEM projects (Bonacci 2016a, 2016b) and participatory science (Bonacci 2020a), that secondary school[35] has always been connected to the ESRIN of Frascati and to "Frascati Scienza" (Bonacci 2018b, 2020b). The short distance (only 55 km) and excellent welcome organization fostered guided tours and solo visits in the decade 2010-2020. The consequent peak of enrolment in university faculties related to space exploration[36] confirmed that both STEM career knowledge and interests are influenced by society at large (Blotnicky et al. 2018) and benefit from the collaboration with multi-stakeholders (Jiménez-Iglesias et al. 2016). Therefore, when ESA ESRIN called for the *GHIS* applications in Italy, the Director of the Planetarium of Latina responded immediately with an *ad hoc* project based on *hands-on laboratory* and summarized in the Table 1. Being the sole school to register in *GHIS*, the "G.B. Grassi" represented the whole Province of Latina, a territory deeply studied[37] by geologists for its peculiar coastal geomorphology.

Table 1. *The 2011 GHIS project of the school "G.B. Grassi" in Latina (Italy)*

Title	A greenhouse in space (original title in Italian: "Una serra nello spazio").
Aims	Seeding, watering and observing the growth of a plant in the laboratory with reference to the results obtained in space (mission MagISStra) and on Earth (in the isolation experiment Mars500 and in other schools).
Goal	Spotting the differences between the terrestrial and the space (micro-g) environment about the evolution of a low technology readiness level (TRL 4) botanic process.
Materials	An ESA's standard miniature greenhouse (i.e., a growth chamber with medium perlite, a transparent cover, a transparent cap, a black cut out piece of foam, a seed bag of *Arabidopsis thaliana* with fertilizer), a watering beaker, a magnifying glass, a pair of thin forceps, some filter paper to place the seeds on, and a large sunny window.
Tools	EPO Educational Kit P/N 309348[38] for ESA's Greenhouse in space
Project Manager	Enzo Bonacci, Teacher of Mathematics and Physics, Director of the Laboratory of Physics and of the Planetarium "Livio Gratton" in Latina.
Project Team	Twenty-five students aged 14, sixteen girls and nine boys, from the Scientific High School "Giovanni Battista Grassi" in Latina (Italy).

Source: https://bit.ly/4mkqxWa.

[34]https://bit.ly/4jsESQm.
[35]https://bit.ly/443wGNk.
[36]https://bit.ly/3MWa9PB.
[37]https://bit.ly/44Tcj8F.
[38]https://bit.ly/3FooEYH.

In August 2011, the Project Manager popularized the Latina's GHIS contribution in a poster session at the University of Jyväskylä (Bonacci 2011b) and, in September 2012, he illustrated the Latina's GHIS experience in a talk at the University of Naples (Bonacci 2012).

The school activity developed through the following seven phases:

1. February 3, 2011: the Director of Planetarium "Livio Gratton" presented the educational project "Greehouse in Space" to the School Executive Committee for urgent approval; the *GHIS* was aimed at bringing research to the classroom (Nistor et al. 2019) through the STEM best practices (Kasza & Slater 2017).
2. February 9, 2011: the School Executive Committee approved the *GHIS* project appointing the presenter as Manager who, subsequently, selected 25 motivated pupils. Sixteen of the twenty-five *GHIS* high schoolers were girls, breaking the gender stereotype of Science for secondary students (Makarova et al. 2019). The percentage of schoolgirls (64%) was stunning if compared, e.g., to the 35% share of female STEM graduates registered in 2024 by the UNESCO Institute for Statistics[39].
1. February 10–16, 2011: since the three *GHIS* subjects (Astronomy, Biology, Physics) are curricular in the Italian Scientific High School, there was no need for special training. The students watched the ESA'S 2009 DVD "Feeding our Future: Nutrition on Earth and in Space", familiarized themselves with the concept of microgravity[40] and with the *Arabidopsis thaliana* (plant also known as *thale* or *mouse ear cress*), studied the ISS as the home of humanity in space and the significant contribution Italy gave to its construction (ASI website[41]).
2. February 17, 2011: the *GHIS* team (i.e., the kids and the Project Manager) linked up via video to Paolo Nespoli on the ISS, learning how to assemble their own greenhouses and plant the *Arabidopsis* seeds[42]. They opened the EPO's kit and placed the medium into the growth chamber, mixing it well with the fertilizer; they poured 40 ml of water onto the growth medium; they shaked the growth chamber to ensure water was well distributed and they placed the cut out black foam pad over the top of the wet growth medium; they opened the seed container and, using magnifying glasses and thin forceps, separated out few Arabidopsis seeds onto a small piece of filter paper; they placed the seeds inside one of the holes in the black foam and pressed down into the growth medium so that it covered the seeds, repeating this till they had planted seeds in all 7 holes; then they remove the black cut out foam, took the transparent plastic cover and placed it over the entire white growth chamber; they put the cap on it and placed their growth chamber near the sunny windows of Physics Lab.

[39] https://bit.ly/45JctQM.
[40] https://bit.ly/3xSkukD.
[41] https://bit.ly/3R8SmS4.
[42] https://bit.ly/4kOAr2p.

3. February 18 – March 16, 2011: the students monitored the germination of their seeds and watered when needed, keeping the substrate moist without causing it to be waterlogged. They also placed a thermometer inside the greenhouse and registered the temperatures, week by week, fifteen times. The ten weekly entries of the observations' form provided by ESA were:

    - Height (mm);
    - Temperature (°C);
    - Number of internodes;
    - Colour (red-green-yellow);
    - Plants problems;
    - Flowers (yes/no);
    - Water (mls);
    - Estimated hours of day light;
    - Condensate (yes/no);
    - Notes.

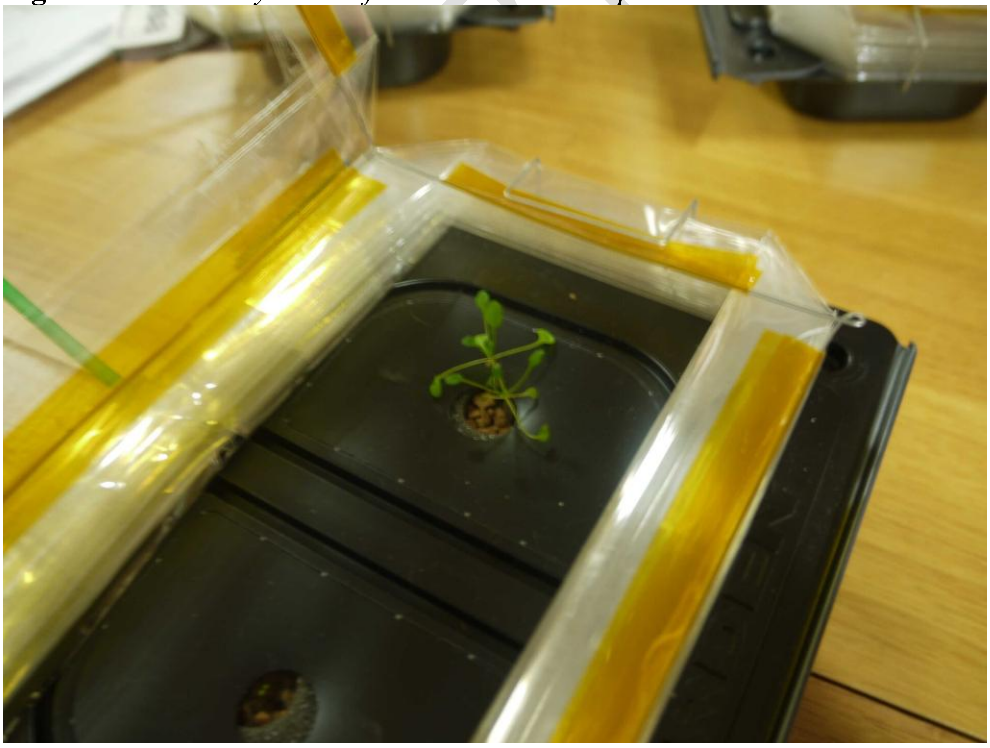
4. March 17, 2011: the *GHIS* team learned about the abrupt interruption of the test in the *micro-g* environment, due to *fungus* in the EPO's kit on ISS, and followed the three-level safety containment packaging by Nespoli[43] (with mask, glasses, plastic bags, insulating tape, and gloves) as waste of *mild* toxicity level (tox 2) to send back to Earth in a cargo spacecraft.
5. March 18 – May 24, 2011: the students decided to change the place from the Physics Lab to the Biology Lab (Fig. 7) for better sunlight; after comparing their early results with those from *Mars500* (Fig. 8), they kept noting down the features of their growing plants (Fig. 9).

[43] https://bit.ly/3DuFSD8.

Figure 7. *Observing the plant at school after one month, on March 18, 2011*

Source: https://bit.ly/3IRV3IJ.

Figure 8. *GHIS early results from the isolation experiment Mars500*



Source: https://bit.ly/44xxWKB.

Figure 9. *Observing the plant at school after two months, on April 22, 2011*

Source: https://bit.ly/3IRV3IJ.

6. May 25, 2011: the team of Latina (Fig. 10) attended remotely the *GHIS* closing event celebrated in Lisbon (Portugal), streamed from the Ciencia Viva science centre[44].

[44] https://bit.ly/3DFpsrq.

Figure 10. *The 25 GHIS students from Liceo "G.B. Grassi" of Latina (Italy)*

Source: https://bit.ly/3IRV3IJ.

7. May 26–27, 2011: the pupils finished filling out the forms in Italian (Fig. 11) and in English (Fig. 12) that the Project Manager attached to his final report, entitled "Greenhouse results from Latina".

Figure 11. *The GHIS report from Latina on ESA's form in Italian*

ARABIDOPSIS: OBSERVAZIONI:

Settimana	Altezza (mm)	Temp °C	N° di Internodi	Colore: Red	Colore: Verde	Colore: Giallo	Problemi alle Piante	Fiori Si/no	Acqua mls	Ore Stimate di Luce del Giorno	Condensa Si/no	NOTE
1	0	13-18	0					NO	40	7	NO	17/02/2011
2	10-20	14-19	0		X			NO	5	8	NO	24/02/2011
3	20-30	14-19	1		X			NO	5	8	NO	04/03/2011
4	40-50	15-20	3		X			QUASI	5	9	NO	11/03/2011
5	60-80	15-20	5		X			SI	5	9	NO	18/03/2011
6	80-100	16-21	6		X			SI	5	10	SI	25/03/2011
7	100-120	16-21	7		X			SI	5	10	SI	01/04/2011
8	120-130	17-22	8		X			SI	5	11	SI	08/04/2011
9	130-150	17-22	10		X			SI	10	11	SI	15/04/2011
10	150-160	18-23	11		X			SI	10	12	SI	22/04/2011
11	160-170	18-23	12		X			SI	10	12	SI	29/04/2011
12	170-180	19-24	13		X			SI	10	13	SI	06/05/2011
13	180-190	19-24	14		X			SI	10	13	SI	13/05/2011
14	190-200	20-25	15		X			SI	10	14	SI	20/05/2011
15	200-210	20-25	15		X			SI	10	14	SI	27/05/2011

European Space Agency

Source: https://bit.ly/3TuZ4oA.

Figure 12. *The GHIS report from Latina on ESA's form in English*

ARABIDOPSIS OBSERVATIONS:

Week	Height (mm)	Temp °C	N° of internodes	Colour: Red	Colour: Green	Colour: Yellow	Plants Problems	Flowers Yes/No	Water mls	Estimated Hours of day light	Condensate Yes/No	NOTES
1	0	13-18	0					NO	40	7	NO	2011-02-17
2	10-20	14-19	0		X			NO	5	8	NO	2011-02-24
3	20-30	14-19	1		X			NO	5	8	NO	2011-03-04
4	40-50	15-20	3		X			NEARLY	5	9	NO	2011-03-11
5	60-80	15-20	5		X			YES	5	9	NO	2011-03-18
6	80-100	16-21	6		X			YES	5	10	YES	2011-03-25
7	100-120	16-21	7		X			YES	5	10	YES	2011-04-01
8	120-130	17-22	8		X			YES	5	11	YES	2011-04-08
9	130-150	17-22	10		X			YES	10	11	YES	2011-04-15
10	150-160	18-23	11		X			YES	10	12	YES	2011-04-22
11	160-170	18-23	12		X			YES	10	12	YES	2011-04-29
12	170-180	19-24	13		X			YES	10	13	YES	2011-05-06
13	180-190	19-24	14		X			YES	10	13	YES	2011-05-13
14	190-200	20-25	15		X			YES	10	14	YES	2011-05-20
15	200-210	20-25	15		X			YES	10	14	YES	2011-05-27

European Space Agency

Source: https://bit.ly/4eIKhjS.

Conclusions

Promoted in 2011 by ESA–HSF, the Greenhouse in Space (GHIS) was hugely participated in schools of four European countries (France, Germany, Italy, Portugal) with more than 800 early adolescents observing the *seed-to-seed* life cycle of an *Arabidopsis thaliana* implanted in a standard miniature greenhouse. The same kit was employed in two parallel ESA missions (*MagISStra* on the ISS and *Mars500* in a Muscovite isolation chamber) to spot the differences among the plants grown naturally (European schools), in microgravity (ISS), and without sunlight (Russian Institute for Biomedical Problems). Unfortunately, the comparison with the ISS experiment was interrupted by the formation of dangerous mold beside the astronaut's plant (toxicity level 2). Nevertheless, the *GHIS* was a tremendous STEM enrichment activity based on *learning by doing* in traditional laboratories (technology level TRL 4). The engaging and sustainable *GHIS* projects developed problem solving, critical analysis, teamwork, communication, and digital literacy, i.e., some of the soft skills requested by labour market (Holik & Sanda 2023). The *GHIS* improved the STEM good practices by integrating HOL, ESD, and ICT. In addition, the positive response of students usually unattracted by *Science* revealed the importance of stimulating the emotional intelligence of kids by involving other cognate subjects, such as *Biology* and *Astronomy*[45], and of nourishing their curiosity by using the Science Laboratories. The Scientific High School "Giovanni Battista Grassi" in Latina, a dynamic[46] agro-industrial Italian province, enrolled in the "Greenhouse in Space" with a team of twenty-five 14-year-old pupils (64% schoolgirls). Those high schoolers faced *GHIS* with expertise also because, in spring 2011, the "G.B. Grassi" had already praxis of citizen science and STEM projects (Bonacci 2018a), propelled by the Planetarium "Livio Gratton". The presence of accessible and well-equipped Physics and Biology Labs was another driving factor in the success of the *GHIS* project from the "G.B. Grassi", that was divulged in national and international symposiums soon after. Along with other ESA's educational projects[47], the "Greenhouse in Space" favored the inclusion of *Astronomy* in most European schools' curriculum (Percy 2005), tough rarely as standalone subject, to enhance the competences (Boon Ng 2019) required in the *high-quality* STEM pedagogy auspicated by the European Education Area (EEA)[48].

[45]https://bit.ly/3GYXTqF.
[46]https://bit.ly/4aJwoCa.
[47]https://bit.ly/4pHCxCE.
[48]https://bit.ly/3L3Z7Vj.

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