ESA Education Payload Operations Greenhouse

- Challenges of preparing and performing a plant biology experiment on ISS

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ESA's Human Spaceflight & Operations directorate's promotion office is responsible for the ISS related educational programs at ESA. The main goal is to encourage young people across Europe to gain and maintain an interest in science and technology, in addition to inspire them to pursue an education within these fields. The target group is youngsters at age 6 – 18 years. Since the installation of the Columbus module on the International Space Station (ISS), ESA astronauts have carried out numerous educational experiments. However, very few of the educational payloads include biology. The purpose of this paper is to describe one plant biology payload, ESA Education Payload Operations (EPO) Greenhouse, and to reflect on some of the challenges preparing an educational biology payload on ISS. The educational yield of experiment is briefly outlined and lessons learned from the project preparation campaign are discussed. The operations of the payload were supported by the Norwegian User Support Centre (N-USOC). The paper focuses on the preparation phase of a 15-week in-flight operational scenario and challenges encountered during the preliminary dry-runs. In addition to follow the inflight experiment, school children also themselves grew plants using similar Greenhouse kits provided by ESA. They compared their observations with the on-orbit seedlings growth. The astronaut onboard regularly hydrated both Greenhouses and document the plants growth by photography. In February 2011 the first on-orbit Greenhouse watering event was broadcasted simultaneously to museums and science centers around Europe. Even though the project was terminated before its planned duration, a number of purposes of the experiment were achieved. In the paper we describe several positive experiences gained.

N-USOC	=	Norwegian User and Operations Centre
ISS	=	International Space station
EPO	=	Education Payload Operation
COL-CC	=	Columbus Control Centre
PD	=	Payload Developer
PI	=	Principle Investigator
EST	=	Experiment Sequence Test
PTR	=	Post Test Review

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I. Introduction

ESA's Education program brings young people from many different nations together. The main objective of the Human Spaceflight and Operations Promotion Office activities is to stimulate the curiosity of students and to motivate them towards STEM (Science, Technology, Engineering and Mathematics) subjects. Furthermore, it is intended for the younger generation to become aware of the importance of the ISS as a testing bed for future exploration activities in space. The target group is youngsters at age 6 – 18 years. Since the installation of the Columbus module on the International Space Station (ISS), ESA astronauts have carried out numerous educational experiments. Very few of the educational payloads include biology.

This paper describes the 'Greenhouse in space' project which includes the plant biology payload, ESA Education Payload Operations (EPO) Greenhouse. The payload consisted of two separate parts; the first one included a greenhouse housing seeds of *Arabidopsis thaliana* to be grown for 8-10 weeks until development of second generation seeds, the other part included a greenhouse housing seeds of lettuce to be grown for approximately 15 weeks, until the lettuce was mature. In parallel to the on-orbit execution of the EPO Greenhouse, students around Europe were to be supporting their own ground models of the greenhouses in order to compare germination and growth of their plants with the ones grown in microgravity on-board the ISS. The comparison would be possible through pictures and status evaluation of the plants, made by the astronaut once per week and made available to the students via the internet. Operations of the payload were supported by the Norwegian User Support Centre (N-USOC).

The experiment was targeted for execution by ESA Astronaut Paolo Nespoli during ISS Increment 26 and 27 and was assigned to N-USOC around Easter 2010. ESA's Directorate of Human Spaceflight, Erasmus Centre hosted the live in-flight call on 17th of February 2011. ESA connected students in four locations in Europe to the ISS to speak with the astronaut Paolo Nespoli about the Greenhouse in Space. The locations were Cite de l'espace in Toulouse France; ESA European Astronaut Centre, Cologne, Germany; ESA ESRIN, Frascati, Italy; Ciencia Viva in Lisbon Portugal.

During the preparation phase, several issues arose that were taken into consideration. These were challenges like unplanned mold growth, poorly penetrateable paper and displacement of the growth medium. Therefore, multiple scenarios were planned for and this made the outcome of the experiment easier to handle. The extent of the preparation activities is detailed in section II. Section III outlines the experiment activities on ISS.

On the last day of the experiment the astronaut said: "Part of the experiment was indeed a success: we were able to grow the plants and observe them." The livelink was a success and all sites could follow the astronaut water the greenhouses and answer several questions that the students had prepared for him. Several successful hydration sessions were performed during the course of the onboard experiment, and two seeds germinated.

Although many things did go well in the EPO Greenhouse experiment, the biological aspect of it proved challenging. The astronaut was the first to remark that simple procedures on Earth are extremely complex in weightlessness.

This paper will focus on the educational experiments onboard the ISS, the challenges, outcome and lessons learned of performing an educational biology experiment onboard.

II. Preparation of experiment

A. ESA EPO Greenhouse Equipment

The major parts of the EPO Greenhouse equipment were two separate greenhouses, one that contained Arabidopsis and the other contained lettuce. The greenhouses were unpowered units that were attached to one of the racks in the Columbus lab, under an ISS light source. The lights were kept on 24hours per day.

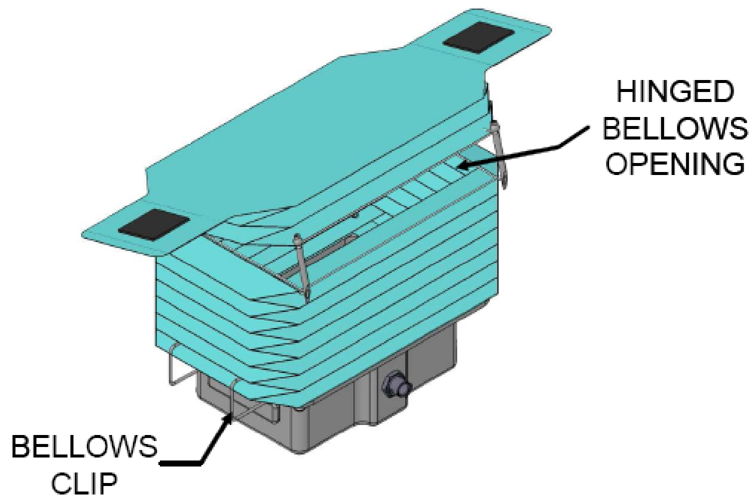

Figure 1. EPO Greenhouse Growth Chamber showing bellows clip used to set bellows height and hinged bellows opening.

The greenhouses consisted of three main parts; the root module, the root-shoot barrier and the compressible/extendable bellows. These parts stayed assembled during operations. Figure 1 shows the growth chamber with the bellows extended and with the hinged bellows opening. The hinge was supposed to be kept closed on both greenhouses. (The debris created by the growth medium and *Arabidopsis thaliana* as new seeds were developed could pose a threat to the astronauts if the hinge was kept open.)

The root module and the root-shoot barrier can be seen in Figure 2.

Figure 3 shows how the additional equipment (water bag, syringe and valve) was attached to the greenhouse by the astronaut.

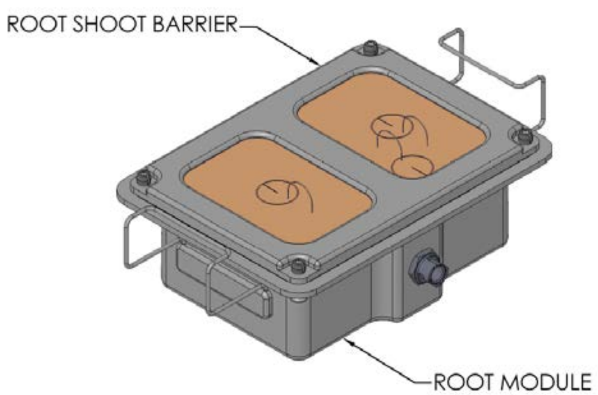

Figure 2. EPO Greenhouse root module assembly with root shoot barrier

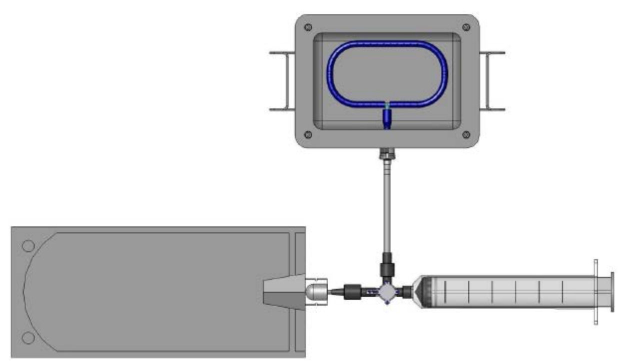

Figure 3. Syringe attached to water bag and root module assembly (bellows, root shoot barrier and growth medium removed for clarity)

B. Payload Operations Teams Responsibility

The main parties involved in the EPO Greenhouse operations were N-USOC, Columbus Control Centre (Col-CC), Erasmus User Centre and Payload Developer (PD) AeroSekur. N-USOC was the Facility Responsible Centre with overall responsibility of planning and execution. Input was provided to Col-CC for timeline reviews, resource needs, scheduling of upcoming events, update of needed products, etc. Information was obtained from the Principle Investigator (PI) and PD upon need-to-need basis. The PI-team was responsible for the requirements consolidation phase, livelink session early in the experiment and for all coordination with the school children. The PD was responsible for most ground tests and packing and transport of the hardware. For off-nominal situations N-USOC coordinated with necessary parties as needed.

C. Testing During Preparation

Several tests were performed during the preparation phase and the biggest challenges were related to hydration and contamination issues, poor germination and an inability of the seedlings to penetrate the paper. The objectives of the tests were:

1. Verify that *planned method* of sterilizing the seeds does not decrease the germination rate of the seeds
2. Verify that the *hardware* and the *planned operations* can meet the experiment scientific requirements
3. Verify the *biocompatibility* between the plant and the hardware
4. Observe and register the weekly operations *sequence*
5. Observe and record by weekly pictures the *plant growth*
6. Monitor the plants' growth by filling in the *questionnaire*
7. Provide advice on possible *improvements* (with ESA agreement) if problems occur
8. Identify any *differences from the flight configuration*
9. Conclude that the *hydration strategy* is functional in terms of intervals, amount and quality of water
10. Verify the *capability of seeds* to germinate after thermal treatment
11. Define the final configuration for the *paper surrounding the seeds*
12. Verify the type of lettuce *seeds to be used for flight* (coated or uncoated)

As a result of the testing performed by the PD, the suggestion was to use lettuce seeds without coating and place both the lettuce seeds and the Arabidopsis seeds between two thin paper layers in the plug holes on top of the growth medium. Two greenhouses were to be used, one containing lettuce seeds (2) and one containing Arabidopsis seeds (12). Initiation of the experiment would happen when inserting 210 ml of water in to each greenhouse. Placement of the greenhouses was supposed to be as close as possible to an ISS light source in Columbus with the lights on 24 hours a day. Every week the greenhouses would receive 30 ml of water.

The outcome of the previous tests was challenged during the Experiment Sequence Test (EST). During the Post Test Review (PTR) it was concluded that the EST was unsuccessful and all parties agreed that the outcome of the EST was not according to expectations and demonstrated several topics that needed resolution before flight preparation. There was also a decision made for performing a delta-EST. The final outcome of the various tests before flight was:

1. After the initiation of the greenhouses and during the weekly watering it was *important to remove any excess water* in the root module to prevent overwatering
2. Displaced *growth medium* seen in ground tests which meant that it was important to *ensure a tight fit between the paper over the seeds and the growth medium*.
3. *Growth of mold* showed the importance of handling the *flight hardware as sterile as possible*.
4. The temperature in direct vicinity to the light source in the Columbus Mock-up on ground was found to be too high as it resulted in *little to no germination of the seeds*, this in turn led to testing that found the optimal distance from the light source to be about 30 cm from the baseplate. Due to this, several crew procedures needed to be updated as they had to reflect the new distance from the MLU. There was also a decision to measure the temperature below the Columbus ISS Light source, and the crew procedures were updated for the Crew to perform this action before setting up the greenhouses.

The light-level measurement crew activity was performed in December, 2010. The conclusion drawn was that the exposure values, and therefore the lighting conditions on-ground and on-orbit, were comparable.

D. Challenges before experiment start

During the ground testing mold was found in the greenhouses. On January 12th samples were taken by biological experts of the mold to see if it could be a potential hazard to the crew. The results from ESA showed two fungal specimens isolated from the samples and both specimens were classified as biosafety level 1 organisms.

The contamination risk was assessed and the Flight Acceptance Review board acknowledged the fact that samples had been taken from a Greenhouse which was not prepared under sterile conditions. A request to review the EPO Greenhouse Ground Non-Compliance Report was delivered from The ESA Payload Safety Review Panel. The feedback from The NASA Johnson Space Center Biosafety Review Board about the Fungi/Mold growth issue of the Greenhouse experiment was that, according to the American Type Culture Collection biosafety level guidelines, one of the mold strains found was categorized as biosafety level 2. Biosafety level 2 microorganisms are considered to be an opportunistic human pathogen. The definition of the mold that was found in the ground tests as biosafety level 2, instead of biosafety level 1, led to numerous challenges for the EPO Greenhouse experiment. A request was issued a week before operations were supposed to start with a “NO OPS constraint”.

As part of the containment of the growth medium particles before start of the experiment, a dissolvable paper covered the growth medium inside the greenhouses. For unknown reasons an incorrect and slowly dissolvable type of paper was used in the flight hardware instead of the planned quick dissolvable paper. When this error was discovered, it was too late to change the paper, and a decision was made to launch the experiment anyway. The risk associated with the thicker paper was mission success related as the plants might have problems penetrating the paper. The Board was informed of the mission success related risks and accepted these. The experiment hardware was launched with 41P in late January 2011from Baikonour.

In order for the experiment to be initiated, numerous safety-related changes to the crew procedures and ops products were necessary at the last moment. A “What-if-scenarios” document was created to specify which actions N-USOC should take in case of unforeseen issues arising for the ESA EPO Greenhouse execution on-board ISS. The Crew was instructed to use gloves whenever handling the greenhouses and look for filamentous/fuzzy fungal growth during all phases of the operational mode. Should the crew observe fungal contamination at any stage during the operational mode, the experiment should be terminated and the growth chamber should be contained in double Ziploc bags and be disposed. The NO OPS constraint could be removed and operations could start on February 16th.

E. Operational Scenario

The EPO Greenhouse Operational Timeline as planned before experiment start is outlined in Figures 4 and 5. The hardware was mounted on ground and the crew operations on board involved EPO Greenhouse specific Crew Procedures. The flowcharts only focus on the planned nominal operational flow and they describe a step-by-step approach of the operations flow. The flow charts are separated into pre-flight-activities (Figure 4) and flight-activities (Figure 5).

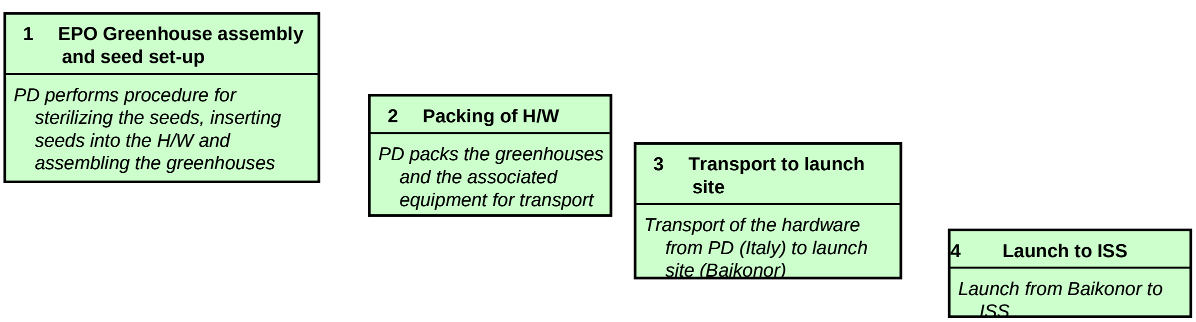

Figure 4. Pre-flight activities

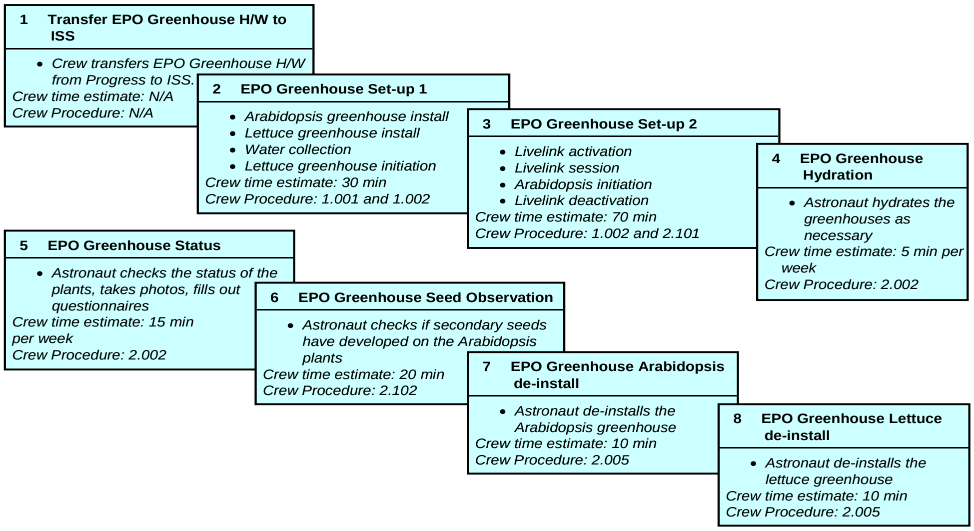

Figure 5. Flight activities

III. ESA EPO Greenhouse Operations

The ESA EPO Greenhouse experiment was performed from February 16th to March 11th, 2011. The real-time operations flow can be seen in Figure 6.

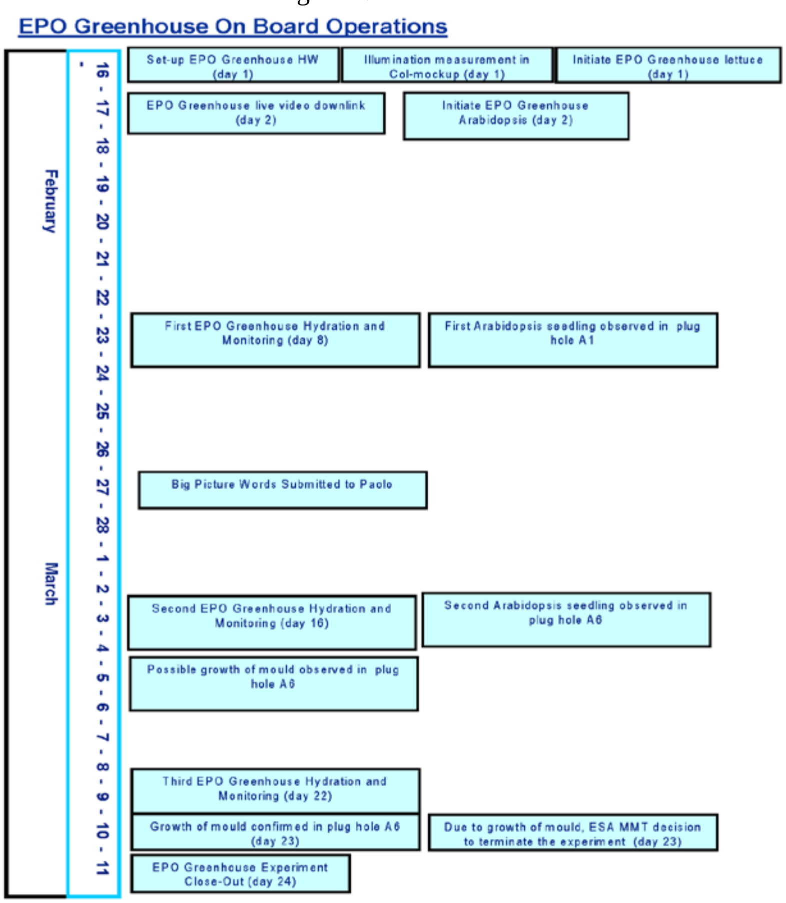

Figure 6. ESA EPO Greenhouse Operations flow

The experiment started with a temperature measurement and hydration of the Greenhouse containing lettuce seeds. On February 17th, a successful livelink session with Paolo Nespoli from Columbus to different sites around Europe was performed as Paolo watered the second Greenhouse containing Arabidopsis seeds in front of the camera.

Figure 7. The astronaut Paolo Nespoli initiating the Greenhouse containing Arabidopsis seeds.

Figure 7 shows Paolo Nespoli during the livelink session.

After seven days, the astronaut performed the first regular hydration and monitoring of the Greenhouses. A picture was provided by Paolo showing germination of one Arabidopsis seedling, Figure 8.

Figure 8. The first Arabidopsis seedling.

During the last week of February, Big Picture Words for crew were written, reviewed and submitted to Paolo for his understanding of the situation regarding the growth of mold. Numerous change requests were also submitted before and after the initiation of the experiment with crew procedures that had been updated with safety steps, the questionnaire to be used during weekly checks and several other issues, all to optimize the outcome of the experiment.

The astronaut performed several watering sessions during the following weeks and photo-documented both Greenhouses. Possible growth of mold was observed where the second Arabidopsis seedling had emerged. As mold growth had been observed in several ground tests, the growth of mold was not unexpected. The issue with the potential appearance of mold was addressed by N-USOC. It was decided to provide input for the Daily Planning Conference onboard, so Paolo would pay attention to the Greenhouses during the watering activity and photo-document them as necessary for ground assessment. Paolo took additional pictures when performing the third watering in March, Figure 9.

Ground assessment of the additional pictures taken by Paolo confirmed that there indeed was mold.

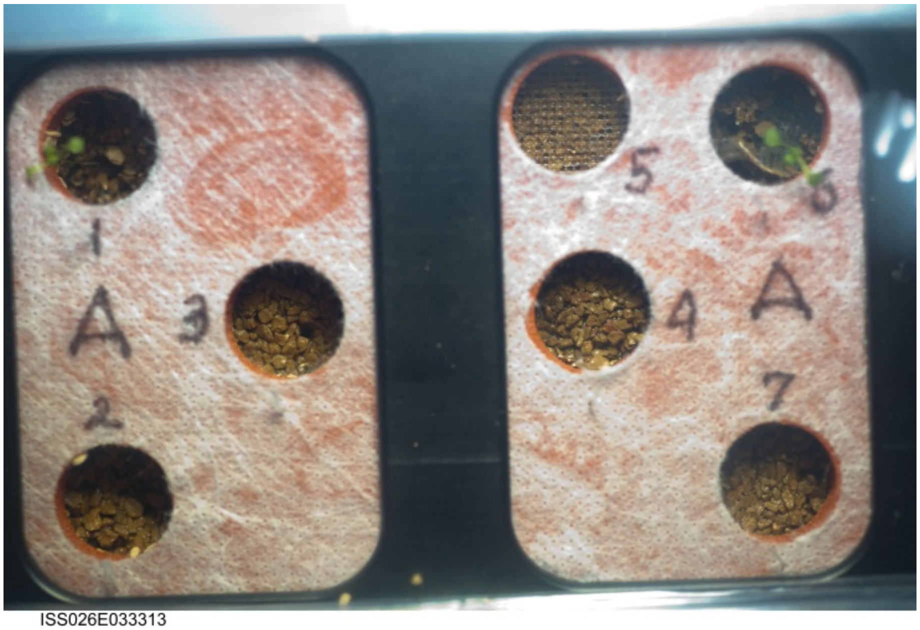

Figure 9. Overview of the growth chamber containing Arabidopsis at the end of the experiment.

Due to observed growth of mold in the hardware, Figure 10, ESA decided to end the experiment after 3 weeks of operation instead of the planned 10 weeks. The lettuce seedlings did not germinate but two small Arabidopsis seedlings germinated.

The experiment was trashed by Paolo using protective equipment, according to the established “What-if-scenarios” document and the Safety-steps in the Crew Procedures.

Figure 10. Growth of Mold confirmed in plug hole

IV. Lesson’s learned

In summary, the primarily lesson learned after the EPO Greenhouse experiment is that biology can complicate the seemingly simplest experiment. Furthermore, the experiment underlines the need to extensively plan biological experiments. In addition it is critical to perform ground tests and allow for plan deviation and to ensure enough time before experiment start. During the implementation phase of the EPO Greenhouse project, the team came to the realization that this educational payload presented many more challenges than the previously flown didactic payloads. From the first steps of the project the target timeline for on orbit execution should have been deemed too challenging and even possible unrealistic. To optimize future potential similar educational biological experiments it would be essential to take into account all of the issues which might arise when dealing with biology taking also into account the challenging ISS environmental constraints. To a certain extent this was successfully done during the real time EPO Greenhouse experiment activities when the “What if Scenario” was established. In that way the astronaut always knew what to do in case he encountered the same issues as on ground.

Further testing and optimization on ground long before experiment start would smoothen the process and hopefully address and resolve many of the issues before flight.

V. Conclusion

Educational experiments onboard the ISS related to plant biology meet some challenges which differ from more traditional, technical payloads. ESA Education Payload Operations (EPO) Greenhouse illustrates issues to have in mind when preparing and operating such experiments. First of all it is important to emphasize the need for an extensive preparation phase.

Although the preparation phase for the EPO Greenhouse experiment was short, a series of tests and mission operations validations were conducted by several teams in order to assure mission readiness and resolve the various encountered issues. The teams worked together in a good manner and many issues were solved in short time. The experiment did not yield great germination but this was not the main focus of the experiment.

This was an educational payload which main goal is to encourage young people across Europe from the age 6 – 18. For the students to learn more about the ISS, the microgravity environment, possible future manned missions and their challenges, the necessity to grow edible food during long manned exploration missions, the concept of following a scientific method in carrying out an experiment, to gain and maintain an interest in science and technology and inspire these people to pursue an education within these fields. In many ways the experiment went well; the livelink was successfully performed; many students across Europe had a chance of live interaction with an astronaut. They received their own small greenhouses to learn about the differences between growing plants on ground and in space. The pupils were educated with the observation from online pictures submitted by the astronaut

The experiment also illustrates some challenges with plant biology payloads. First, it is more complicated to grow plants in space than on ground. This is underlined by the astronaut Paolo Nespoli who himself did remark that simple procedures on Earth are extremely complex in weightlessness, but "Part of the experiment was indeed a success: we were able to grow the plants and observe them."

In the future there should be room for more educational biological experiments and by starting planning and testing a couple of years in advance, the yield will perhaps be even better.

Acknowledgments

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