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The Greenhouse in Space (GHIS) as STEM Educational Experience

*By Enzo Bonacci**

Artemis lunar settlement project has renovated the interest in space gardening, a topic addressed in 2011 by the section Human Spaceflight (HSF) of the European Space Agency (ESA) through the instructional project Greenhouse in Space (GHIS). Targeted to young teens (ages 12 to 14), the GHIS compared 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 toxic mold hazard alert 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 as a case study. 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, NDVI, SEND, ICT, TRL, secondary school, educational project, Arabidopsis thaliana, Artemis*

Introduction

Recognized as "a superstar of plant biology"[1], the *Arabidopsis thaliana* is object of accurate investigation since 1873 (Freed et al. 2025). It will be protagonist of the study LEAF[2] (Lunar Effects on Agricultural Flora) when the astronauts of Artemis III mission deploy a mini greenhouse on the Moon. Nevertheless, the information about one of the most inspiring scientific experiments and valid didactical opportunities ever devised around such plant, i.e., the "Greenhouse in Space" (acronym GHIS), is still partial and scattered. Why did it happen? This astonishing lack of specific literature on *GHIS* is

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[1]https://bit.ly/3QJm5pD.
[2]https://bit.ly/4cL132z.

probably due to the nature of participants: pupils too young to think about converting their experience into manuscripts or talks and secondary school teachers not used to academic research. This paper is meant as an exhaustive and organic survey on *GHIS*, reflecting on its long-term multifaceted impact, with the full awareness that the time span between the experiment (2011) and final version of the article (2026) represents a limitation. 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 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[3]).

Figure 1. *The 2011 Official Logo of the Greenhouse in Space*

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

[3]https://bit.ly/3TLHixl.

Approximately eight hundred 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 augmented the Information & Communication Technologies (ICT) because students and teachers attended a live in-flight call with Paolo Nespoli[4], and they were invited to send their photos and talk to each other on a Facebook page as well as by emailing the Human Spaceflight education team. The paper is organized as follows. In the first section we describe the initiative from the 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*. The second section analyzes the GHIS methodology by choosing, as a topical case study, the contribution from the Scientific High School "G.B. Grassi" of Latina (Italy), whose pupils seeded, watered and observed an *Arabidopsis thaliana* growing in a standard mini greenhouse (Figure 2). In the third section we discuss the scientific and educational implications of GHIS along a temporal range of 15 years. Most of the material about that trailblazing STEM activity comes from a thematical 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*

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

[4]https://bit.ly/44ichaD.

History of GHIS

The 2009 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*[6] 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

[5]https://bit.ly/45ppQVF.
[6]https://bit.ly/494CHis.

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[7]).

The 2010-2011 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[8] (Figure 3);
- *Mars500*, 520 days in an isolation chamber in Moscow[9].

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.

[7]https://bit.ly/4q6xAUU.
[8]https://bit.ly/40vhYiT.
[9]https://bit.ly/4kgoWiO.

The 2010 Preliminary Greenhouse Test by Paolo Nespoli

Onboard the ISS module Columbus, Paolo Nespoli performed an illumination test[10] within the operation "Greenhouse", supported by the Education Payload Operations[11] (EPO) and by the Norwegian USOC (Basit 2012), on December 26, 2010.

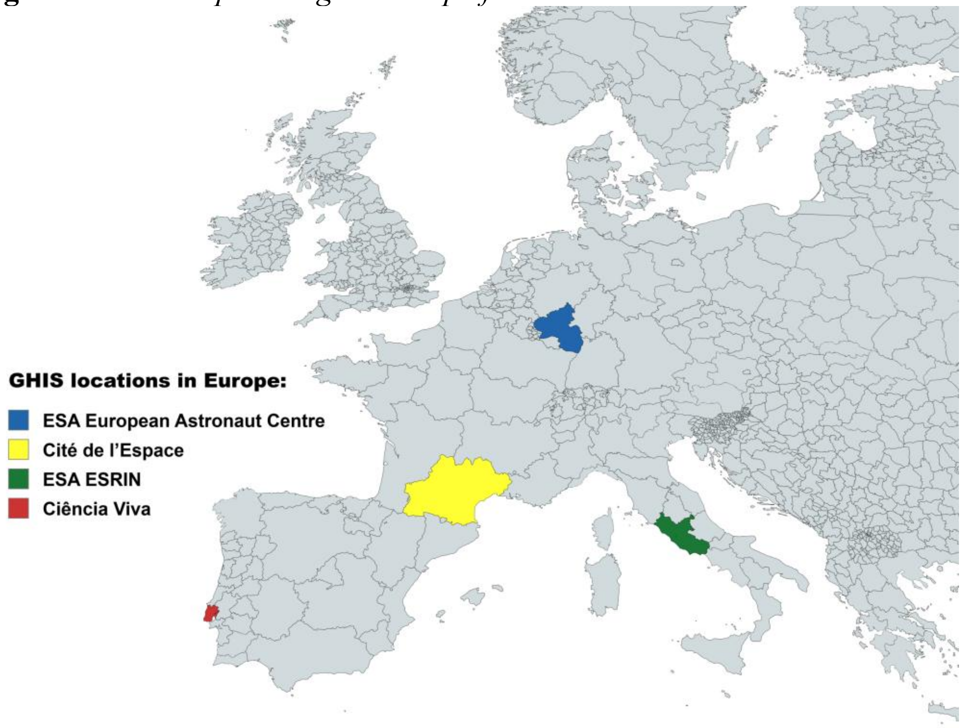
The 2011 GHIS Announcement by ESA-HSF

On February 3, 2011, the European Space Agency – Human Spaceflight Education (ESA–HSF for short) announced the project Greenhouse in Space (GHIS) as follows[12]: "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

[10]https://bit.ly/3L1DBDc.
[11]https://bit.ly/4jBridA.
[12]https://bit.ly/4ipZ0kB.

observations to the ESA 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[13]; ESRIN in Frascati, Italy[14]; Cité de l'Espace in Toulouse, France[15]; and Ciência Viva – Agência Nacional para a Cultura Científica e Tecnológica in Lisbon, Portugal[16]. 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 (Figure 4).

Figure 4. *The European Regional Map of the GHIS Locations in 2011*



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

GHIS Inauguration by ESA-HSF

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

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

relaxing. And they 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[17]).

Mixed News from the ESA's Missions

In March 2011, the mission MagISStra interrupted the *GHIS* for the presence of a dangerous fungus, whilst 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 the first one to remark that simple

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

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[18]).

The GHIS Closing Event

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 for gaining

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

knowledge for space missions. They found that one experience leads to many others, and that learning is a continuous process." (From ESA website[19]).

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[20] (manufacturing hub in southern Lazio[21]) 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 terminate 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[22]).

Methodology of GHIS

A Case Study: The GHIS by the Italian High School "G.B. Grassi"

We focus on the educational project "A greenhouse in space" by which the Scientific High School "Giovanni Battista Grassi" of Latina[23] (Miltiadis 2020) signed up 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[24] 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[25] 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). Being the sole school to

[19]https://bit.ly/3DFpsrq.
[20]https://bit.ly/4spx0mN.
[21]https://bit.ly/4js9tO2.
[22]https://bit.ly/41Qp6pY.
[23]https://bit.ly/4jsESQm.
[24]https://bit.ly/443wGNk.
[25]https://bit.ly/3MWa9PB.

register in *GHIS*, the "G.B. Grassi" represented the whole Province of Latina, a territory deeply studied[26] by geologists (Cappucci et al. 2024) for its peculiar coastal geomorphology (Perazzotti & del Valle 2025).

Project Design and Participants

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.

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[27] 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.

On February 9, 2011, the School Executive Committee urgently approved the educational project "Greehouse in Space" (Italian title: "Una serra nello spazio") appointing the Director of the Planetarium as Manager who, subsequently, selected 25 motivated pupils (Figure 5). 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 recorded in 2024 by the UNESCO Institute for Statistics[28].

[26]https://bit.ly/44Tcj8F.
[27]https://bit.ly/3FooEYH.
[28]https://bit.ly/45JctQM.

Figure 5. *The 25 GHIS Students from "G.B. Grassi" of Latina (Italy)*

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

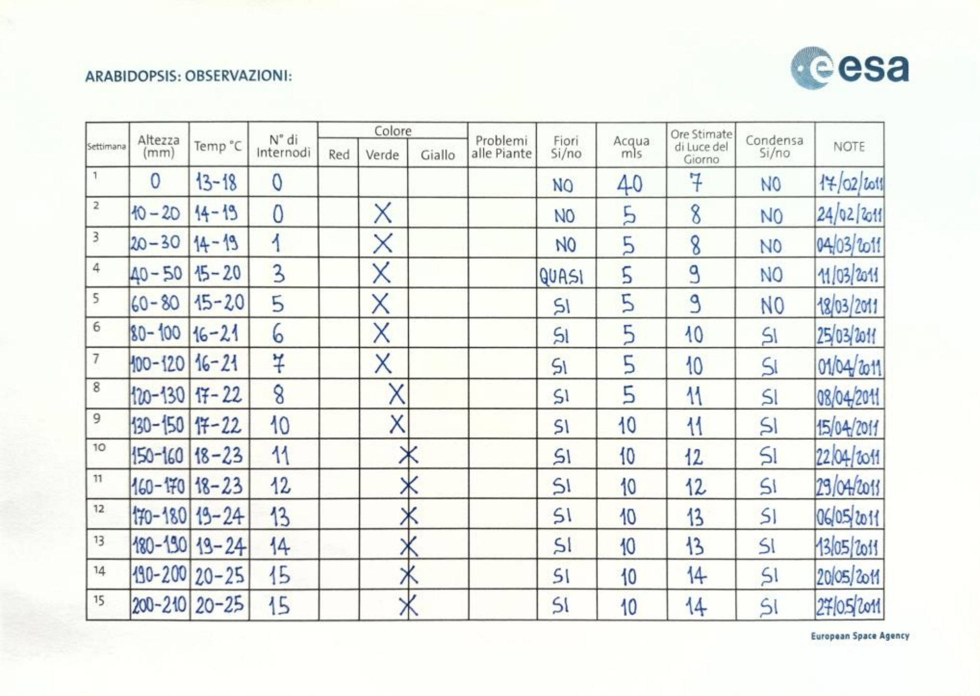
Data Collection and Analysis

Since the three *GHIS* subjects (Astronomy, Biology, Physics) were curricular in the Italian Scientific High School[29], there was no need for special training. Between February 10 and 16, 2011, the students watched the ESA'S 2009 DVD "Feeding our Future: Nutrition on Earth and in Space", familiarized themselves with the concept of microgravity[30] 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[31]). On February 17, 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[32]. 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 shook 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. From February 18 until March 16, 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 annotated the temperatures, week by week, fifteen times. The ten weekly entries of the observations' form, provided by ESA both in Italian (Figure 6) and in English (Figure 7), were:

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

[29]https://bit.ly/4vQ4sVh.
[30]https://bit.ly/3xSkukD.
[31]https://bit.ly/3R8SmS4.
[32]https://bit.ly/4kOAr2p.

Figure 6. *The GHIS Report from Latina on ESA's Form in Italian*



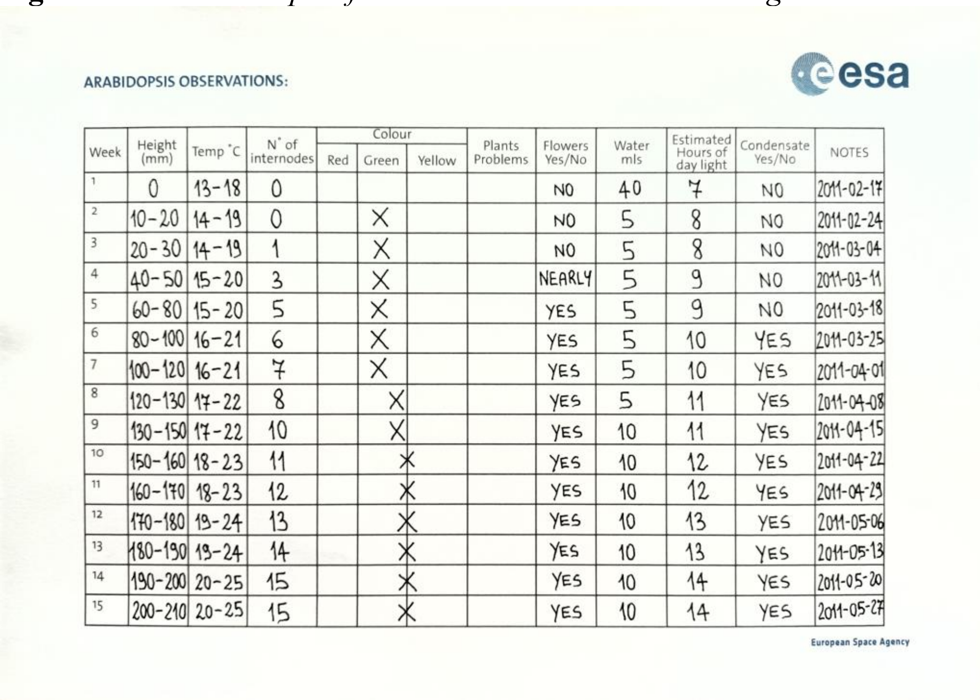
ARABIDOPSIS: OBSERVAZIONI:

Settimana	Altezza (mm)	Temp °C	N° di Internodi	Colore Red	Verde	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 7. *The GHIS Report from Latina on ESA's Form in English*



ARABIDOPSIS OBSERVATIONS:

Week	Height (mm)	Temp °C	N° of internodes	Colour Red	Green	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.

Development

On March 17, 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[33] (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. On March 18, the students changed place from the Physics Lab to the Biology Lab (Figure 8) for better sunlight; after comparing their early results with those from *Mars500* (Figure 9), they kept noting down the features of their growing plants (Figure 10).

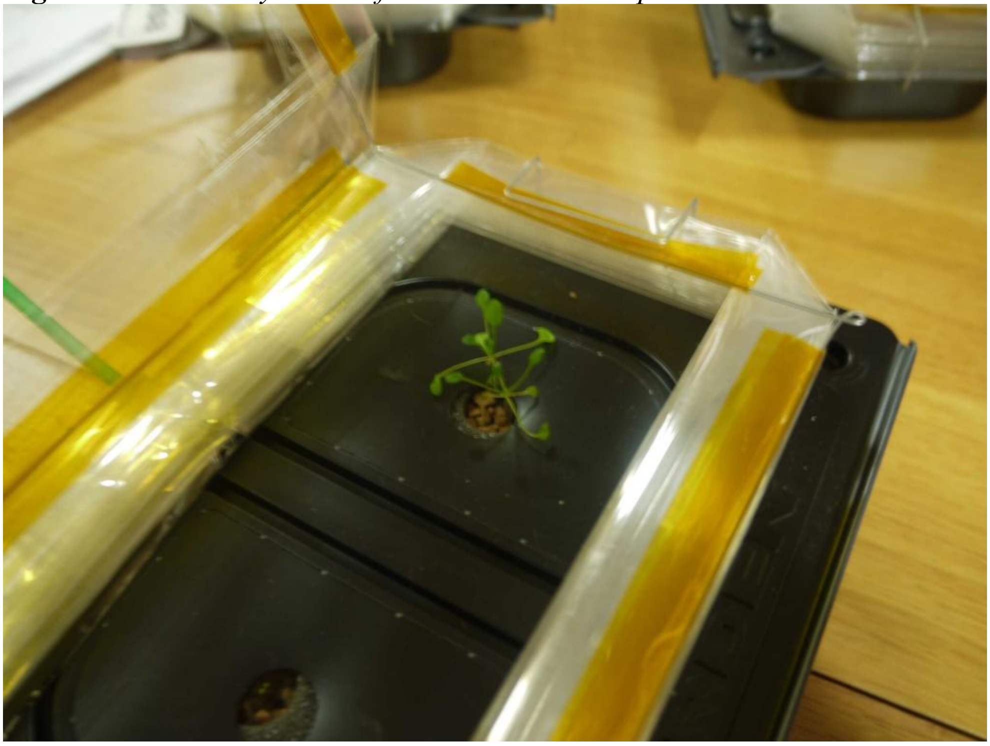
Figure 8. *Observing the Plant at School After One Month, on March 18, 2011*

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

After attending remotely the *GHIS* closing event celebrated in Lisbon[34], the pupils finished filling out the forms for the final report "Greenhouse results from Latina". 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).

[33]https://bit.ly/3DuFSD8.
[34]https://bit.ly/3DFpsrq.

Figure 9. *GHIS Early Results from the Isolation Experiment Mars500*



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

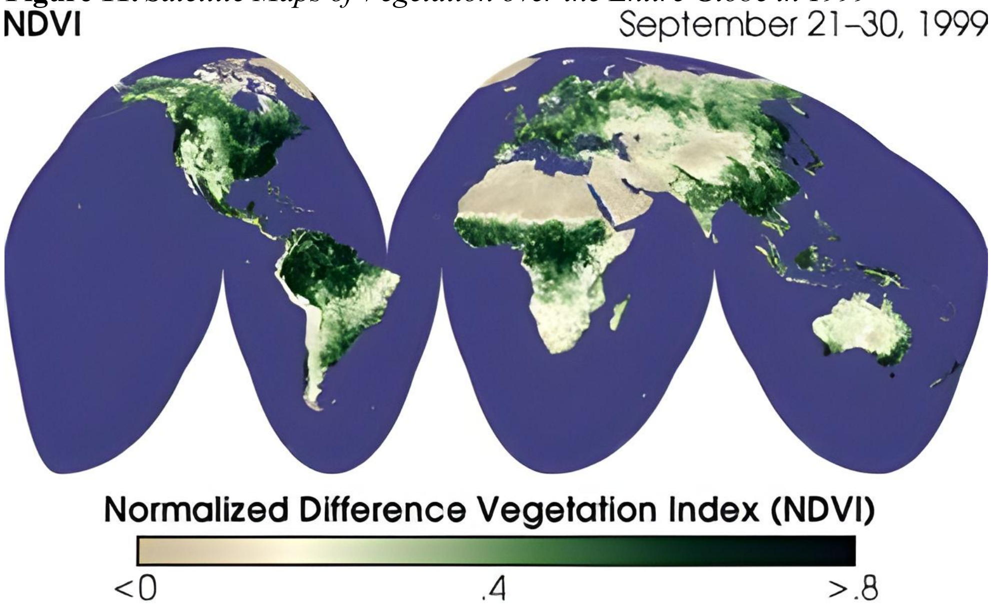
Figure 10. *Observing the Plant at School After Two Months, on April 22, 2011*

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

Findings

The *GHIS* brought research into the classroom (Nistor et al. 2019) by adopting what we today call the STEM best practices (Kasza & Slater 2017) and ensured optimal conditions to improve the girls' STEM self-efficacy (Wieselmann 2019). Latina's kids were the first to notice that the color of the plants seemed sensitive to the latitude and decided autonomously to confront via email with Italian and foreign schools to find statistical evidence to their empirical observation. From the data of twenty European teams, they verified that the average shift from green to yellowish had happened first in Portugal (7-8 weeks), soon after in Italy (8-9 weeks), then in France (9-10 weeks), and finally in Germany (12-13 weeks). Latina's GHIS team was congratulated by the Provincial Head of the International Year of Chemistry, *Francesco Giuliano*, for carrying out constructivist didactics (Giuliano 2015). While presenting the GHIS at the University of Jyväskylä (Bonacci 2011b), the Team Manager was advised that Latina's high schoolers might have unknowingly grasped of a broader trend (Figure 11) tracked through the satellite scrutiny of the Normalized Difference Vegetation Index (NDVI) and fairly popular in in Finland at the time[35]: the "Northern Greening".

Figure 11. *Satellite Maps of Vegetation over the Entire Globe in 1999*



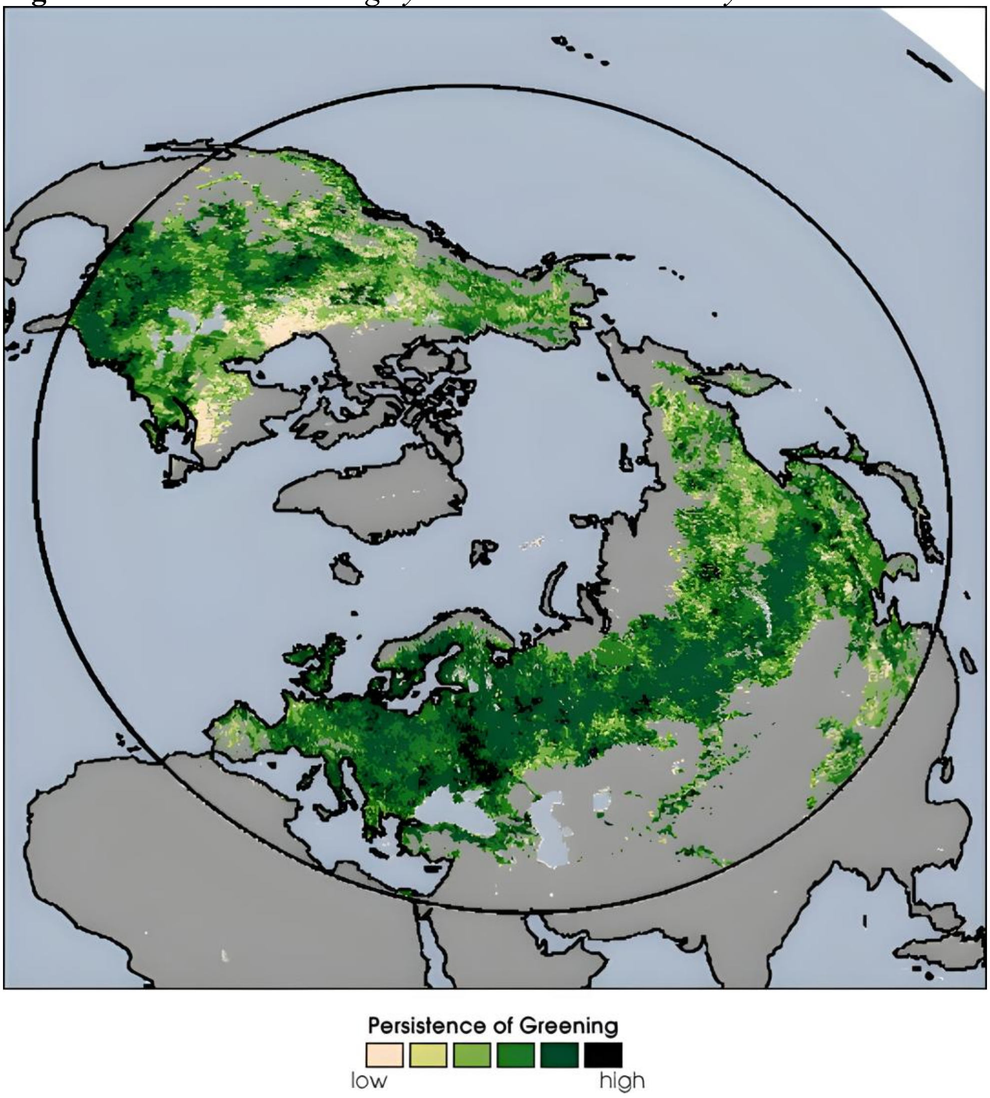
Source: https://bit.ly/4d23fRW.

The *Northern Greening* (Figure 12) was unveiled as follows: "NASA satellite data suggest that for more than two decades there's been a gradual greening of the northern latitudes of Earth. Researchers confirm that plant life seen above 40 degrees north latitude, which represents a line stretching from New York to Madrid to Beijing, has been growing more vigorously since 1981. One suspected cause is rising temperatures possibly linked to the buildup of greenhouse gases

[35]https://bit.ly/48EckiO.

in our atmosphere. Over this same time period, parts of the Northern Hemisphere have become much greener and the growing season has increased by several days. Further, Eurasia appears to be greening more than North America, with more lush vegetation for longer periods of time." (From NASA website[36]).

Figure 12. *Northern Greening by NASA Earth Observatory in 2001*



Source: https://bit.ly/4uuHL7l.

Since *Northern Greening* was a phenomenon which the Italian pupils had never heard about, their insight could not be an elaboration of previous knowledge but was due to an accommodation of their mental structure. Where did the STEM mindset[37] of those kids come from? It presumably derived from intuition as developable skill (Miskioğlu et al. 2024), collaborative partnership (Reid-Griffin et al. 2023), and perseverance (Shechtman et al. 2018).

[36]https://bit.ly/4tSMqAj.
[37]https://bit.ly/4ePBD5p.

Implications of GHIS

Scientific Implications

After the *GHIS* experience, ESA dedicated a webpage[38] to 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". Today we know that such plants germinate in diverse lunar regoliths (samples from Apollo 11, 12, and 17) but their growth is slow and affected by severe stress morphologies (Paul et al. 2022) so that we need to find efficacious mediums for horticultural crops on the Moon. For instance, the *Arbuscular Mycorrhizal* fungi furnish the *Cicer arietinum* (chickpea), cultivated in lunar regolith simulant[39] (Atkin et al. 2026), with a powerful bioremediation. Suddenly, the *GHIS* mold accident accelerated the studies on the fungal responses in space environments named, collectively, "Astromycology". This recent research area (Simões et al. 2023) has considerably progressed from the 2012 Micro-6[40] investigation on Candida albicans by NASA[41] to the 2024 microbial consortia for space biomining by ESA[42]; the latter led to discovering that bacteria *Sphingomonas desiccabilis* and fungi *Penicillium simplicissimum* under microgravity could potentially extract forty-four elements out of L-chondrite asteroidal material (Santomartino et al. 2026). Astromycology employs also terrestrial facilities, such as the ESA's Large Diameter Centrifuge[43] where the growth of fungal colonies is tested under double normal Earth's gravity. 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[44] team. Data recorded via a smartphone app will be sent to ESA for processing." (From ESA website[45]). The *GHIS* paved the way to modern microgravity plant research outside Europe too, 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[46]). 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

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[38] https://bit.ly/44f9YVG.
[39] https://bit.ly/4bvPIl5.
[40] https://bit.ly/4sIMe5P.
[41] https://bit.ly/3P1JK3R.
[42] https://bit.ly/4ljlR3E.
[43] https://bit.ly/3MVg0Fd.
[44] https://bit.ly/4leb0am.
[45] https://bit.ly/3IcYGss.
[46] https://bit.ly/44X0gHn.

Space 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." (From NASA website[47]). In April 2026, the second successful stage[48] of Artemis program for a permanent human presence on the Moon[49] has invigorated NASA's endeavors to cultivate plants in extraterrestrial habitats (Fountain et al. 2026).

Educational Implications

We define *GHIS* as a STEM activity for entailing 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[50], *GHIS* sparked 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 unwelcome fungus onboard the ISS turned into an instructional opportunity, letting the pupils realize that laboratory tests can be affected by accidents neglected by simulations (Bonacci 2025) and that virtual and hands-on laboratories may offer complementary affordances (Kapici et al. 2019). 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 2016, 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 2011a, 2013), whose students were the first to observe and measure the persistence of *greening* at higher latitudes, was quite 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 annual conference (August 1–5, 2011) of the International Research Group on Physics Teaching (GIREP) & the European Physical Society – Physics Education Division (EPEC) at the University of Jyväskylä in Finland (Bonacci 2011b). The latter projected the young city of Latina[51] 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

[47]https://bit.ly/49pQmQ4.
[48]https://bit.ly/4uh7NuJ.
[49]https://bit.ly/4cO4Z1o.
[50]https://bit.ly/4iNbxyr.
[51]https://bit.ly/4mKNJhg.

Space Education Resource Office (ESERO[52]); opened in 2006[53], 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) raised other instructional initiatives with the endorsement of astronauts as science ambassador (McNamee 2025), like the competition "YiSS – Youth ISS Science" publicized by Paolo Nespoli[54] (Rizzo 2022). In Spain, instead, the "Ignacio da Riva" University Microgravity Institute[55] advocated the "Europe to Space" program (EU2Space[56]), a challenge tailored for 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[57]).

Conclusions

We have tried to revive the *Greenhouse in Space* (GHIS), whose memory was quickly fading away, by collecting, arranging, and evaluating documentary evidence of that grandiose project from both its organizers and participants. Promoted in 2011 by ESA–HSF, the *GHIS* was hugely run by 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 gardening experiment was interrupted by the formation of dangerous mold beside the astronaut's plant (toxicity level 2). The fungal contamination that occurred on the ISS did not stop the *GHIS* school projects and, as collateral beneficial effect, lifted the role of *Astromycology* in ameliorating the conditions for life support within hypothetical lunar stations. Actually, the *GHIS* was a tremendous STEM enrichment activity based on *learning by doing* in traditional laboratories (technology level TRL 4). The engaging and sustainable (Carroll et al. 2019) *GHIS* projects strengthened 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* maximized the STEM good practices by integrating the HOL (Bonacci 2026), the ESD (Bilgin et al. 2022), and the ICT (Lukychova et al. 2021) in innovative SEND-inclusive environments (Fortepiani & Marsh 2023). Additionally, the positive response of students usually unattracted by *Science* revealed the importance of stimulating the emotional intelligence of kids (Petrides et al. 2004) by involving other cognate subjects, such as *Biology* and

[52]https://bit.ly/3HBG8lP.
[53]https://bit.ly/4lO6Mpp.
[54]https://bit.ly/47XKf6a.
[55]https://bit.ly/4qISWYZ.
[56]https://bit.ly/4pHy2ru.
[57]https://bit.ly/49qgHyB.

Astronomy[58], and of nourishing their curiosity (Kowalski & Kowalski 2015) by using the Science Laboratories (Hofstein & Kind 2012). The Scientific High School "Giovanni Battista Grassi" in Latina, a dynamic[59] agro-industrial Italian province, joined the "Greenhouse in Space" with a team of twenty-five 14-year-old pupils (64% schoolgirls). Those high schoolers faced *GHIS* with expertise because, in spring 2011, the "G.B. Grassi" had already praxis of citizen science (Heigl et al. 2019) and STEM projects (Bonacci 2018a), propelled by the Planetarium "Livio Gratton" (Bonacci 2017). 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 the students had inferred, on a reasonable sample of data, a correlation between the plants' period of turning color and the tests' latitudes. Along with other ESA's educational projects[60], the "Greenhouse in Space" favored the inclusion of *Astronomy* in most European schools' curriculum (Percy 2005), tough rarely as standalone subject, to amplify many of the competences (Boon 2019) required in the *high-quality* STEM pedagogy auspicated by the European Education Area (EEA)[61]. Besides the strong instructional impact[62], bridging the gap between advanced space missions and classroom education[63], the *GHIS* left a long-lasting scientific inheritance to ASI, ESA, and NASA. Nowadays, topical examples of the *GHIS* legacy are: the ENEA's HortSpace[64], a research initiative co-funded by ASI and focused on high-tech systems for cultivating plants in space; the "Adaptive Vertical Farm" (AVF[65]), a spatial greenhouse devised by the startup Space V[66]; the Greencube[67], a micro-garden of fresh vegetables built by the University "La Sapienza" of Rome[68] and installed in an ASI's mini-satellite[69] sent to 6000 Km from Earth on ESA's vector Vega-C[70]; and NASA's LEAF[71], a mini-greenhouse on the lunar surface to study how the plants *Arabidopsis thaliana*, *Brassica rapa*, and *Wolffia* grow in partial gravity and high radiation.

[58]https://bit.ly/3GYXTqF.
[59]https://bit.ly/4aJwoCa.
[60]https://bit.ly/4pHCxCE.
[61]https://bit.ly/3L3Z7Vj.
[62]https://bit.ly/4q9hPfO.
[63]https://bit.ly/4srLMcF.
[64]https://bit.ly/49rZnrM.
[65]https://bit.ly/3HcWGA7.
[66]https://bit.ly/45tJO1Y.
[67]https://bit.ly/3Lzplld.
[68]https://bit.ly/3NvWiiY.
[69]https://bit.ly/49GpaO6.
[70]https://bit.ly/3Z2c1J9.
[71]https://bit.ly/4tKKJoi.

Remarks

The reader should not be surprised that the EPO Educational Kit P/N 309348[72] was manufactured by a firm in Aprilia, a town 26 km north of Latina. In fact, the Province of Latina has a distinct agricultural propensity, with the largest number of farm workers in the Lazio region (slightly higher than Rome)[73]. Latina is also the Italian second province (next to Milan) for number of employees in pharma companies, and the first for pharmaceutical exports (ahead of Milan)[74]. On November 24, 2025, the Mayor Matilde Celentano signed a Memorandum of Understanding[75] with "La Sapienza" University[76] and Unindustria[77] to expand the chemical-pharmaceutical hub of Latina.

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[72]https://bit.ly/3FooEYH.
[73]https://bit.ly/3Hwnskw.
[74]https://bit.ly/3jbez6v.
[75]https://bit.ly/4jsymJa.
[76]https://bit.ly/4bkPA9q.
[77]https://bit.ly/497imci.

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