

Rocket Science

Our Voyage of Discovery





Sale High School, Cheshire

“ I had the ambition to not only go farther than man had gone before, but to go as far as it was possible to go ”

Captain James Cook FRS RN
(1728 -1779)

Welcome to Rocket Science

In the summer of 2016, six hundred thousand children became space biologists as they began a 35 day experiment to sow and grow rocket seeds that had spent six months on board the International Space Station.

The story we are about to tell is one of commitment and endeavour, and the way we can all work together to seek out knowledge and understanding. It is about being part of the amazing science and pioneering discoveries that are taking place in our lifetimes, and reconnecting with the natural world.

The Royal Horticultural Society (RHS) believes that without plants, we have no future. Plants are fundamental to life, and nurturing new growth is one of the most memorable experiences we can hope to achieve.

By being part of the Rocket Science project, thousands of schools and youth groups have contributed to the world’s developing knowledge of plants in space. They have questioned whether space travel can affect tiny seeds, and offered explanations based on real research and observation.

This report celebrates the creativity, curiosity and independent thinking of children and young people across the UK, as well as the teachers and leaders who inspire them. It brings together their findings and observations with those of leading plant scientists, drawing on their expert skills and knowledge. Finally, this report acknowledges the incredible support of Tim Peake, who through his Principia Mission has become one of the most important role models of our generation.



Contents



02 Welcome to Rocket Science

04 What is Rocket Science?

05 The Rocket Science Experiment Timeline

06 Our Rocket Science Community

09 The Red or Blue Conundrum

11 Exploring the Curriculum through Rocket Science

15 Voices of Rocket Science

16 Why Rocket Science Matters

19 Rocket Science National Results

21 National Average Results at a Glance

22 Key Findings

23 The RHS and Royal Holloway Collaborative Experiment

27 Theories from our Young Space Biologists

29 Meet our Science Experts

30 The Gravity Factor

31 The Radiation Factor

33 The Journey Factor

34 The Temperature (and Humidity) Factor

35 The Gas Factor

36 The Curiosity Factor

37 Galactic Gardening for Health and Happiness

39 Why is Citizen Science Important?

43 Thank You to our Partners and Collaborators

44 A Thank You from Tim

45 About the Project Partners

What is Rocket Science?

On 3 September 2015, one million (2kg) tiny rocket seeds (*Eruca sativa*) were launched into space on Soyuz 44S to begin their six month stay on board the International Space Station (ISS).

Over 8,600 schools and groups across the UK, making up 600,000 young people, signed up to be a recipient of a pack of these very special seeds. Their mission: To grow the seeds once they returned alongside an identical pack of seeds that had remained on Earth. Through this they would discover whether humans can grow their own food on long term space missions or even on another planet in the future.

Unaware of which packet contained the space seeds, our young space biologists nurtured their seedlings from April through to June 2016 in a blind science experiment, taking specified measurements and carefully recording their data ready to be inputted later into a national results database. In addition, participants set their own hypotheses on the scientific question: How does space travel and exposure to the conditions of the space environment affect rocket (*Eruca sativa*) seed germination and plant growth?

This report tells of the journey these young people took to discover the answer to this question and the impact the project has had on their understanding and perception of scientific investigation, and future careers in STEM (Science, Technology, Engineering and Maths) subjects.

Rocket Science is a nationwide initiative developed by the RHS Campaign for School Gardening and RHS Science team, in collaboration with the UK Space Agency, and supported by the European Space Agency (ESA).

The project is one of 30 educational initiatives designed by the UK Space Agency to engage young people in practical scientific inquiry throughout the duration of British ESA astronaut Tim Peake's Principia mission to the ISS, and beyond.

Whilst carrying out some unique and fascinating experiments in micro-gravity, 248 miles above the Earth, Tim wanted to inspire young people to develop their interest in science and to learn more about the career opportunities it opens up – a vision shared by the RHS and the UK Space Agency.

And so Rocket Science was born. A chance to give over half a million young people the opportunity to explore science and be a part of something meaningful.

So could humans grow their own food in space one day? Read on to find out. It really is Rocket Science...



The Rocket Science Timeline



- ◆ **18 May 2015:** Rocket Science is announced at RHS Chelsea Flower Show
- ◆ **28 June 2015, 14:21 GMT:** 2kg of rocket seeds launch from Cape Canaveral, Florida on SpaceX-7, an unmanned cargo rocket
- ◆ **28 June 2015, 14:23 GMT:** SpaceX-7 suffers a catastrophic failure and explodes 2 minutes after take-off
- ◆ **02 September 2015, 04:37 GMT:** 2kg of new rocket seeds launch from Baikonur, Kazakhstan on Soyuz TMA-18M
- ◆ **04 September 2015, 07:42 GMT:** Soyuz TMA-18M docks with the International Space Station and the seeds are unloaded
- ◆ **23 September 2015:** Applications open for schools to sign up to take part in Rocket Science
- ◆ **15 December 2015, 17:33 GMT:** Tim Peake arrives at the ISS to begin his Principia mission
- ◆ **29 January 2016:** Tim delivers a video message to schools across the UK inviting them to take part in Rocket Science
- ◆ **02 March 2016, 01:02 GMT:** Soyuz TMA-18M undocks from the ISS with our seeds on board
- ◆ **02 March 2016, 04:26 GMT:** Our rocket seeds land on the Kazakh steppe with astronaut Scott Kelly
- ◆ **20 April 2016:** The first Rocket Science participants begin their experiment
- ◆ **22 April 2016:** The first rocket seeds germinate
- ◆ **26 April 2016:** The first rocket seedlings grow their true leaves
- ◆ **28 April 2016:** A video is released showing Tim choosing whether the space seeds would be red or blue
- ◆ **17 June 2016:** Final Rocket Science data is collected in the national results database
- ◆ **18 June 2016, 09:15 GMT:** Tim returns to Earth
- ◆ **22 June 2016:** Tim reveals the identity of the space seeds!
- ◆ **02 and 05 November 2016:** Rocket Science participants present their work to Tim Peake at the Principia Schools Conferences at the University of Portsmouth and University of York





The Red or Blue Conundrum

Two seed packets identical in every way except for their colour – one red and one blue.

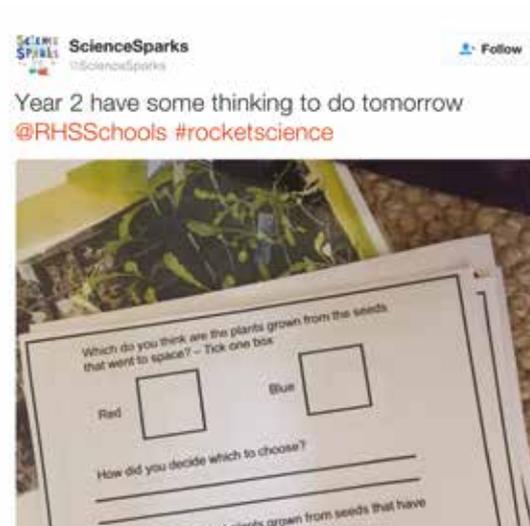
One would contain the seeds that had been into space and one the seeds that had remained on Earth.

Before Tim Peake made his journey to the International Space Station in December 2015, he recorded a secret video to determine which colour packet the space seeds were destined for. A simple coin flip decided their fate and the secret was kept hidden for several months. You can rewatch the video at [youtube.com/rhsschoolgardening](https://www.youtube.com/rhsschoolgardening).

In April 2016, to coincide with schools beginning the experiment, a teaser video was released on YouTube showing the coin flip, but not the result.



This sparked a frenzy on Twitter with schools trying to guess the identity of the space seeds!



In fact we asked our participants to predict which colour packet they thought contained the space seeds. Here is what they predicted:



On 22 June 2016, the full video was released on YouTube and Tim Peake finally revealed the identity of the space seeds – BLUE!

To date the video has been watched over 10,000 times as Rocket Science participants across the UK watched the big reveal in their classrooms and assemblies to see if their predictions were correct.



Now we know that the space seeds were in the blue packet, turn to page 19 for the experiment results or read on to see just how creative schools were with the Rocket Science theme.

Exploring the Curriculum through Rocket Science

Throughout the Rocket Science project, the RHS Campaign for School Gardening team was inundated with amazing work carried out by young people; from stories and poems to pictures, posters and models.

Here is just a small selection of the incredibly creative and inventive ways that our young space biologists took Rocket Science to infinity and beyond...

OUT OF THIS WORLD RAPPING

As part of a literacy topic on performance poetry, a class of students from Park School in Bournemouth wrote and performed their very own rap:

Time for Tim to say goodbye,
Rocket roaring through the sky,
Supersonic flying high,
Blue turned to black,
What an awesome guy.

Through the window shining stars,
Off in the distance planet Mars,
Not a car in sight, his route was clear,
On his way to the station, Mir?!

Station in sight it was time to attach,
With a click and a clunk he turned the latch,
Zero gravity, floating free,
How I wish it could be me!



Soaring seeds

Teachers at St. John's First School in Bishops Wood, Stafford delivered their Rocket Science pack to their pupils with a bang! Pupils were told to head outside and were surprised to find a silver box attached to a parachute in a tree. They followed the instructions inside the box and watched Tim's video message to begin their Rocket Science adventure, researching space facts and reading space stories as they went.



Inspiring investigations

Pupils from St Joseph the Worker RC Primary School in Essex were treated to an exciting visit to Jodrell Bank Discovery Centre to develop their understanding of space science while New Ash Green Primary School in Kent made a trip to The Observatory Science Centre in Herstmonceux, East Sussex to take part in telescope tours and learn how to use robotic arms.





Cosmic cakes

After saying that cake would be the food they would miss most in space, the Beavers and leaders of 2nd Willington Scout Group in East Sussex made a whole solar system out of the stuff. To celebrate her birthday during the experiment, Mrs Street of Bealings School in Suffolk treated her Rocket Scientists to a cake in the shape of our Rocket Science logo.



Brampton Manor Academy, London



Voices of Rocket Science

Our young space biologists loved taking part in Rocket Science, but don't just take our word for it! Here are some of their thoughts on the project and what they learnt...



Through the UK Space Agency, we learnt about scientific methods including randomisation. We like to think that Cottenham Village College has helped the growth of human knowledge about space travel and plant biology.

Abi Spray, aged 13, Cottenham Village College, Cambridge



We all love space and we feel very lucky to be one of the schools that were chosen.

Caleb Southworth, aged 11, Chetwynd Junior School, Nuneaton

I learnt from Rocket Science about space science and gardening. It made me feel accomplished and I felt really focused when we were planting the rocket.

Gene Mills, aged 9, Chudleigh Knighton C of E Primary School, Devon



I learnt how it feels to make an actual contribution to science and how team work is very important in that.

George Teague, Devonport High School for Boys, Plymouth



I have learnt how important randomisation is for a fair scientific test.

Callum Burns, aged 10, Gilnahirk Primary School, Belfast

Thank you Tim Peake for your videos which have inspired me to study science.

Stephanie, Eldon Primary School, London



It was really exciting to be in an experiment that no one has done before.

Kiera Atherton, aged 9, Fairway Primary School, Birmingham



We learnt that seeds grow differently in different environments. We felt very excited about this project. Gardening is more interesting than we thought.

Maddy Oglesby, aged 9, Park Grove Primary School, York



I really, really want to be a scientist

Zara Ajmal, aged 6, Christ Church Primary, Battersea

I really enjoyed doing this project because I learnt a lot more about space and science. I also enjoyed it because I worked really hard with my friends.

Anna Birchall, aged 11, Hall School, Wimbledon



Why Rocket Science Matters

We received thousands of statements from teachers across the whole educational spectrum telling us why they wanted to take part in Rocket Science. We asked Professor David Uzzell from the University of Surrey's School of Environmental Psychology to analyse the statements. He found out that the most important benefits of the project from the teachers' point of view were:

- ◆ To capture young people's imagination by using Tim Peake as a role model
- ◆ To help teachers relate the importance of STEM subjects to everyday life
- ◆ To foster that imagination and extend their interest in space, the growing of plants (and food) in space and on Earth, and the relevance of space to life on Earth
- ◆ To apply scientific processes and skills from start to finish in a large scale, real life, national experiment
- ◆ To stimulate interest in the environment, horticulture, and the importance of environmental sustainability
- ◆ To support cross curricular teaching, including non-STEM subjects
- ◆ To encourage pupils into STEM subjects at school, and careers later
- ◆ To enrich teaching beyond the curriculum, for example by promoting team working, taking responsibility, and communicating with others
- ◆ To provide teachers with imaginative teaching material to support the teaching of STEM subjects
- ◆ To demonstrate what scientists actually 'do'
- ◆ To explore food supply as a citizenship issue

"A wonderful opportunity to be a part of history and engaged in living science."

Mrs A Holland, Thomas Willingale School and Nursery, Essex

"The most phenomenal, engaging science activity I've been part of. Out of this world!"

Mrs C McDonald, St Agatha's RC Primary School, Fife

"I have never seen a whole class so motivated to learn and take responsibility for sharing findings with the school."

Mrs A Bill, Powick C of E Primary School, Worcester



Applemore College, Hampshire

"It has made lots of girls realise science is fun and relevant and they have seen themselves as real scientists."

Ms Rachel Franklin, Green Leaf Primary School, Walthamstow

"It's fantastic to be involved in a national experiment and allows students to look at the bigger picture."

Mrs Cathryn Hill, Cleaswell High School, Northumberland

"It gets the children involved in real science that has implications for the future of our planet and its occupants."

Mr John Teasdale, Martongate Primary School, East Riding of Yorkshire



Brixington Primary School, Devon



Rocket Science National Results



OVER
5,000
SUBMITTED THEIR DATA

320,000
INDIVIDUAL DATA POINTS
WERE COLLECTED
& ANALYSED

Thanks to such a huge number of participants submitting their results, we were able to find very strong statistical evidence of differences between the Earth (red) and space (blue) seed batches, even when the mean differences observed nationally were actually very small.

To help us make sense of all the data, we called on the help of Biomathematics & Statistics Scotland (BioSS) to analyse the results.

Nationally across all Rocket Science groups we observed differences in the germination and growth of Earth seeds when compared with space seeds.

Overall results suggest that, on average, the space seeds performed less well than seeds that had remained on Earth. These findings are further supported by results from a Royal Horticultural Society and Royal Holloway University of London collaborative experiment comparing the seeds under controlled laboratory conditions (see page 23). In addition, differences between the seeds varied appreciably from group to group.

Although several differences were statistically significant, they were small and are unlikely to be of any biological significance. However these small differences may indicate that the space seeds had been affected by environmental factors such as temperature, microgravity, radiation or vibrations from the acceleration of the rocket.

This research provides further evidence to support that seeds, in this case rocket (*Eruca sativa*) seeds, can be flown and stored on the International Space Station (ISS) for six months without having any significant impacts on their ability to germinate and grow.

This means that for short term missions at least, the impact of environmental factors, such as vibration from launching, temperature fluctuations, cosmic rays and microgravity inside the ISS, has not been sufficient to prevent seeds from germinating and growing. Find out more about how these factors could have affected the seeds from page 27.

Of course, the environment and cultivation conditions are very different in space than on Earth, but this is the first step in knowing that astronauts have the potential to grow their own food.

These results add to our scientific evidence base to support the future of growing plants in order to sustain human life in space and highlight the crucial need for further research in space biology.



National average results at a glance...

Here are the average results from all data collected by our space biologists*:

Experiment questions	Red Seeds (Earth)	Blue Seeds (Space)
1. Count how many seeds were sown (per tray)	24	24
2. Record how many days until the first seed germinated	3.71	3.78
3. Calculate the percentage of seeds that have germinated by day 10	71.85%	67.38%
4. Record how many days it took the first seedling in each replicate to grow its first pair of true leaves	13	13
5. Calculate the percentage of seedlings alive on day 17	70.69%	66.35%
6. Measure the height, in millimetres, of the tallest seedling in each replicate on day 21	67.89mm	66.44mm
7. Calculate the average (mean) number of leaves on the FIVE randomly selected seedlings from each replicate on day 28. Only include plants that remain alive	4.05	3.96
8. Calculate the percentage of seedlings alive on day 35	57.95%	54.16%

*A total of 5,147 participants entered data that was useable and valid for some or all of the questions.

Key Findings



- ◆ A large proportion of participants (81 %) found no difference between the red and blue seeds in **the number of days until the first seed germinated**. Of the groups that did find a difference (18 %), more showed that time to the first seed germinating was slightly faster for the Earth seeds than the space seeds. The time difference was small, i.e. rarely more than 1 day difference.
- ◆ Overall the **mean germination at day 10** was 4 % higher for the Earth seeds at 71.85 % compared with the space seeds at 67.38 %. However, almost a third of groups (31 %) observed greater germination in the space seeds and 4 % of groups observed no difference.
- ◆ 48 % of participants found no difference between the Earth seeds and space seeds in **the number of days it took for the first two true leaves to appear**. Of those that did find a difference, more showed that the first two true leaves appeared slightly earlier in the Earth seeds than the space seeds. The mean number of days it took for the first true leaves to appear was 13.03 for the red seeds and 13.18 for the blue seeds, a very small difference of 0.15 days.
- ◆ Overall the mean **percentage of seedlings recorded still alive at day 17** was higher for the Earth seeds at 70.69 % compared with the space seeds at 66.35 %. 31 % of groups observed the opposite and 5 % of groups observed no difference.
- ◆ On average, at **day 21 seedlings from the Earth seeds were slightly taller at 67.89mm compared with the space seeds at 66.44mm**. It is also worth noting that there was a wide variation in the mean height differences across participants.
- ◆ The **average leaf count at day 28** was slightly higher for the Earth seeds than the space seeds. This difference was also very small.
- ◆ The mean **percentage of seedlings recorded still alive at day 35** was higher for the Earth seeds at 57.95 % compared with the space seeds at 54.16 %.

The Royal Horticultural Society and Royal Holloway Collaborative Experiment

While our space biologists were busy carrying out their Rocket Science experiment, The Royal Horticultural Society and Royal Holloway University of London undertook a germination experiment under controlled laboratory conditions.

The percentage germination was measured by observing 'testa rupture' (figure 1) over time, at the optimum germination temperature of 29°C.

Findings from this research provided further evidence to support the overall national findings that the Earth seeds (red) performed better than space seeds (blue) at germination (see figure 2).

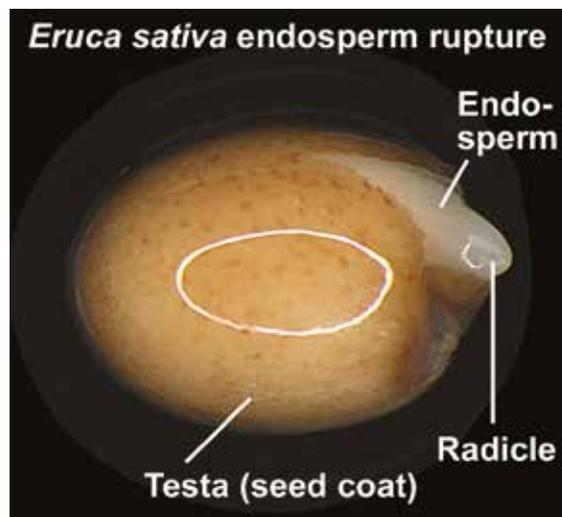


Figure 1: Photograph illustrating endosperm rupture as the completion of rocket (*Eruca sativa*) seed germination

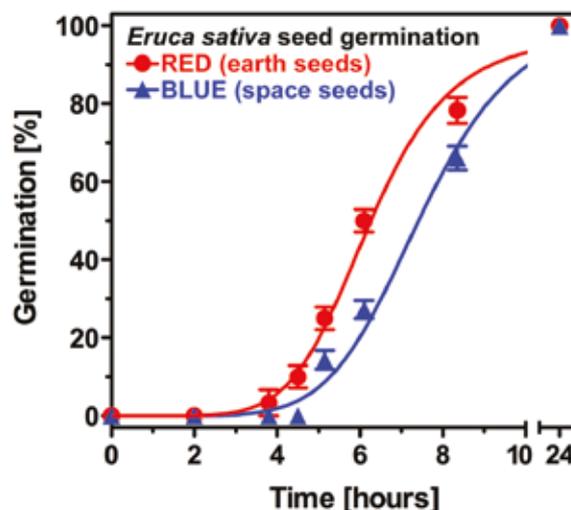


Figure 2: Germination (%) kinetics comparing endosperm rupture and radicle emergence of the Earth (red) and space (blue) rocket (*Eruca sativa*) seed batches. Mean values \pm SE (standard error)





The Cotswold School Academy, Cheltenham



Theories from our Young Space Biologists

We asked our schools and groups to tell us what factors they thought may have affected the space seeds and why.

Here are the most popular theories:



1. Micro-gravity



2. Radiation



3. The journey



4. Temperature



5. Gases





Robert Gordon's College, Aberdeen

**Read on to see what
our experts think about
their theories...**

Meet our Science Experts

We asked four leading plant scientists to look at the theories put forward by our young people as to which seeds were red and which were blue, and to give us their thoughts.

On the pages that follow, each expert will consider the physical or environmental factors that may have contributed to differences in germination and growth of the seeds.



Dr Jason Hatton (JH)

Jason is the Head of Biology and Environmental Monitoring at the European Space Agency (ESA) where he co-ordinates all of the Agency's Biology Science Experiments. Jason's involvement in space started with experiments flown on the Space Shuttle looking at the effect of microgravity on signal transduction in human T-cells and monocytes, which help our bodies to fight infection. Jason's career has taken him to France, the USA and now the Netherlands.



Dr Frances Gawthrop (FG)

Frances is Director of Research and Development at Tozer Seeds in Cobham, Surrey, the largest independent vegetable breeding company in the UK. Frances is responsible for breeding new and innovative vegetable varieties, and was part of a team that worked on Kalette – a cross between Brussels sprouts and kale which has been billed in the USA as a great health food.



Dr Greg Briarty (GB)

Greg is a retired scientist who previously worked at the Department of Life Sciences, University of Nottingham where, with his colleague Paddy Maher, he successfully proposed an experiment which flew on the Space Shuttle STS-42 mission in 1992. The experiment involved looking at *Arabidopsis thaliana* germination in microgravity, in particular the way that the seeds' lipids and proteins were affected. In 1989 Greg wrote a training manual for ESA entitled 'Biology in Microgravity - A Guide for Experimenters' and he has been involved in several other microgravity experiments with ESA and NASA.



Professor Gerhard Leubner (GL)

Gerhard is Chair of Plant Biochemistry at Royal Holloway University of London and leads the Group of Seed Biology and Engineering. Their website 'The Seed Biology Place' is internationally among the most visited in the field combining research and teaching information, and refers to the group's publications. Their aim is to understand the underpinning mechanisms of seed dormancy and germination to improve seed quality and seedling performance of horticultural and agricultural crops in a changing climate.

The Gravity Factor



What our young space biologists said:

“If the blue seeds had been up in space, then they would have to re-adjust to life on Earth with gravity, just as humans have to. This adjustment would cause them some distress.”

Langham Village School, Norfolk

“One possible discussion was about how microgravity affects shoot and root growth and whether these can be confused by the seed if it has been to space.”

Englefield C.E. Primary School, Berkshire

“Pupils suggested the seeds had difficulty germinating as they had been in zero gravity. This could have interrupted their dormant state. Some pupils suggested that when they returned to Earth’s gravity from zero they felt gravity doubly strong so took longer to push up through the soil.”

Cawdor Primary School, Nairn

“We felt microgravity would have a negligible effect until the seeds actually germinated, but they were back in the effects of full gravity by the time they actually germinated, so gravitropism was unaffected.”

Queen Anne’s School, Reading

What our experts say:

JH: ESA and NASA are collaborating together on a series of experiments called Seedling Growth 1, 2 and 3 (3 being due to launch in late 2017). These experiments are helping us to understand the basic mechanisms in plant life, in particular the effects of gravity and light on plant growth, development and cell division. Some plants can detect even the smallest amount of gravity, and Mars with 38 % of the Earth’s gravity, should be able to sustain plant life if plants are adequately protected.

FG: I do not believe microgravity would have influenced the results of this experiment. No matter which way a seed falls, the plant hormones which are activated as the seed begins to germinate ensure the root grows down in the direction of gravity and the shoot grows up towards the light... Amazing!

GB: The seeds were not growing, and so had not developed their systems for sensing gravity. If they had been growing the young plants would have developed differently on the ISS (in space), in comparison to the way they grew on Earth in the schools’ experiments. In the absence of gravity, the roots would have grown in whatever direction the seed’s radicle (root tip) was pointing; the shoots would have grown towards the light however, as their response to light is generally stronger than the gravity response.

GL: The seeds were not germinated in space and therefore experienced the gravity changes in a dry state which is not gravity-sensitive. Water uptake during germination is required to trigger hormonally-controlled gravity responses. This seems to require starch grains inside cells which exert directed pressure onto membranes and thereby influence hormone distributions between tissues. This is why emerging seedling roots grow downwards and shoots grow upwards, a phenomenon called negative and positive gravitropism, respectively. Seedling production in microgravity itself would indeed result in altered growth patterns, but this experiment was of course conducted on Earth.



The Radiation Factor



What our young space biologists said:

"The few blue seeds that developed better might have been affected by radiation altering them into 'super seeds'!"

Hoe Bridge School, Surrey

"Our blue plants flowered which we thought showed they had been under stress so the pupils believed this is due to being in space and the journey there and back".

Woodmill High School, Dunfermline

"Potentially the effect of cosmic radiation affected the genetic makeup of the seedlings."

St Dunstan's College, London

"The higher radiation dose in space may have had an effect. However, we did not expect much of an effect, as the seeds had been stored in space for only six months and were still inside the Earth's magnetic field. It is more likely to be that we on our own are quite a small sample size and our results show random fluctuation."

The Leigh Academy, Kent

"Most thought that radiation was most likely to have had a negative effect on growth given that it is 15 times the levels on Earth. One student researched NASA's suggestion that nutritional and epidermal layers are more porous after space exposure which would have led to improved development."

Caistor Yarborough Academy, Lincolnshire

What our experts say:

JH: Radiation is the biggest risk for dormant seeds stored for a long time in the space environment because cosmic rays are so energetic. When they impact the ISS there is a showering effect and they fragment further and become even more energetic. Nuclei and some protons can penetrate the ISS and interact with any biological material on board. They either pass through the seed, or deposit energy there. They can fragment further once inside the seed too, which leads to greater damage.

Cosmic rays can degrade the protein structure within the seed and break strands of the DNA - the genetic code for different proteins that make up the structure of a cell. Plants have a remarkable ability to repair their own DNA if it is damaged once they are growing. They cannot do this if the seed is still dormant, which may account for some lasting damage. If the doses of radiation over time become too great this repair mechanism in living plants cannot cope.

FG: I can see from the schools' data that overall, the space seeds (blue) did not grow quite as well as the Earth seeds (red). The blue seeds exhibited reduced vigour which is a sign of damage due to ageing. All seeds degrade with time, and with each passing year in storage we would expect to see a fall in germination percentage, but the fact of the seeds being exposed to radiation in space may have speeded up this process. It is interesting to note that Woodmill High School's plants flowered. This is a sign of stress and the plants reproducing to complete their lifecycle.

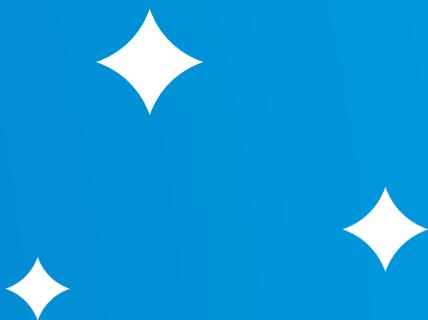




Bradway Primary School, Sheffield

GB: In 1984 NASA put into orbit an experiment called LDEF (Long Duration Exposure Facility) to study the effects of cosmic rays radiation and solar wind on tomato seeds, amongst other experiments. After 5 years 9 months on board, the seeds germinated at a rate of 73.8%, only slightly less than the controls. This shows how resilient some seeds can be when exposed to higher levels of radiation than on Earth, although the lower germination and growth rates of the blue seeds might have resulted partly from radiation damage to DNA and proteins.

GL: The young people's and our results both show a small delay in the germination speed of the blue seeds which had been in space. Minor damage of DNA, RNA and proteins by radiation could indeed be a possible explanation for this, but germinating seeds and emerging seedlings also have powerful repair mechanisms. As the seeds were not exposed to the high radiation in space, but to the considerably lower radiation inside the ISS, only a small effect would have been expected. That the possible damage is small, is also evident from the fact that there was no reduction in the final germination percentages. Extended exposure to high radiation would be more severe as it could cause seed viability loss and irreparable mutations.



The Journey Factor



What our young space biologists said:

“The seeds had been through some ‘trauma’ whilst travelling.”

**63rd Leicester St Thomas More
Scout Group, Leicester**

“We discussed the shaking and squashing that would have taken place on the journey to and from the launch site as well as the space travel itself.”

Kingsbridge Community College, Devon

What our experts say:

FG: Vibration can cause mechanical damage to seeds especially if the seed is not dry enough when it is thrashed. Dry seeds are remarkably resilient, however. Vibration could only be a problem if it was combined with another factor such as the seed packets having condensation in them and the seeds getting damp. This would be unlikely with the range of temperatures experienced by the seeds on their journey to space and back. The root meristem is vulnerable and damage to the roots may have been responsible for the poorer survival of the seeds which had been in space.

GB: Vibrations, acceleration and very high sound levels from the take-off, landing and space flight may have an impact on the seedling growth when combined with other factors. There is some evidence that these spaceflight factors may act synergistically with radiation – that means that the effects of these things together is greater than if they were applied individually.

GL: In its dry state the seed contains a very low moisture content of approximately 10%. Seedlings and turgid leaves of green plants have approximately 90% water content. Seedlings or leaves would die if you dried them down to 10% as would your houseplant if you forgot to water it. The dry seed is in a desiccation-tolerant state which protects its molecules and cellular structures from some types of damage, but the dry stage is prone to mechanical impact. Mechanical vibration experiments with dry seeds have shown that this can lead to increased germination speed as well as to mechanical damage by breakage. The forces experienced during this journey into space may indeed have a small impact on the seed quality.

St Mary's & St Patrick's Catholic Primary School, Bridgend



The Temperature (and Humidity) Factor



What our young space biologists said:

"The lower temperature on the journey to space affected their ability to grow."

Coleg Cymunedol Y Dderwen, Bridgend

"The temperatures that the seeds were exposed to may have damaged some of the seeds."

Dinglewell Junior School, Gloucester

"Some said they thought the space ones wouldn't grow as well as they would have got really cold in space."

West Jesmond Primary School, Newcastle-upon-Tyne

"We thought perhaps the seeds lost weight or moisture on their journey."

Bredon Hill Middle School, Worcestershire

What our experts say:

JH: It is difficult to say what different temperatures the seeds may have been exposed to during their journey to the ISS and back, and of course this includes overland travel from the UK via the Netherlands to Baikonur for the launch. They would have been kept at 22-23°C on the ISS (ambient temperature) but on landing the Soyuz would have experienced a 'heat soak' from the 'heat charge' it experiences during its return flight to Earth. This can raise cabin temperatures to 30°C. These temperatures are higher than the temperature at which the Earth seeds were stored which was 12°C.

FG: We know that seeds become damaged during storage and transport by high humidity and high temperatures. As a consequence, Tozer have invested in temperature and humidity controlled storage to keep seeds in ideal conditions. The rocket seeds were dried and sent to the ISS in hermetically sealed packs which would have protected them from changes in humidity. The temperature changes endured as the capsule re-enters the earth's atmosphere may have contributed to the ageing found in the blue seeds but rocket is a Mediterranean plant that is native to Italy. In the wild, a seed will be exposed to really hot and dry spells as well as to cold and wet periods before it germinates.

GB: It is essential in any experiment to keep all the conditions during the experiment the same apart from the parameter being measured – this is called a controlled experiment. So for example any differences in the storage conditions between the flown seeds and the ground controls might affect the results.

GL: In general, there are three major threats which cause the seed aging: high humidity, high temperature, and oxygen from the air. This is very important for seed storage at Genebanks and also in the seed industry. The hermetically sealed packaging of the dry rocket seeds did not allow any uptake of moisture or oxygen from the ambient environment. Temperature therefore remains as a potentially damaging factor. The experienced temperatures are however not really in the damaging range and it is therefore unlikely that fluctuations in ambient temperature are the major cause for the decreased germination speed.



St Peter's Primary School, London

The Gas Factor



What our young space biologists said:

“The blue packet was impacted by the lack of oxygen and gravity in space. The time spent in space in its packet was too long, and affected its growth.”

Sunnyhill Primary School, London

“The children thought that the seeds were damaged due to the atmosphere and lack of oxygen in space.”

Hursthead Junior School, Cheshire

“The seeds were starved of oxygen and deprived of nutrients.”

**St. Peter’s CE Voluntary Aided Primary School,
South Weald**

What our experts say:

JH: One of the key things to solve as we move towards longer term missions is the need to create life support systems where plants can help provide clean air (oxygen) and water as well as a source of food for the crew. European scientists have been investigating the use of a blue-green algae spirulina as part of a bio-regenerative system called MELiSSA. Spirulina’s rate of photosynthesis is very efficient, and good amounts of oxygen can be produced to help plants in an attached plant growth chamber to grow. There will be other elements of waste re-cycling within the system, but for now ESA would like to test whether these elements can be made to work efficiently in microgravity conditions.

FG: In a seed, all biological processes have slowed right down. The seed is still respiring, but not very much. The requirement for oxygen is minimal and whilst reduced oxygen is known to contribute to ageing, the available oxygen within the pack should have been sufficient for dry seeds. Seeds can lie dormant in seed banks for decades. Therefore, lack of oxygen is unlikely to have affected the seed. As soon as conditions change (with the addition of warmth and water) the seed will germinate.

GB: One important difference between the conditions on Earth and in ISS is that on Earth the air is always moving. It moves because of convection – warm, lighter air rises above cold, denser air. It’s this that causes our changing weather conditions. On board the ISS there are extremely low levels of gravity and convection - the air is still, unless it is moved around by fans. If the air is still, then the gases that diffuse in and out of plants and animals (oxygen, carbon dioxide) will do so more slowly as their concentrations are depleted, or build up, as a result of the lack of air movement. The seeds on ISS were packed tightly in sealed packs with little air space between them, and as they were dormant they would have been respiring very slowly, and are unlikely to have been affected by a lack of oxygen.

GL: The dry seed state is also termed the “quiescent state” because the seeds’ metabolism is at a very low level simply due to the lack of free water available for enzymatic reactions. However, dry seeds “consume” a very low amount of oxygen from the air. This oxygen is involved in chemical reactions during dry seed storage which are initially a cause of after-ripening to increase germination speed. During prolonged storage, the oxygen causes damage, seed aging and can eventually lead to a loss in seed viability. In the school experiments water uptake by imbibition activates the seed metabolism, biochemical mechanisms may repair the damage, and eventually the seed will successfully complete germination and establish as a seedling.

The Curiosity Factor!



As well as receiving hundreds of scientific predictions as to why there were differences in the seeds, we also received some fantastically creative explanations!

What our young space biologists said:

“Our older children thought that the seeds would not grow as well because they would be ‘floating instead of growing’.”
Bright Beginnings Childcare Centre, Leeds

“One 7 year old girl wondered if the seeds had lived longer on Earth or in space? She thought this might make a difference - how long ago were the seeds harvested from the parent plant before their trip to space? Interesting idea...”
St Ita’s Primary School, Belfast

“The seeds were influenced by aliens!”
Barming Primary School, Kent

“The seeds got travel sick and wanted to come home!”
Lingfield Nursery School, Surrey

“Maybe they got used to space and didn’t know what to do when they got back.”
Priestlands School, Hampshire

What our experts say:

GB: Well, what imagination! These are some interesting ideas, and all you need to do to test them out is to run a controlled experiment – make sure that your tested plants are compared to controls that are exactly the same, apart from the thing that you’re asking questions about. Maybe seeds do get travel sick if they are bombarded by radiation and loud sounds and deprived of gravity. I think I would!

For young people who have enjoyed the Rocket Science project and are interested in following this career path, here is Greg’s advice: Get a good basic knowledge of science or engineering; be open to the ideas of specialists in other subjects. Be flexible and move between different subject areas. Many of the important developments in research and industry happen in the areas between disciplines. I needed the skills of engineers to help design the equipment for my seeds to grow in Space. Think about studying in another country; You will never regret the opportunities that arise from these contacts with people of different backgrounds.

Galactic Gardening for Health and Happiness

Now we have taken the first steps to knowing that astronauts do have the potential to grow their own food on long missions, we must work to help them become self-sufficient gardeners of the future. Fresh crops can provide a much healthier diet than pre-packaged space food and the act of growing plants can have an incredibly positive effect on an astronaut's happiness.

Green fingered astronauts

In the future, astronauts on long term missions will need to have the skills and knowledge to grow their own crops to supplement their basic food rations. Over time they may tire of pre-packaged food and crave the taste and vitamins provided by healthy, fresh fruit and vegetables.

Unlike on Earth where gardeners can let the rain take care of the watering, astronauts will be completely responsible for the survival of their plants. They will need to become knowledgeable gardeners in order to understand the needs of their crops, just like Russian cosmonaut Vladimir Kovalyonok who, in the 1970's, carefully nurtured an onion plant he was growing in space, removing the first signs of rot (disease) when it appeared on the leaves.

Physiological changes to the human nose in space make it difficult for space farers to taste and smell their food. In 2016 the Japanese Space Agency undertook an experiment on board the ISS to test the growth and taste of herbs in space. Three years of eating the same boring food means that space gardeners will be keen to grow fresh food and savour those tastes that remind them of home.

Plants make you happy - even in space!

Long missions to far away destinations such as Mars will result in astronauts being confined to their spacecraft for three years or more. Stress, depression and falling out with others could spell disaster for a spacecraft which is reliant on the co-operation of its crew, so a variety of hobbies on board can help to relax the mind and body.

According to The King's Fund Report (2016) (1), there are positive links between health and gardening and over half the adult population of England is involved in gardening as a recreational activity. People enjoy the experience gardening provides, watching seeds grow into plants, getting lost in the activity of tending plants and focusing their attention away from everyday chores (2). The colour green is also said to have a restorative effect for people in stressful conditions. For astronauts, gardening could provide an opportunity for mindfulness, spirituality and time away from other people.

Astronauts are surrounded by technical equipment with no sense of day and night and can suffer from 'long eye syndrome' where they gaze back at Earth for long periods of time, thinking of their loved ones and all that they are missing. Researchers who have interviewed returning astronauts found that plant experiments in space provide an important link back to Earth and are a useful tool in the psychological wellbeing and happiness of astronauts (3).

(1) Buck, D 2016, *Gardens and health: Implications for policy and practice*, The King's Fund, London.

(2) Kaplan, R and Kaplan, S 1989 cited in Sempik, J; Aldrige, J & Becker, S 2003 *Social and therapeutic horticulture: Evidence and messages from research*, Thrive, Reading.

(3) Häuplik- Mausberger, S et al. 2014, Greenhouses and their humanizing synergies. *Acta Astronautica*, 138-150.



Why is Citizen Science important?

Q&A with Dr Alistair Griffiths, RHS Director of Science and Collections

Rocket Science was the first young citizen science project organised by the RHS. How well do you think it contributed to the fulfilment of the RHS Science Strategy?

This project addressed Theme 4 of the RHS Science Strategy: Plant Science for all. People, Plants, Planet. We received high quality data and it is reassuring to know that we have such great talent in our schools. I hope Rocket Science inspires this talent to become our future generation of plant and horticultural scientists as these scientists are critically important in finding solutions to our current and future global challenges.



Could Rocket Science be the inspiration for a wider programme of RHS-led citizen science for all age groups?

Rocket Science is the first step in engaging and involving more people of all ages to help our 50 scientists collect data and undertake mass experimentation on real life scientific experiments in both classrooms and gardens. Young people can get involved now and help the RHS Science team with pest surveillance by looking for and reporting the pests that we are looking for in your garden or school (see <https://www.rhs.org.uk/science/plant-health-in-gardens/entomology>)

What should the RHS Campaign for School Gardening's next young citizen science project be?

The RHS Greening Grey Britain report highlights that our green spaces and in particular many front gardens are disappearing by being paved over. Therefore we need everyone's help to reverse this trend. I would ask all school children and teachers to make a promise to green up a piece of grey in their school or at home and to encourage their friends and family to do the same (see [rhs.org.uk/science/gardening-in-a-changing-world/greening-grey-britain](https://www.rhs.org.uk/science/gardening-in-a-changing-world/greening-grey-britain)).

A continuation of Greening Grey Britain as a project is essential for our health and for the health of our environment.

Can you foresee a day when the RHS Science Strategy will need to take into account horticulture not only on Earth, but also in space?

I guess we already have with this experiment. Our scientific research provides evidence to answer over 95,000 gardening questions from our members each year. We also provide free advice profiles and information on plants and gardening on our website. This information is used by over 17 million people. Who knows, perhaps one day we might be responding to questions from people gardening on Mars, now that really would be a long distance call!



Many secondary school students enjoyed participating in Rocket Science. What advice would you give to them now?

Remain open minded:

Always strive to have a mind that is opened by discovery and wonder rather than one that is closed.

Develop a collaborative approach in both life and work:

It's critical that scientists work with social scientists, psychologists, engineers, economists and other disciplines to find collective solutions to the current and future global challenges ahead of us.

Get involved and take part:

Get involved in growing plants, visit your nearest RHS Garden, either as a school or youth group or with your family and friends. Invite plant STEM ambassadors to your school, join science clubs, find out about Science and Plants for Schools (SAPS) and the Gatsby Plant Science Summer School, go to science museums, summer schools, lectures and festivals.

Never stop learning:

Never stop learning about people and the natural world around you and whenever you get an opportunity to learn something new grab it with both hands, even if the opportunity seems scary!





Thank you...



Thank you to Tim

From the RHS and on behalf of all 600,000 of our space biologists, we would like to say a huge thank you to Tim Peake for supporting our project and looking after our seeds on the ISS! This project has given so many young minds the chance to explore and investigate the world of plants and science and think freely about the possibilities of future food production in space. We want to thank you for being an ambassador for STEM subjects and for inspiring young people to take one giant leap towards a career full of exciting opportunities in science and technology, as well as horticulture.

So from all of us, THANK YOU!

Thank you to the UK Space Agency

A very special thank you to everyone at the UK Space Agency who made this project possible. With your help we have been able to inspire hundreds of thousands of young people to think scientifically and help put horticulture and space on the map! Thank you for all of your support, we look forward to seeing where our next journey takes us.

Thank you to our collaborators

A huge thank you to the European Space Agency (ESA) for working with us so closely and helping us bring Rocket Science to life. Thank you also to Airbus Defence & Space, Biomathematics & Statistics Scotland (BioSS), European Space Education Resource Office (ESERO), Ginger Horticulture, Greg Briarty, Growing Promotions, Madestein UK Ltd, Material_Works, Maybarn Consultancy, PhytoLux, Royal Holloway University of London, Science and Plants for Schools (SAPS), Science & Advice for Scottish Agriculture (SASA), Tozer Seeds, University of Surrey Department of Environmental Psychology.

Without you this project could not have been possible!

Thank you from Tim

I want to say a huge thank you to every single young person that took part in this project. I had great fun watching your photos and messages pour in via Twitter while I was working on board the International Space Station. It was brilliant to see you all enjoying being part of such a fascinating science experiment – and a spot of gardening too! I hope that this project and my Principia mission have inspired you to study STEM (Science, Technology, Engineering and Maths) subjects throughout your time at school or college.

There are many exciting and rewarding careers out there waiting for you. If you work hard and aim high, there is no reason why you cannot achieve your dreams.

Thank you

Tim Peake



About the project partners

About the RHS

The Royal Horticultural Society is the world's largest gardening charity, continuing to safeguard and advance the science, art and practice of horticulture, and helping gardeners develop by sharing a knowledge of plants, gardens and the environment. Find out more at rhs.org.uk

About the RHS Science Strategy

The founding purpose of the RHS was to improve the science, art and practice of horticulture, with horticulture and science firmly placed at the heart of the Society. The RHS science strategy focuses on four key themes to deliver improvements in garden and plant knowledge, plant health, human health and wellbeing and good stewardship of our gardens and garden plants:

Theme 1. A global knowledge bank for gardening and garden plants: To share knowledge and promote the conservation, cultivation and use of gardens and ornamental plants.

Theme 2. Plant health in gardens: To help safeguard against the increasing number of pests and diseases and help gardeners achieve an optimal balance between wildlife benefit and horticultural enjoyment.

Theme 3. Gardening in a changing world: To develop sustainable resource use in gardens and help better understand how plants and gardens can provide benefits for our environment and health and wellbeing.

Theme 4. Plant science for all: people, plants, planet: To ensure our accumulated expertise and research results inspires others and is made available to gardeners, industry, government, policy makers and society as a whole.

Find out more at rhs.org.uk/science/pdf/rhs-science-strategy-2015-2019

About the RHS Campaign for School Gardening

The RHS Campaign for School Gardening actively involves more than 29,000 schools and youth organisations across the UK in horticulture. Working through teachers and groups leaders, the Campaign inspires young people to engage with plants, gardening and the environment and to consider further education and careers in horticulture and science. Through gardening young people learn about healthy food and wildlife as well as important life skills such as teamwork, social skills and co-operation. Find out more at schoolgardening.rhs.org.uk

About the UK Space Agency

The UK Space Agency is responsible for all strategic decisions on the UK civil space programme and provides a clear, single voice for UK space ambitions. At the heart of UK efforts to explore and benefit from space, we are responsible for ensuring that the UK retains and grows a strategic capability in space-based systems, technologies, science and applications. We lead the UK's civil space programme in order to win sustainable economic growth, secure new scientific knowledge and provide benefit to all citizens. Find out more at gov.uk/ukspaceagency

About the European Space Agency

The European Space Agency (ESA) provides Europe's gateway to space. ESA is an intergovernmental organisation developing and launching satellites for Earth observation, navigation, telecommunications and astronomy, and sending probes to the far reaches of the Solar System and cooperating in the human exploration of space.

Find out more at esa.int



