The European Astro Pi Challenge – utilizing the International Space Station as an educational platform for STEM subject learning

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Abstract

The European Astro Pi Challenge is an annual computer coding-based educational programme developed by the European Space Agency (ESA) Education Office, in collaboration with the Raspberry Pi Foundation (RPF). The primary objective of the challenge is to enrich the competencies and skills of pupils across Europe in Science, Technology, Engineering and Mathematics (STEM) subjects, and so, motivate them towards further study and careers in these fields. This paper outlines the technical development of the Astro Pi payload and reviews the 2015 to 2017 educational ground-programmes. Two augmented Raspberry Pi Model B+ computers, called Astro Pi's, equipped with a suite of peripheral sensors and cameras were uploaded to the ISS in 2015. Upgrades to the Astro Pi software were made in 2016, allowing the Pi's to be connected to the ISS Joint Station LAN (JSL) network, and thus, operated directly from ground, thereby minimizing required crew-time support, while maximizing autonomous capabilities. The challenge evolved out of the 'Astro Pi Competition', created in conjunction with the UK Space Agency for Timothy Peake's Principia mission to the ISS. Two competitions were organised from December 2014 to July 2015, aimed at primary and secondary school age groups, respectively, across the UK. The winning teams in both categories had their computer codes executed on the ISS. The European Astro Pi Challenge 2016/17, linked to the educational programme around the Proxima mission, expanded educational learning objectives and aimed to increase pupil engagement across Europe. Pupil teams were tasked to design a scientific experiment related to living in the ISS and to write the computer code needed to run their experiment, using one of the two on-board Astro Pi computers. In support of the programme, dedicated training resources were produced, online and hands-on training courses for teachers were held, and 600 Astro Pi kits were produced and distributed to participating teams. Demographics showed 295 teams participating, with 184 teams from 15 ESA Member States passing the final selection and submitting their scientific missions and computer codes for the challenge. Following the success of the first instalment, the European Astro Pi Challenge continues with a 2017/18 cycle. Thematic mission assignments have been designed for the participating teams and are used to guide pupils' learning and experimentation process, based on the model of real-life science investigation practices. The recent launch of an online emulator, with supporting classroom resources, has allowed greater accessibility to the programme for pupils and teachers throughout Europe.

Keywords: education, STEM, programming, digital making, ISS

Acronyms/Abbreviations

Science, Technology, Engineering, Mathematics (STEM), International Space Station (ISS), European Space Agency (ESA), Raspberry Pi Foundation (RPF), UK Space Agency (UKSA), Sense Hardware Attached on Top (SenseHAT), Joint Station LAN (JSL), Transmission Control Protocol/Internet Protocol (TCP/IP), Tracking and Data Relay Satellites (TDRS)

1. Introduction

The European Space Agency (ESA) Education Office runs an education programme in support of curricular Science Technology, Engineering, Mathematics (STEM) teaching and learning in school for primary and secondary schools. The theme of space is used as a context to enable and enhance students' literacy and competences in STEM disciplines, to encourage them to take up STEM-related studies and careers, and to create awareness about the importance of space in modern society. A special added value is given to the ESA Education activities by the privileged access, for educational purposes, to unique space facilities, namely the International Space Station (ISS).

As part of ESA Astronaut Tim Peake's Principia mission, ESA, the UK Space Agency (UKSA) and the Raspberry Pi Foundation (RPF) collaborated on the Astro Pi UK competition (2015-2016), focused on the development of computing and digital making skills by school children. For the purpose, two augmented Raspberry Pi computers, called Astro Pi's, equipped with a Sense HAT (Hardware Attached on Top), were uploaded to the ISS and used to run the student and young people's programs. Following the completion of the Astro Pi UK competition, ESA decided to extend the challenge concept to the whole of Europe. ESA and RPF formed a collaboration and launched the first European Astro Pi Challenge (2016-2017).

Both ESA and RPF share common goals to inspire young people to learn about computing and digital making, to pursue STEM subjects, and to consider careers in the space industry. The European Astro Pi Challenge represents for the ESA Education programme one of the elected ways to boost the learning of computer programming skills, scientific experimentation, and scientific methodology in school. Through the challenge, ESA aims to help bridge the gap between the theoretical learning and practical applications of science; contribute to the development of soft skills and critical thinking; attract young people to STEM-related studies; and by means of education, contribute to the growth of Europe as a knowledge based society. For the Raspberry Pi Foundation, continuing the Astro Pi competition and extending its reach to all of Europe represents a way to further engage the existing RPF community in European countries. In addition, it provides a new avenue to reach young people not otherwise engaged, with the foundation's goal to put the power of digital making into the hands of people all over the world..

The European Astro Pi Challenge is supported and disseminated to the ESA Member and Associate Member States through ESA Education's European Space Education Resource Offices (ESERO), which provide national support and resources for teachers and schools. In addition, RPF promotes the programme through their network of Code Clubs and CoderDojos across ESA Member and Associate Member States.

2. Technical Set-up

The Astro Pi computer is based on commercial off the shelf (COTS) components that are easily available to the public. A Raspberry Pi 1 model B+ is the main general purpose computer and peripherals are attached using its 40 pin GPIO header in the form of two expansion boards arranged in a stack and held in place by standoffs. Additionally, a COTS mobile phone-quality camera module is connected to the CSI port of the Raspberry Pi.

The first expansion board houses a real time clock, a crystal oscillator, a coin cell battery and terminals for six external push buttons. This board was custom made for the mission and not publicly available. The second board is another COTS item, called the Sense HAT (Hardware Attached on Top), which houses a range of scientific sensors including temperature, pressure, humidity, a gyroscope, an accelerometer, and a magnetometer, along with a joystick and an 8x8 RGB LED display, (Figure 1).

A milled aluminium flight case then encloses the hardware while externally exposing all of the Raspberry Pi ports, the lens of the camera module, the six general purpose push buttons, the Sense HAT joystick and its display, (Figure 2). The flight case incorporates external heat sink pins for thermal dissipation, as well as an attachment point for the ISS multi-use brackets, allowing the Astro Pi's to be hard-mounted on any section of seat-tack throughout the ISS.

For flight, two Astro Pi units were made with different camera modules; one unit has a standard visible light camera, while the other uses a similar camera with the near infrared exclusion filter removed which allows for a number of infragram modes of operation. Navarathinam & Honess (2015) discuss further details of the launch preparation procedures for the Astro Pi units [1]. The Raspberry Pi computer acquires its programming through a removable micro SD card that contains both the operating system, which is a variant of Debian Linux optimised for the Raspberry Pi, and the scientific programs to be executed. The scientific programs are written using the Python programming language, for which there are existing libraries to permit the commanding of the Sense HAT and camera modules- this includes the ability to read from all of the sensors and to take pictures or record video from the camera.

Figure 1: SenseHAT

3.3 Phase 3 – Winning experiment programs run on ISS:

In this phase, the winners had their programs uploaded to the ISS and run on the Astro Pi computers deployed in the Columbus module. The collected data was downlinked to Earth and distributed to the teams for analysis.

For the 2016-2017 challenge, 295 student teams from 15 Member States subscribed to the challenge, for a total of 3497 students and about 300 teachers. After a first screening, out of 295 teams, 184 more than 1800 students), submitted their scientific missions and the computer programs in order to execute their experiments on the ISS. Late March 2017, Thomas Pesquet announced that 45 teams, and 19 highly commended teams, had been selected to have their experiments running space.

4. 2017/18 Challenge

The second European Astro Pi Challenge was launched in the 2017/2018 school year. The challenge structure was modified to include two separate 'missions' teams could choose to take part in, a beginner's mission (Mission Zero) and an advanced mission (Mission Space Lab).

4.1 Mission Zero: Beginner's Mission

Mission Zero was introduced as a way of increasing participation to younger and less experienced coders. Open to students and young people under the age of 14 years in teams of two to four people, the mission was intended to provide a less intensive experience, whilst still attracting young people to programming, digital making, and space exploration, by allowing them to have their program run in space.

The entire mission was completed through the online Astro Pi emulator. In order to fully support this new mission, developments to the emulator were completed, adding emulation for the motion sensors, as well as a 3D representation of the Sense HAT, with an alternative Astro Pi flight unit mode, (Figure 3). With these upgrades, the mouse could be used to move the on-screen model into different orientations and simulate sensor readings for the accelerometer, gyroscope and magnetometer.

Figure 3: SenseHAT emulator on trinket website

The upgraded emulator allowed teams to take part in the challenge without need for any special equipment ,as they were able to write their python programs, test them, and see them run entirely within their web browser. Entries required just a few simple lines of code to be written to display the internal ISS temperature and a greeting message for the astronauts, with an in-built code checking system to signify to teams when their program had satisfied all requirements. Teams who completed the activity were guaranteed to have their code run for 30 seconds on board the ISS . Team were assisted in their completion of the activity through an online resource, which guided users through the activity step by step.

All teams who had their program successfully run on-board the ISS received a certificate of completion, displaying the coordinates of the ISS at the time of their program run, (Figure 4).

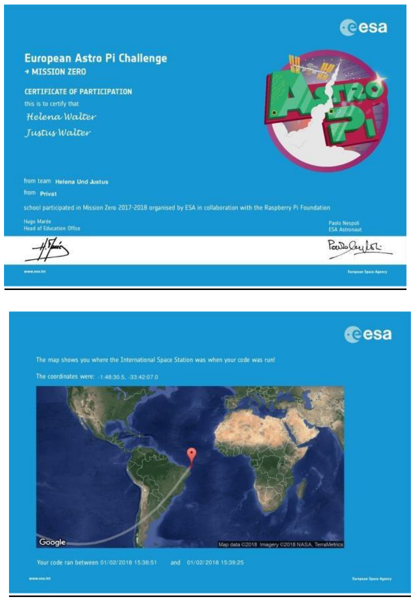

Figure 4: Mission Zero participation certificate

4.2 Mission Space Lab: Advanced Mission

Mission Space Lab was an extension of the challenge run in the 2016/2017 school year and was intended to increase the scientific learning objectives of the programme. In order to broaden the scientific capabilities of the Astro Pi, several hardware upgrades were made.

Two USB wireless dongles for operational purposes, optical filters for student EO experiments, and 32 GByte MicroSD cards to provide additional disk space were uploaded to the ISS in early 2017, (Figures 5,6,7).

Figure 5: USB wireless dongle

Figure 6: MicroSD card slot

Both Astro Pi computers were then able to be deployed on the ISS in a location suitable for the needs of the student software (one in Columbus where ESA crew work and one with the camera aimed at ground through a window). JSL connectivity in both deployment scenarios was necessary to ensure that the Astro Pi user science operations centre could perform software deployment, execution and science data retrieval. To maintain JSL connectivity while operating outside of Columbus the USB wireless dongles were required.

The addition of the optical filter permitted a type of EO analysis that identifies chlorophyll levels in living green plants; chlorophyll strongly absorbs visible light, but strongly reflects infrared light. By comparing the amount of visible to infrared light reflected by green plants the chlorophyll level present can be estimated. The Raspberry Pi NoIR camera, integrated with one of the Astro Pi computers, can perceive both visible and near infrared light at the same time. An optical filter is needed to exclude all visible red light, so that only infrared light goes into the red RGB channel of captured image data. This then allows a comparison between the level of visible and infrared light recorded in an image file at a later stage, usually using the blue and red channels. The supporting educational programme encouraged students to attempt EO experiments that may have explored this principle.

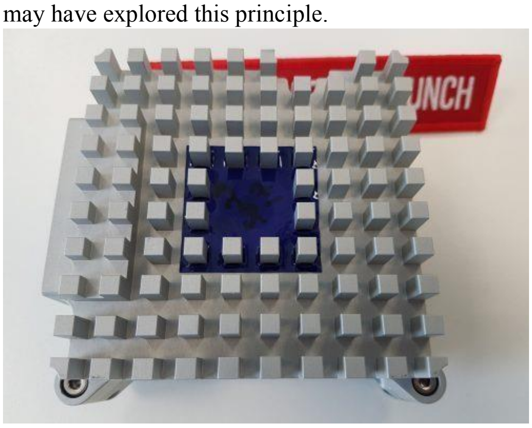

Figure 7: integrated optical filter

4.3 Phase 1 – Registration and submission of Experiment Idea.

This phase ran in the same manner as the previous year, with participants asked to submit their experiment ideas. A new element was added to the brief, with students asked to choose from one of two themes to base their experiment ideas around:

- Life in space: Teams would use Astro Pi Vis (Ed) in the European Columbus Module. They were permitted to use all of its sensors, but not to record images or videos.
- Life on Earth: Teams would use Astro Pi IR (Izzy), which was aimed towards the Earth through a window. They were permitted to use all of its sensors as well as its infrared camera. In total, over 320 individual teams registered across 15 ESA member states.

4.4 Phase 2 – Discover the Astro Pi, design the experiment to accomplish the mission, write and submit your code.

In this phase, teams were asked to write a program to run the experiment they had submitted in Phase 1. In support of this challenge, free Astro Pi kits were \distributed to participating teams for use in this phase. Over 200 teams submitted entries for Phase Two of the challenge.

4.5 Phase 3 – Programs run on the ISS.

In this phase, the entries were assessed to determine the feasibility of the experiment, scientific value, and to ensure the code could run without error or violation of rules. Over 100 entries were judged viable and had their programs uploaded to the ISS and run on the Astro Pi computers deployed in the Columbus module. The collected data was downlinked to Earth and distributed to the teams for analysis.

4.6 Phase 4 - Teams analyse the data returned to them and write scientific reports, the best of which are selected as winners.

This phase was a new addition to the challenge and required teams to write a report using a prescribed template, analysing the results for their experiments. 98 teams, of a possible 114, submitted their final reports. The best 10 were selected as winners and given the opportunity to take part in an exclusive webinar with ESA Astronaut Tim Peake.

5. Current impact

The 2017/2018 Astro Pi Challenge saw a huge increase in participation, largely owing to the introduction of Mission Zero. The combined reach of both Challenges totalled over 6800 young people across 24 different countries.

The most well-represented country in both challenges was the United Kingdom, this reflected the UKSA origins of the programme, the extensive reach that the Raspberry Pi Foundation has into schools and clubs in the UK, and the availability of the majority of the programme information in English. We hope to increase participation in non-English speaking European countries in 2018/2019 programme through the introduction of Mission Zero resources translated into all 18 official ESA languages and through more effectively mobilising ESERO partners across ESA member states.

Taken together, the overall female participation in the 2017/2018 Astro Pi Challenge was 38.3%. We intend to conduct further analysis to understand why and to identify opportunities to increase representation by girls in Mission Space Lab.

Mission Zero and Mission Space Lab are intended to have a different impact, based on the ages and skills levels they are aimed at.

5.1 Mission Zero impact

The intended impact of Mission Zero is for young people aged 14 and under to learn basic programming skills using Python and be inspired to learn more about programming and its role in the space industry. All entrants to the competition had to develop or use basic Python skills. 5412 children in 2506 teams submitted entries, demonstrating their grasp of these skills.

We received feedback from a number of adults that they found the competition a beneficial way to introduce children who had previously only used visual 'block based' programming to using text based programming languages. This transition between types of languages is a concern for many teachers of computing, and efforts are being made by researchers and educators alike to understand and support this transition, [3]. Providing a motivating and exciting context with well supported educational materials appears to be an opportunity for educators to make this transition with young students. This opens up the power of text based programming languages to these students, and allows them to move to the next stage of their education in programming.

The lack of girls taking part in computing education activities in many countries is well documented. 41.2% of the participants in Mission Zero were girls, with 56.7% boys and 2.1% indicating 'other' or leaving this part of the entry form blank. This is a relatively well balanced programme in terms of gender representation, and we are glad to be having an impact on many girls. There are some indications that young girls respond well to computing projects that they see as relevant and as tools to achieve something in the wider world rather than for learning about technology for its own sake [4]. The Astro Pi missions are clearly linked to an authentic context, and this may explain the involvement of girls. The Mission Zero project is also designed to be accessible for a teacher to provide large numbers of students, and we can see in the data that many teachers involved a whole class or even a whole year group of children. Opportunities provided to all children in this way are more likely to involve girls, and give them the opportunity to see that computing could be for them without having to proactively choose to get involved without any experience [4]. We will continue to monitor the gender balance of participants in the programme, and explore initiatives to ensure the gender balance of the programme.

We hope that in future participants in Mission Zero will be inspired by their success to build their skills further and take part in the Mission Space Lab program in future years.

5.2 Mission Space Lab impact

The impact of Mission Space Lab is broadly for young people to learn programming and science skills through applying them to the authentic and exciting scenario of deploying an experiment in space. The specific skills that young people learn are dependent on the project they choose.

1402 young people took part in Mission Space Lab from 330 teams, all demonstrating their engagement with science and computing skills. 27.2% of the team members were female. This is notably less balanced than Mission Zero, and we are exploring approaches to address this. In the future, we hope the pool of Mission Zero graduates with a good gender balance will help to increase participation in Mission Space Lab.

5.3 Mission Space Lab winners

The winning entries from Mission Space Lab show the diversity of skills that young people taking part in the competition have developed. This diversity and ambition was evident across the entries to the competition.

The Dark Side of Light from Branksome Hall, Canada, investigated whether the light pollution in an area could be used to determine the source of energy for the electricity consumption.

Spaceballs from Attert Lycée Redange, Luxembourg, successfully calculated the speed of the ISS by analysing ground photographs.

Enrico Fermi from Liceo XXV Aprile, Italy, investigated the link between the Astro Pi's magnetometer and X-ray measurements from the GOES-15 satellite.

Team Aurora from Hyvinkään yhteiskoulun lukio, Finland, showed how the Astro Pi's magnetometer could be used to map the Earth's magnetic field and determine the latitude of the ISS.

@stroMega from Institut de Genech, France, used Astro Pi Izzy's near-infrared Camera Module to measure the health and density of vegetation on Earth.

Ursa Major from a CoderDojo in Belgium created a program to autonomously measure the percentage of vegetation, water, and clouds in photographs from Astro Pi Izzy.

Canarias 1 from IES El Calero, Spain, built on existing data and successfully determined whether the ISS was eclipsed from on-board sensor data.

The Earth Watchers from S.T.E.M Robotics Academy, Greece, used Astro Pi Izzy to compare the health of vegetation in Quebec, Canada, and Guam.

Trentini DOP from CoderDojo Trento, Italy, investigated the stability of the on-board conditions of the ISS and whether or not they were affected by eclipsing.

Team Lampone from CoderDojo Trento, Italy, accurately measured the speed of the ISS by analysing ground photographs taken by Astro Pi Izzy.

5.4 Entries

The winners represent the diversity of ideas and subject matter that was addressed across the entries that were received. Projects were ambitious, of a high quality, and addressing a wide range of scientific concepts and programming approaches.

The hours spent on the projects submitted for phase 2 was estimated by adults to be around 13,700, with each team estimated to have spent an average of 83 hours on their projects. For these teams this is a high impact project, with a high level of challenge and significant engagement with challenging scientific and programming concepts.

At the submission stage for code at the end of 'Phase 2: Create' we asked the adult submitting entries about the development of skills they had seen in the young people. This included programming skills, science skills and soft skills, which we described as skills such as teamwork, responsibility and communication. These were high, with around three quarters rating the improvement of skills at 4 or 5 out of 5. Programming skills were indicated to be the most improved, with 52% giving the top rating and and 86% either 4 or 5 out of 5. Science skills were second most liked to be rated top, followed by soft skills.

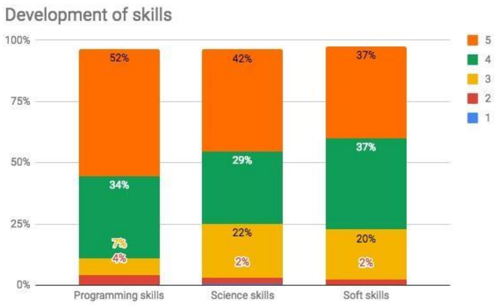

Figure 8: skill development of students as reported by teacher/mentor. 1 is low, 5 is high

5.5 Reports

The winning entries are impressive, and the field of entries generally was of a high quality. The average overall score across all projects submitted to the final report stage was 8.4 out of a possible 12 points. 12% of projects submitted at this stage managed to score full marks in the judging.

The learning that teams have gone through is clearly evident across many of the reports they submitted. Challenges they had to meet in designing their experiments are described, as well as inventive ways they have solved them. Not all experiments performed as expected once onboard the ISS, for many reasons including unforseen aspects to how the code ran or the physical environment.

For example, one project experiences issues with light from the sun reflecting on the window and obscuring their photographs. Several projects had issues with the way they had written their code to log data or photographs, causing this data to be overwritten when the program was run subsequent times. These challenges are well documented in their reports, and have resulted in some authentic learning about some of the challenges of deploying code to unfamiliar environments; all part of the learning in this programme.

5.6 Future participation

At the submission stage for code we asked how interested adults and their students would be in taking part in the competition in future, and 91% rated this either 4 or 5, with 72% giving the question the top rating.

Based on feedback from adults involved in the European Astro Pi Challenge, the programme's net promoter score is 85, demonstrating the very strong feelings that it has been a beneficial experience for the young people involved.

6. Future Directions

Following the success of the 2015-2016, 2016-2017, and 2017-2018 instalments of the Europe-wide challenge, ESA and RPF plan to organise further rounds of the European Astro Pi Challenge in the school-years 2018-2019, 2019-2020 and 2020-2021.

Short term objectives to further increase participation in the program will focus on the expansion of classroom resources to better support students' journey through the phases of the challenge. Specifically, the Mission Space Lab Guidelines have been expanded to provide a more comprehensive guide for educators supporting a team through the challenge. Supporting video resources and promotional materials will be developed to motivate students and young people to take part in the program, and to help them understand the capabilities of the hardware when developing their experiment ideas. Furthermore, a push in providing translated resources, into all ESA Member and Associate Member State languages, will be made for Mission Zero as its target audience is younger and more needing of materials in national languages.

As the program continues into the future, each annual challenge will strive to strengthen educational outputs, increase students' skills and competencies, and reach new audiences. In order to achieve this growth, innovative and diverse mission themes must be developed and supported by technical advancements in the on-board ISS hardware.

Additionally, as a part of the didactics support for challenge, participating teams are offered Astro Pi kits, which contain equivalent hardware to the Astro Pi computers on-board the ISS and are used by the teams to develop and test the software for their experiments. Due to the ever increasing availability of more powerful Raspberry Pi hardware, the computing capabilities found in the Astro Pi kits in schools and the hardware on-board the ISS have diverged over time. With the understanding that this disparity will increase and that the current hardware on-board the ISS is life–limited, the need for an updated Astro Pi payload becomes more critical.

In the coming years, ESA, with the support of RPF, will upload new and improved replacement hardware to ensure ongoing Astro Pi operations, mitigate student software performance issues, and add exciting new educational science capabilities.

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