Joining Astronauts in Space

Teaching Materials and Hands-On Experiments

for children aged 9 to 12

DLR_School_Info
Raumfahrt

In cooperation with

DPG
JUGEND FORSCHT

Published by

DLR
Klett MINT

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Note:
In the interests of easier readability, the female form is not always explicitly mentioned in this issue. However, it goes without saying that it always refers to female and male persons: scientists, astronauts, pilots, etc. We ask for your understanding for this procedure.

2. Edition 2018

Published by the German Aerospace Centre (DLR) and Klett MINT GmbH
in cooperation with the German Physical Society and the Jugend forscht Foundation.

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Disclaimer
The hands-on experiments described in this brochure have been developed carefully. However, they may be dangerous even when performed and handled properly. The experiments proposed here are intended exclusively for use in school lessons. Their execution should in any case be supervised by a teacher. The guidelines for safety in school teaching must be observed. The editors cannot guarantee the accuracy, completeness and practicality of the experiments described here. The editors do not accept any liability for any damage that may occur during the execution of the experiments proposed here. The editors do not warrant or assume any responsibility for the accuracy of the contents of third-party websites mentioned here.

Welcome

Natural sciences and technology offer young people many possibilities for their future live. This is in addition to the exciting career prospects that are opening up here: By asking questions, looking for answers, discovering and exploring new things, we are broadening the horizon of our thinking and knowledge. All of this enriches our lives in a wonderful way.

Children, with their curiosity and thirst for knowledge, already have the most important qualities that are essential for research. This enthusiasm also gripped me when I was a child. And it lasts to this day. With this in mind, I wish this booklet many young readers–and many teachers who will pass on the fascination of research to their students.

Alexander Gerst
ESA-Astronaut

Small photo: Alexander Gerst with a copy of this booklet

Large photo: View into the interior of the time capsule which will orbit the earth together with Alexander Gerst. It contains, among other things, the wishes of thousands of pupils for the future (stored on a data carrier) and will only be reopened 50 years after their return to Earth. Here you can see on the inside of the small aluminium sphere the signature of Alexander Gerst, written with a UV pen and therefore only visible when exposed to special light.

Preface

Space travel is particularly suitable for promoting the interest of children and young people in scientific topics and subjects. This is all the more true when astronauts, and not "inanimate" satellites, fly to space.

How strongly can you feel the acceleration during take-off? How does it feel to float weightlessly through the space station? How do astronauts sleep there? What do they eat? And of course: What does the Earth look like from space?

Again and again these and many other questions are asked when it comes to the experiences of space travellers. Young people, in particular, want to understand all of this, to comprehend it in their thoughts, and most of all to experience it.

This booklet makes it possible–almost, at least. It lets the pupils themselves become "astronauts" and slip into this role. In addition, it contains numerous suggestions for tasks, exercises and hands-on experiments, which–modelled on a "real" space mission–are arranged in such a way that all the important stages of a flight into space, from take-off to landing, are dealt with.

In addition to the technology that makes the journey into space possible at all, the topic of weightlessness plays a central role in this booklet. It has an impact on almost all everyday processes and allows scientific investigations that are not possible on Earth–and in very different disciplines: First of all, this concerns physics, but also biological questions, processes in the human body and many other fields of research. This way, pupils get to know technical and scientific topics that are related to the corresponding school subjects. At the same time, they apply the appropriate methods by constructing and experimenting, measuring and calculating themselves. And they also understand that space travel is not only fascinating, but above all has a multitude of applications that benefit us on Earth.

Alexander Gerst views Earth from the *ISS*.
The way he passes on his impressions on the internet enables him to inspire young people in particular.
Picture: NASA/ESA

Enormous public interest: Alexander Gerst at a lecture.
Picture: Stadt Stralsund/Ch. Rödell

Four partner institutions have contributed to this issue: the German Aerospace Centre (DLR), the German Physical Society (DPG), the Stiftung Jugend forscht e. V. and Klett MINT. The reason for this special edition of DLR_School_Info was the second mission by German ESA astronaut Alexander Gerst. Four years after his first flight to the International Space Station, he was on board the *ISS* again in 2018 to carry out a large number of experiments.

As before, his mission has been very well received by the public, especially children and young adults. It would be a good idea to make this event, and thus also the scientific and technical aspects, the subject of the lessons in a simplified form appropriate to the age group. You as a teacher can use this opportunity to inspire your students with the fascinating world of research and take them on an exciting journey into space.

10, 9, 8 … the countdown has started!

Prof. Dr. Anke Kaysser-Pyzalla,
Chair of the Executive Board of the German Aerospace Center (DLR)

Dr. Sven Baszio, Managing Director of the Youth Research Foundation e. V.

Dr. Lutz Schröter,
President of the German Physical Society

Dr. Benny Pock,
Director Klett MINT

Space exploration–an overview

An American space shuttle in orbit. These space shuttles have transported many elements of the *ISS* into space. Image: NASA

To get you started, we have compiled some basic information on space travel and on the subject of "Research in weightlessness". Additional background information can be found in the individual chapters–always followed by suggestions for exciting hands-on experiments, to which in some cases student worksheets are attached as templates (a PDF of the entire booklet is available for you at www.DLR.de/next under the heading "School" and at www.dpg-physik.de). If some of the experiments are aimed more at younger children in the 3rd and 4th grades or if others are only suitable for slightly older pupils from the 5th grade onwards, we have noted this. The entire booklet, including all exercises were developed with the intense cooperation of scientists and educational specialists. They were also tested extensively in the DLR student laboratories (the so-called DLR_School_Labs), in individual DPG projects as well as by teachers. We have taken particular care to ensure that the tests can be carried out with easily available "on-board equipment". The required materials are listed for each experiment.

In all of this, we follow an interdisciplinary approach. Firstly, because it is typical of space travel, which serves a wide range of disciplines: from geosciences to astrophysics, from human medicine to material sciences. On the other hand, however, we also want to accommodate as many children as possible according to their interests and talents. Thus, although MINT topics are clearly the focus of attention, there is also room for sports and artistic and creative exercises. And finally, there are also "learning goals" that you might not think of when you first think of space travel. This applies, for example, to a healthy lifestyle: astronauts eat a conscious diet and keep themselves physically fit, which can serve as a model for many children. The tasks also highlight another aspect that is important to us: space travel is teamwork, often international cooperation. This means respect, consideration and tolerance–for a crew in space as well as for each other in school.

A brief history of space travel

Space travel began in 1957 with the launch of the first satellite, called *Sputnik*, by the former Soviet Union. To date, a multitude of other satellites and probes have been launched to observe the Earth, provide data on climate and weather, transmit television programs and supply modern navigation systems –or explore distant celestial bodies far away from Earth. On 12 April 1961, Yuri Gagarin was the first human being to fly into space. Later, the Americans Alan Shepard and then John Glenn followed his example. The following years were marked by the "race to the moon". On July 20 1969, humans landed on our natural satellite for the first time: the Americans Neil Armstrong and Buzz Aldrin. By 1972, a total of twelve people had set foot on the moon as part of the *Apollo* program. They brought several hundred kilograms of lunar rock to Earth, the analysis of which provided many insights into the history of the Moon's formation, but also into the cosmic past of the Earth and the entire solar system.

Earth–as seen from the orbit around the moon. The picture was taken during the last manned mission, Apollo 17. Image: NASA

Afterwards, manned space travel concentrated on the Earth's orbit. The first space stations–they were called *Salyut*, *Skylab* and *Mir*–were used for research in weightlessness. They circled the Earth for months and even years, with changing crews on board. Finally, the US space agency NASA developed the *Space Shuttle*, a reusable spacecraft. Among other things, it was used to piggyback the *Spacelab* research laboratory developed in Europe into space and back to Earth. Many elements that make up today's International Space Station *ISS* were also brought into orbit by *Shuttle* flights.

The first shuttle launch took place on April 12, 1981. Image: NASA

The International Space Station

The International Space Station *ISS*. The picture was taken in 2009 from a *Space Shuttle*. Image: NASA

The construction of the *ISS* began in 1998. The USA, Russia, Europe, Canada and Japan are involved in this largest space project ever realized in peaceful international cooperation. The station orbits the Earth at an altitude of around 400 kilometres. It travels at approximately 27,500 kilometres per hour and takes about 90 minutes to orbit the Earth.

Together with its solar modules, the *ISS* is as large as a football field: about 80 by 100 metres. Its mass is just under 500 tonnes, and its interior is the equivalent of the volume of two passenger aircraft.

There are usually six crew members on board. In a fixed rhythm, three astronauts return to Earth after six months, only to be replaced by three new crew members a few weeks later. About a quarter of a year later the three older crew members are also replaced.

Since the end of the *Shuttle* programme in 2011, Russian *Soyuz* spacecraft launching from the Baikonur spaceport in Kazakhstan have been the only way for astronauts to reach the ISS. The spacecraft are launched into orbit by *Soyuz* rockets and then approach the station on their own power, where they remain docked until they return. The return also takes place in the *Soyuz* spacecraft–more precisely in the landing module, in which the crew is protected from the hot temperatures during the entrance into the atmosphere by a heat shield and which finally lands softly by parachute.

Research in weightlessness

Weightlessness exists on the *ISS*. Not only children and young people, but also adults often mistakenly assume that this has something to do with the distance from Earth. In reality, however, the gravitational force of our planet is still almost completely effective at an altitude of 400 kilometres (the Earth even attracts the Moon, which is about 400,000 kilometres away). Rather, it is permanent free fall which results weightlessness: The *ISS* "falls" around the Earth without propulsion–and the astronauts inside the station fall and float along with it. Weightlessness (experts speak of "microgravity", which we explain in more detail at the appropriate point) offers several scientific disciplines unique opportunities for very informative research. You can read some examples of this in the following paragraphs.

When metal is heated to produce a liquid melt, many processes take place during cooling and solidification, which ultimately influence the quality of the material. On Earth, however, these physical effects are superimposed by the dominant force of gravity, so that they can only be analysed to a limited extent. In weightlessness, on the other hand, they can be examined "flawlessly" and, with this knowledge, industrial production on Earth can then be optimized, which is important for many metalworking industries. Other experiments concern the mixing behaviour of liquids or crystal growth. So as not to be misunderstood: The experiments in weightlessness are not intended to mass-produce new materials on the space station, but rather to provide insights into physical processes in order to then use this knowledge to optimize the corresponding processes on Earth.

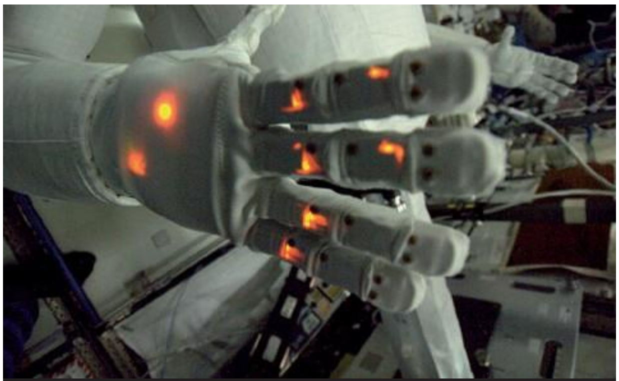
Weightlessness also has profound effects on the processes in the human organism. The astronauts develop symptoms that correspond to earthly disease patterns: Bones break down calcium, muscle mass decreases due to lack of use, the immune system is weakened and astronauts develop an electrolyte imbalance. In addition, bodily fluids shift to the upper part of the body–because gravity no longer pulls them towards the ground–which leads to further complaints: from increased intraocular pressure to circulatory problems. Balance problems and disorientation can also occur in a world without "up" and "down". After returning to Earth, all these symptoms recede again. Since only very healthy people are allowed to fly into space, and since their medical data is collected during the entire preparation for the flight (and of course also during the mission and after landing), physicians have the opportunity to follow the development of disease patterns and "recovery" under laboratory conditions. Their findings are also of interest and importance for terrestrial medicine.

How do plant roots "know" which direction to grow in? How do cells perceive gravity? And how sensitive are their "sensors"? These are only a few questions of gravitational biology. In addition to basic research, the question of whether, some day, a crew on a flight to Mars that lasts many months will be able to grow various crops without them withering is also of interest.

Besides research in weightlessness, there are other experiments that investigate other "environmental conditions" of space. For example, a large detector mounted on the outside of the *ISS* searches for antimatter particles. This experiment is thus concerned with fundamental questions about the origin and nature of the universe. Radiobiological experiments are investigating whether bacterial cultures survive cosmic radiation. The results could also provide clues as to whether comets once imported the "building blocks" of life to Earth. Finally, robotic experiments are used to relieve the strain on humans during future space flights, especially when working on risky outboard missions. The know-how required for the extremely complicated control of a space robot is also used in terrestrial robotics: for defusing bombs, for deep-sea robots to search for wrecks or even in microsurgery.

Alexander Gerst installs a system for materials research. Image: NASA/ESA

A plant in zero gravity. Image: NASA



The "hand" of a space robot being tested on the ISS. Image: NASA/ESA

With this short history of space travel, we have arrived in the present and are ready to begin!

1. Preparation, Launch and Flight to the *ISS*

The Baikonur Cosmodrome (Kazakhstan). This is where the astronauts heading to the *ISS* launch from. Picture: NASA/Bill Ingalls

Survival training is a part of astronaut training, too. Should the crew land far from the target recovery area, they may have to fend for themselves several days. This is trained long before launch. Here, Alexander Gerst lights a flare to alert rescue teams to his presence.
Picture: Gagarin Cosmonaut Training Centre

Projects in space flight begin at launch. Actually, that is not true. They begin years before, with meticulous planning, training of the crew, and with the selection of scientific experiments. In this chapter, you will find some small exercises that are dedicated to the preparations for a trip into space. They will be followed by experiments concerning the actual lift-off and ascent into orbit.

Strictly speaking, all of this is preceded by the selection of suitable candidates for space flight. Since children often ask how to become an astronaut, here are some notes on this in advance: First and foremost, scientists or also pilots are selected. Often, they are physicists or graduates of a different natural science course. German ESA astronaut Alexander Gerst, for example, is a geophysicist. Special achievements like a doctoral thesis, scientific employment abroad or participation in an expedition are beneficial. And one has to be healthy, obviously. Another important factor is the ability to work in a team.

Two who made it: Together with Alexander Gerst, Italian Samantha Cristoforetti was accepted into the European Astronaut Corps–from over 8000 applicants! Here, both of them can be seen during diving training in the Russian training centre near Moscow. Picture: ESA

Experiments and exercises

Task 1: The Astronaut Test

Astronauts have to know and be able to do a lot, and they have to learn huge amounts as well. This includes, among other things, a detailed knowledge of various spacecraft with all their technical systems. A mission into space requires knowledge not only of the International Space Station itself, but also the spacecraft the crew flies in. Of course, solid knowledge of the history of space travel and space in general is also expected. Furthermore, excellent background knowledge in the scientific fields of research is needed. An engineer or physicist has to be adept in biology and medicine, and vice versa. Language courses are an important part of training: English is obviously required and for the ISS, Russian is necessary, too. Physical fitness is another requirement for a trip to space, therefore a lot of sports and a healthy diet are mandatory. Dexterity and a talent for improvisation are important as well, in case something has to be repaired on the way.

Our first exercise is a mixture of a quiz and other tasks for younger children. For this purpose, all the students will make up the astronaut corps. They have trained for a long time, and now it is time for the exam! Give the questions and tasks on the next page to the children. Whoever wants to can give the answer or do the exercise. In the end, of course, the entire class is the “winner” and is capable of space flight!

Didactics

- The children learn the importance of versatile education and training.
- The children understand the need for a healthy lifestyle with sport and a healthy diet.

1. Who can get to the blackboard and back to the seat by hopping on just one leg?
2. A biology question: What do you call a newly-hatched frog?
   Answer: tadpole
3. Write your given name at the blackboard or on a piece of paper, and draw a large circle with your other hand at the same time!
4. What are the five senses of humans?
   Answer: vision, hearing, smell, taste, touch.
   Note: nowadays, temperature and pain are often counted among the senses, which should be neglected in this case
5. Do you know a word or expression in three different languages?
   Example: “thank you”, “merci”, “danke”
6. Which is heavier: 1 kilogram of lead or 1 kilogram of iron?
   Note: This is obviously a trick question to test the attentiveness of the children. If you were to compare two equally-sized cubes made of lead and iron, the cube made of lead would be heavier.
7. Close your eyes and extend your arms far to either side. Now, slowly bring the arms together, until the extended index fingers meet. Who can do it on the first attempt?
8. The teacher reads aloud the following combination of letters and numbers two or three times:
   L 1 O 2 O 3 H 4 C 5 S 6
   Who remembers the sequence and can recite it? Who recognizes the word written in reverse?
   Answer: SCHOOL
9. Who was the first human in space?
   Answer: Yuri Gagarin (1961)
10. Now it’s all about a healthy diet: anybody who brought fruit or vegetables for lunch break, raise your hands!
11. What are the names of Earth’s neighbouring planets?
    Answer: Venus and Mars.
    Note: The Moon is not a planet.

Task 2: Design your mission logo!

How it’s done:

Every crew that launches into space has a mission logo. It is placed on the space suits and space enthusiasts can get it as sticker or pin. The emblem can also be seen on the web pages of the large space agencies. Our task is made of two parts, first research and discussion (part A), followed by drawing (part B).

Materials:

- coloured pencils
- paper
- scissors
- if applicable white disposable coveralls as “space suits” (in that case also glue for fixing the logos)
- if applicable PC with internet connection for research

Didactics:

- The children practice a simplified form of conceptual design
- The children learn about the function of symbols
- The children learn about some space flight missions through their research

Part A: What do the symbols mean?

The students (depending on their age) read up on emblems of previous space missions, their looks and meanings. Here are two examples that can be shown to the students and discussed in class without prior research:

- **Question:** Why is there an eagle on the mission patch of Apollo 11, the first human landing on the moon?

Answer: The bald eagle is the national bird of the USA. That is why the lunar excursion module that landed on the moon with Neil Armstrong and Buzz Aldrin in July 1969 was called “Eagle”.

- **Question:** Why is “blue dot” written on the mission patch for Alexander Gerst’s first flight?

Answer: The mission was called “blue dot”. It symbolises the Earth, which is also referred to as the “blue planet”. It indicates that the scientific results of this flight serve life on Earth. The wording comes from the famous astronomer Carl Sagan: On a picture taken by space probe “Voyager 1” that had travelled far into space over the years, the Earth looked like a “pale blue dot”. Sagan warned that we should treat our precious small world carefully (which is why there are protective hands around Earth in the mission’s emblem).

Part B: Your own mission logo!

For a change, the children can draw and paint now: In teams, the children will design their own mission logo! Of course, every team should come up with a name or slogan for their mission into space. The only specification the teacher needs to make is the format, as the patch should be about the size of a saucer. Everything else is up to the children’s imagination: Perhaps they want to incorporate stars, symbolising the number of crew members, or perhaps their mission name will be a composition of the team’s names. This is followed by student presentations of their drafts to class in which they explain the meaning of their choices.

Note: To bring this to “perfection”, the finished patches can be glued to the chest or upper arm of white coveralls (used for decorating), and in these “space suits” the children can complete the other exercises in this booklet.

Alexander Gerst’s second mission is called “Horizons”. The name suggests that space travel and research always broaden our metaphorical horizon. This can also be discussed with the students, depending on their age.

Task 3: Rocket engine experiments

A Soyuz rocket on its way into space.
Picture: NASA/Joel Kowsky

The crew has finished their training, spacecraft and rocket are ready for launch. The three astronauts–that's how many people fit into a *Soyuz* spacecraft–arrive at the launch pad just over two hours before lift-off. They take an elevator up 50 meters, where they take their seats in the spacecraft, and then it is time: The rocket engines ignite and the flight into space begins!

But how and why does a rocket lift off, exactly? The answer lies in Newton's third law of motion: actio equals reactio. But do not worry: Even without Latin and complicated mathematics, younger students can grasp the fundamental physics of a rocket launch intuitively. The action-reaction law is easily comprehensible: At the lower end of the rocket, hot gases are emitted through a nozzle–and this pushes the rocket in the opposite direction. For this purpose, there are experiments on the following pages of varying degrees of difficulty–without hot gases, of course. You can either pick a version depending on the age of the students that can be built and tested in groups, or every version can be given a try.

Didactics

- The children learn fundamental physical principles intuitively–in this case mainly the principle of action and reaction.
- The children practice their mechanical skills and learn to conduct an experiment thoroughly.

Explanation

A medicine ball cures misconceptions

Rocket engines emit hot gases downwards–and this not only leads to the rocket lifting off, but may also result in misconceptions: many children believe that a rocket pushes itself off against the ground or air, and that heat is an important factor.

To counter these preconceptions, we offer the following explanations:

- Firstly, rocket engines also work in the vacuum of space, where there is nothing for exhaust fumes to push against.
- Secondly, from a physics perspective, it is not important that the gas released from the nozzle is hot: in one of the experiments proposed here, cold water streams out, which propels the rocket as well. Rather, it is important that a lot of mass is expelled as fast as possible against the direction of travel. And this is exactly what happens in a real rocket, by burning tons of propellant and ejecting the exhaust backwards.

A simple demonstration can help to clear up both misconceptions: A child sits on a skateboard or a chair with wheels, tosses a medicine ball away and, together with the skateboard or chair, is propelled in the opposite direction as a result. The medicine ball has a mass, but is without a doubt neither gas and not hot, and it is obvious that nothing and nobody is pushing themselves off against the air, either. If the medicine ball is thrown at lower speed, or a lighter tennis ball is used, the recoil is weaker. Thus, all that matters are the speed and mass of the “ejected” medium.

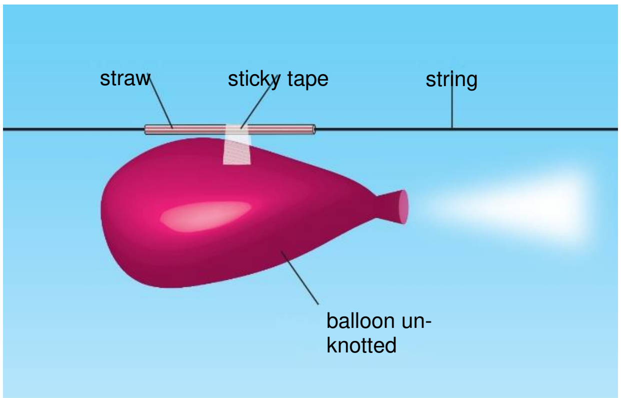
Version A:
The balloon and straw rocket

A very simple experiment for younger children.

Material:

- 1 thin string (2 metres in length)
- 1 straw
- sticky tape
- 1 balloon (of elongated form, if possible)

How it's done:



The action-reaction principle is easily demonstrated

First of all, an approx. 2 metres long piece of string is threaded through the straw, so that the straw is able to slide along the string. Next, the string is stretched as tightly as possible (between two chairs, for example). Finally, the inflated (but not knotted) balloon is fitted to the straw with sticky tape. If it is let go now, air will leak out and the balloon speeds along the string.

Version B:
The effervescent tablet rocket

Another simple experiment for younger children.

Material:

- 1 tube of effervescent tablets
- Some water

How it's done:

Empty a tube of effervescent tablets of its contents and then fill it with half a tablet and some water (it is best to test the ideal dose beforehand) and close the lid immediately. Now quickly place the tube upside down on its lid–and step back one or two meters!

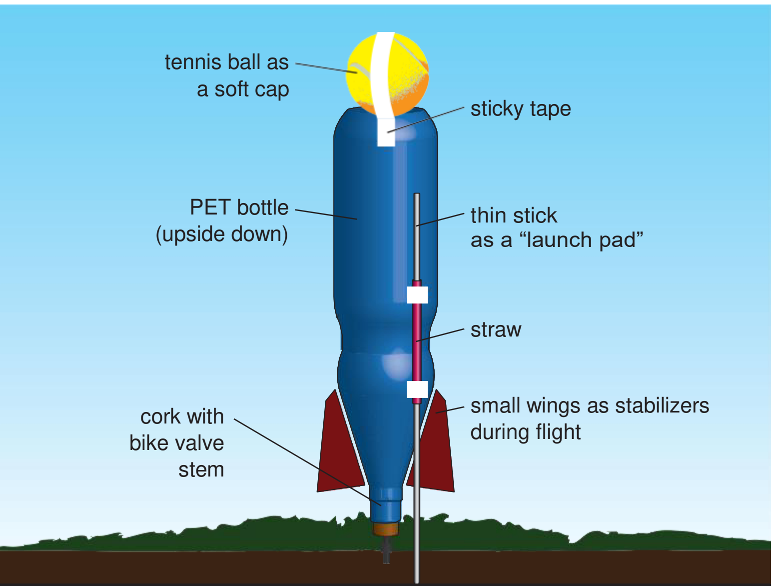
Within a few seconds the effervescent tablet will have dissolved and the bubbles generate pressure high enough for the "mini-rocket" to blast off.

Note: It is best to do this experiment outside, since the water and tablet can leave stains on the floor. You can also try out different amounts to test which "mixture" yields the highest thrust.

Version C: The water rocket

The water rocket is more challenging and better suited to students aged 11 and above.

The experiment can be carried out with younger children as well, but they will require more help during the building process and the launch should be conducted by an adult.



With the help of household items, a PET bottle can be converted into a water rocket.

Materials

- 1 PET bottle (1.5 litres)
- cardboard
- 1 tennis ball (as protective cap)
- 1 cork (plus more in reserve)
- 1 valve stem (from a bike)
- 1 bicycle pump (in order to maintain a safe distance, use a floor pump with a tube)
- tools (knife, scissors, drill)
- sticky tape, glue
- water
- 1 thin metal or wooden stick (launch pad)
- 1 straw (has to fit over launchpad stick)
- for optional variants see below
- protective goggles, if applicable

How it's done:

Launch of a water rocket. Picture: DLR

Finished water rockets are available to purchase; however, the rocket can be built with a few household materials. The principle is simple: The rocket consists primarily of a PET bottle with its opening facing the ground and the bottom end pointing upwards.

The PET bottle is fitted with three small cardboard wings that are fitted to the "lower end", near the neck of the bottle, with tape. At the "tip" of the rocket, a soft, blunt "cap" is added (e.g. a tennis ball or half a tennis ball, attached with tape and glue).

The bottle opening, pointing downwards at launch, is sealed by a cork. The teacher is required to drill hole through the cork beforehand, into which the valve is inserted (for the valve to fit into the cork, and the latter to fit into the bottle, the cork may have to be trimmed). Now all that is missing is a straw glued to the outside of the bottle: It works as a mount that is placed over the "launch pad"–a thin metal or wooden stick, firmly stuck into the ground.

Before it can launch, the rocket is "fuelled" by filling one third of the bottle with water. After that, it is brought to the launch pad. Finally, pressure is built using the bicycle pump (only use one with a tube to keep a safe distance, and use protective glasses, if possible), until the cork is pushed out the bottle and the rocket shoots into the sky.

Complete instructions with many useful tips can be found at the DLR's website for young people, DLR_next, under www.DLR.de/next/Experimente. They also include tips on building a parachute system.

(for advanced learners). By the way, the instructions were written by a team of students who made building water rockets their hobby and even set the German record for height of water rocket flights –Check out www.raketfuedrockets.com.

Arrange in advance with the students who is to bring which material. Then, during the next lesson, the rocket can be built together. **Note:** Of course, the rocket can be painted and perhaps given a name. After construction and the first test launch (e.g. on the sports ground or a large lawn), students can carry out several trials with different amounts of water and analyse their results qualitatively. What is the best ratio of water to air?

Caution: This experiment should only be conducted under the supervision and with the guidance of teaching staff. The students should be told in advance to keep several metres distance during the launch. Moreover, the rocket should be stable and pointing upwards when attached to the launch stick. Everyone present should keep track of the rocket during its flight to avoid being struck when it descends, if necessary. Use a blunt and soft "cap" as the tip of the rocket to avoid any injuries.

Whether you try one or many of these rocket variants: Finish by summarising the central aspects of the action-reaction principle. Such a debriefing is also common in space flight.

Task 4: "I packed my space bag and in it I put ..."

Thorough preparations of a space mission are indispensable. Years in advance, ground teams begin their work. Which experiments should be conducted, what equipment is already on board, what needs to be transported additionally to the station by cargo spacecraft? A game in the style of "I packed my space bag and in it I put ..." can help younger children to loosen up and train their concentration at the same time.

Of course, this is not about a complete listing of equipment and paraphernalia. Rather, we focus on the question of what humans need for survival far from Earth. Does that include adequate amounts of food, or also clothing? Helmet, space suit, gloves– got everything?

Task 5: Acceleration in an elevator

The rocket has launched, the crew is on its way into space. The rocket travels faster and faster. This phase of the flight takes just over eight minutes and at its end, the rocket reaches its required speed of 27,500 kilometres per hour. The engines are then shut off and the spacecraft enters Earth's orbit. The crew experiences quite a high acceleration from lift off to engine cut-off: The astronauts are pressed into their seats at three times their own weight.

Materials

- 1 domestic bathroom scales (**Important!** You will require "old-fashioned" mechanical scales, not digital scales)
- 1 smartphone (for filming)
- smartphone app for measuring acceleration, if applicable

How it's done:

Children can feel the impact of acceleration in an elevator, and can also measure it (depending on their age). In the easiest version, one child stands on the spring scale in an elevator and another films the display with the smartphone. Then the elevator travels upwards. At the moment the movement begins, the scale shows a visible spike in weight that may be only one or two kilogrammes above normal, depending on the elevator and weight of the child.

Note: The higher the mass of the person on the scale, the more pronounced the spike will be. Measurements using an accelerometer app on a smart-phone are more exact, if more laborious during execution and analysis. Several apps can be found on the internet, as well as instructions for school experiments about acceleration.

Task 6: Why do rockets head east?

Material

- 1 globe
- 1 pen

In this long-exposure picture of a Soyuz launch, the rocket leaves a luminous streak in the night sky. The curve shows how the rocket heads towards orbit, following the Earth's curvature. Picture: NASA/Bill Ingalls

How it's done:

All *Soyuz* rockets (and formerly space shuttles as well) launch in an easterly direction. But why? The answer is astounding: Because the Earth rotates from west to east! Therefore, the rocket uses the momentum of the Earth's rotation. It is like throwing a ball from a spinning merry-go-round. If thrown in the direction of rotation, it flies much faster than against it. Or, to put it in another way: To get the ball up to a certain speed, much less force is needed when it is thrown in the direction of rotation, as compared to it being thrown against the carousel's rotation. With regard to rockets, this means that to get the spacecraft up to a speed where it can overcome Earth's gravity and enter a stable orbit, less propellant is needed when launching in an easterly direction. This can be easily demonstrated using a globe that is spun counter-clockwise when looking from above (at the north pole). If a rocket launches from this globe, it retains the "kick" of the rotation. A pen can be used as the rocket, flown from the surface into "space" by hand.

Further notes: This also makes clear why launch sites are often as close to the equator as possible, as permitted by national territory. The Earth spins faster at the equator compared to regions to the north or south (we refer to circumferential velocity). For comparison: While a location at the equator moves at 1,670 km/h due to Earth's rotation, London only travels at about 1,040 km/h.

Older students can calculate the value for the equator themselves. How does that work? Answer: A point at the equator travels 40,000 km (circumference of the Earth) in one day or 24 hours (one rotation). 40,000 kilometres divided by 24 hours yields the speed in km/h: the already mentioned 1,670 kilometres per hour.

2. Docking: „Rendezvous“ in Space

The space station in the sights of the docking system. The picture was taken from an American *Space Shuttle*. But the Russian *Soyuz* spacecrafts also have such a system, in which the crew can follow the docking process with a periscope. Picture: NASA

The docking of a spaceship to the International Space Station is a complicated process. The *ISS* flies around the Earth at an altitude of approx. 400 kilometres. The rocket takes the spacecraft to an altitude of approx. 200 kilometres. After its separation from the burnt-out rocket, it ignites its own engines several times and gradually approaches the station until it reaches the same altitude and speed as the space station. In the past, all of this took two days for a *Soyuz* spacecraft, but today, thanks to new on-board systems, it usually takes just a few hours. Then it comes it is time for "rendezvous" in space–at 27,500 kilometres per hour! However, during the final phase of the manoeuvre, the *Soyuz* approaches the space station at only a few centimetres per second relative to the speed of the *ISS*.

When approaching and docking, the angle and speed must be matched exactly. Two different methods are used for this. First, there is a fully automatic navigation system that uses radar impulses to locate the station. Second, the *Soyuz* crew can also dock manually if, for example, the automatic system fails. The entire process is also monitored by ground personnel.

It's very tight in the *Soyuz* capsule. Here Alexander Gerst is in an identical simulator during training. Besides the "cockpit" in which the three astronauts sit shoulder to shoulder, the spaceship also has a small service room with a "mini toilet". Picture: ESA

Experiments and exercises

Task 7: We build a periscope and use it to find our way to the *ISS*

A *Soyuz* spacecraft approaching the *ISS*. On the bottom right, at the 5 o'clock position, the periscope (recognizable by its green color) protrudes from the capsule. The image of the periscope is transmitted to the crew on a monitor. The antennae of the automatic docking system are located at the top at 11 and 2 o'clock. The docking mechanism can be seen at the front at the tip. Picture: NASA

First the children build a small periscope from cardboard rolls and mirror foil. It corresponds very simply to the instruments with which the crew aboard the *Soyuz* spaceship observes the docking manoeuvre.

When constructing and assembling, it becomes intuitively clear how you can look "around the corner" with the help of two mirrors. The children then playfully recreate the docking manoeuvre using their periscope (intended more for younger children).

Note: Although the following student worksheet contains a complete construction manual, as a teacher you can still help the children by showing them the steps and supporting them with each step in small groups.

Didactics

- By constructing and building a periscope, children get to know the structure and function of a technical instrument in an exemplary way.
- Intuitively the children get to know the topic of the optical beam path.
- The children train their technical skills and practice careful handling.
- In the game, the children strengthen their ability to work together as a team.
- The children playfully experience the docking manoeuvre of a spaceship to the ISS.

In reality, the approach takes place in quite complex stages; in this game we use a simplified spiral approach.

Hint: A lot of space is needed for this playful exercise. It is therefore recommended to use the gymnasium or a classroom where all tables have been placed along the walls beforehand.

How it’s done:

1. Mark two concentric circles in the middle of the room with masking tape. The inner circle represents the Earth (about 2 metres in diameter); the outer circle symbolizes the *ISS* orbit (at least 4 metres in diameter).
   Note: The sizes are of course not true to scale.
2. Two children now assume the role of the *Soyuz* spaceship: one child sits on a swivel chair with castors with the periscope in hand, another child pushes the chair–but blindfolded. For clarification, a sign with the label "*Soyuz*" can be affixed with masking tape.
3. Two other children represent the *ISS*: One child sits on another swivel chair with castors while another child pulls the chair (possibly labelled "*ISS*" with a piece of paper) in the same direction as the Soyuz spacecraft. The seated *ISS* team member receives a torch. Since the spaceship is to dock from behind, the "*ISS* light" points to the rear.
4. The other children sit on the ground outside the *ISS* orbit and represent the ground staff in the control centre.
5. Now you're ready to go: The *ISS* slowly orbits the Earth. The *Soyuz* spacecraft starts from the Earth, and begins to chase the *ISS*. Gradually, the Soyuz spacecraft approaches the *ISS* in a spiral from the inside to the outside–controlled by the children in the "control centre", who call out instructions.
6. When the *Soyuz* spacecraft is only a semicircle away from the *ISS*, the periscope is used by the seated Soyuz child. With this it aims at the light of the *ISS* and gives commands to its crew member pushing the chair.
7. The *ISS* child stretches out arms or legs that the *Soyuz* child is supposed to grab from the spaceship. Once *ISS* and *Soyuz* are in contact, the docking manoeuvre is complete.

With the self-made periscope on the way to the International Space Station. Picture: DLR/Timm Bourry

Material

- 1 self-made periscope (see below)
- 2 swivel chairs with castors
- masking tape
- 1 thick pencil
- 1 sheet A4 paper labelled Soyuz spacecraft
- 1 sheet A4 paper labelled *ISS*
- 1 tape measure
- 1 torch
- Cloth or similar as blindfolds

Even if the children move the chairs only slowly, this exercise makes clear: the approach of a spaceship to the *ISS* is a complicated process that depends on exact speed, the right angle and precision.

Note: In order to make the exercise an exciting experience, the room should be darkened a little. This makes the game seem more realistic.

Maybe all the children in the control centre can wear headlamps and illuminate the scene mysteriously…

Build your own periscope!

A periscope is a kind of telescope with which you can see "around the corner". Every submarine has something like this: the submarine is beneath the surface of the water and a pipe sticks out of the water. The crew uses the periscope to see what is happening above the water before it surfaces.

But why do astronauts need that? Well, if they want to take their small spaceship to the big space station, they have to fly in exactly the right direction. Usually, this happens automatically. But sometimes the astronauts have to steer the spaceship themselves. The only problem is that, unlike a car or an airplane, the spaceship has no windows at the front through which you can see the space station. So how do you find the right way? That's what the periscope is for! It allows the astronauts to see the space station and know how far away it is and whether, for example, they have to fly further to the left or to the right.

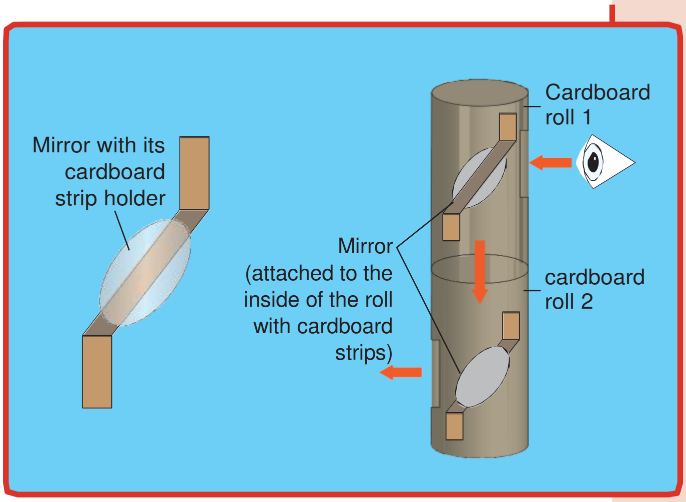
Now you can build your own periscope and "fly" to the space station in a little game.

You need:

- 2 cardboard rolls (the inside of a roll of toilet paper–of course without the paper)
- cardboard
- self-adhesive mirror foil
- scissors
- adhesive tape
- 1 pencil
- 1 pair of compasses

How it's done:

This drawing will help you to build a periscope. It shows the periscope as a whole and how to put the mirror foil on a cardboard strip.



1. The cardboard roll is about 9.5 cm high. Use the pencil to draw a line on the roll from top to bottom.

2. Now a window is cut into the roll: Cut a rectangle into the middle of the line with the following dimensions: 1.5 cm x 2 cm. Hint: The rectangle is exactly right if there is a distance of 4 cm between the top and bottom of the rectangle and the edges of the roll.

3. Repeat steps 1 and 2 for the second cardboard roll.

4. Mirrors must be inserted into the rolls.
To mount your mirrors, first cut two strips (12 cm x 2 cm) and two circles (4 cm in diameter) out of cardboard.

5. Glue a cardboard circle onto each of the two cardboard strips– exactly in the middle of the strips.

6. Fold the cardboard strips a little downwards on one side and upwards on the other side.

7. Now glue the mirror foil onto both cardboard circles.

8. Next, insert a mirror into each cardboard roll and affix the cardboard to the roll with adhesive tape at the upper and lower edges. The mirrors now "hang" at the same angle within in the two rolls.

9. Now place the two rolls exactly on top of each other, fix them with adhesive tape and do the "peek test"! If you look at one "window", you should be able to look out of the other window.

3. Welcome to the Space Station!

The International Space Station *ISS*. In the centre of the image you can see the tubular modules in which the astronauts live and work. The large solar panels that supply the station with electricity are attached to the long truss structure that extends horizontally through the photo. The bright structures protruding upwards and downwards are radiators that move excess heat from the inside of the station to the outside. Picture: NASA

The crew has arrived on the space station. Welcome aboard! In this chapter we will cover some "basics" of the ISS. First of all, this means the structure of the station. Numerous flights by American Space Shuttles (and also Russian rockets) were necessary for its construction: Each flight brought individual elements–the so-called modules and connecting nodes–into orbit. This began in November 1998 with the Russian module *Sarja*, and was followed two weeks later by the US connecting node *Unity*.

Then came *Swesda*: This is a Russian living and service module with control devices, toilets, a small kitchen and several living cabins. Over a period of about ten years, further elements were added to the station. In addition to a large truss structure on which the solar panels are mounted, these include several laboratory modules in which the astronauts can carry out scientific experiments: the US *Destiny* module, the Japanese *Kibo* module and the European *Columbus* module.

The modules are connected to each other by several "nodes". In addition, a small observatory module called *Cupola* offers astronauts a great view of the Earth; but most importantly, it provides a good view of the external robotic arm with which the crew must regularly dock unmanned spacecraft. Finally, in 2016, an experimental expandable "mini-module" called *BEAM* was berthed to the *ISS*. The aim is to investigate whether such lightweight structures could also be used on future missions to the Moon or Mars.

All in all, the station was put together bit by bit like a puzzle. A puzzle and a replica of the *ISS* are also the focus of the subsequent activities. We also suggest an exercise in which the distance of the *ISS* to Earth is represented to scale.

Exciting!

Watch the *ISS* live!

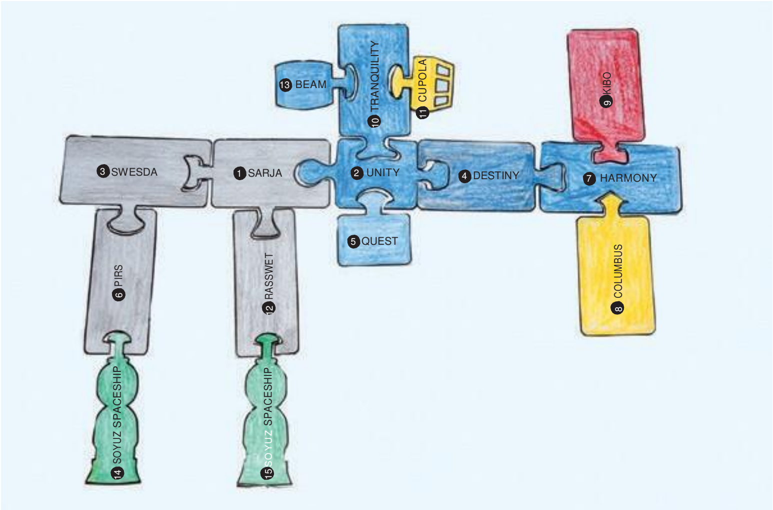
First of all, some very special information: you and your pupils can see the space station live! Whenever the *ISS* flies over a region (like Germany) in the morning or evening hours, it stands out from the dark sky–illuminated by the sun. The *ISS* moves quite quickly across the sky from west to east within a few minutes. The exact dates and times of when *ISS* is visible in your region, as well as much more information can be found at www.DLR.de/next/ISSlive, which is part of the DLR website for young people DLR_next.

This website also contains a link that leads to a livestream from aboard the ISS. There, you and the students can watch the astronauts at work or enjoy the view of the Earth: just like the astronauts themselves! Further information on various *ISS* missions and videos can also be found at DLR_next–in the category "Space travel" under "Joining Astronauts in Space" and on the special pages about Alexander Gerst. Show the children some of these videos or photos to get them started! This is guaranteed to arouse their interest and inspire their imagination for further tasks.

Experiments and exercises

Task 8: The space station: a real puzzle!

In this exercise, the children recreate the *ISS* as a puzzle, whereby we offer two puzzle versions: Version A as a small table puzzle and version B as a large floor puzzle. Both versions have in common a small challenge that we have included in the instructions: Like astronauts are equipped with gloves and helmets for spacewalks, the children are required to put on gloves and ski or swimming goggles. Of course, neither version includes all of the *ISS* modules. Nevertheless, the exercises introduce the most important elements of the *ISS* in a playful way



The *ISS* as a puzzle. As shown here in the picture, you can mark the individual modules in different colours (see notes in the text) or leave the space station as white as it is in reality.

Materials

- Photo of *ISS* (taken from this issue or the internet)
- Puzzle print-out (www.dlr.de/next/MitAstronautenInsWeltall)
- Colour pencils (with coloured version)
- Ski goggles / swimming goggles and gloves (children should bring their own)

You need the following items for version B:
- Laminating unit and 14 A3 or A4 laminating films
- coloured (or white) sheets of A3 or A4 paper

Didactics

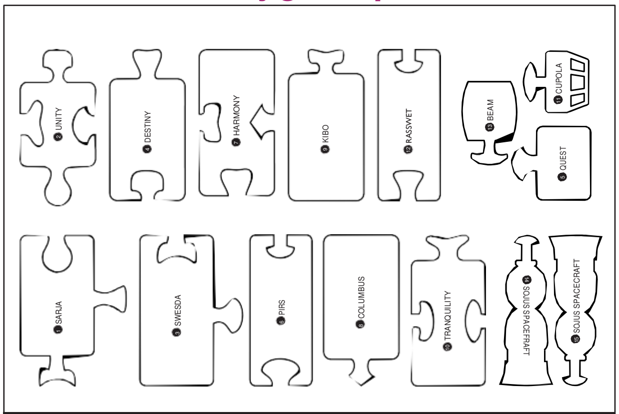
- The children get to know the basic set-up of the space station.
- The children train their ability to work in a team by putting together the puzzle and also train motor skills.

How it's done:

Just as astronauts gradually connected the *ISS* modules to each other, the space station is assembled here as a floor puzzle. Picture: DLR/Timm Bourry.

The puzzle pieces are shaped in such a way that only the right elements fit each other. In both versions, the individual modules can be given certain colours that symbolize the countries from which the respective modules originate:
For the table jigsaw puzzle this can be done by colouring in the paper, for the large floor jigsaw puzzle by using coloured sheets of paper.

Version A:
The small table jigsaw puzzle



Template for the table jigsaw puzzle (large template see www.dlr.de/next/MitAstronautenInsWeltall).

Explanation:

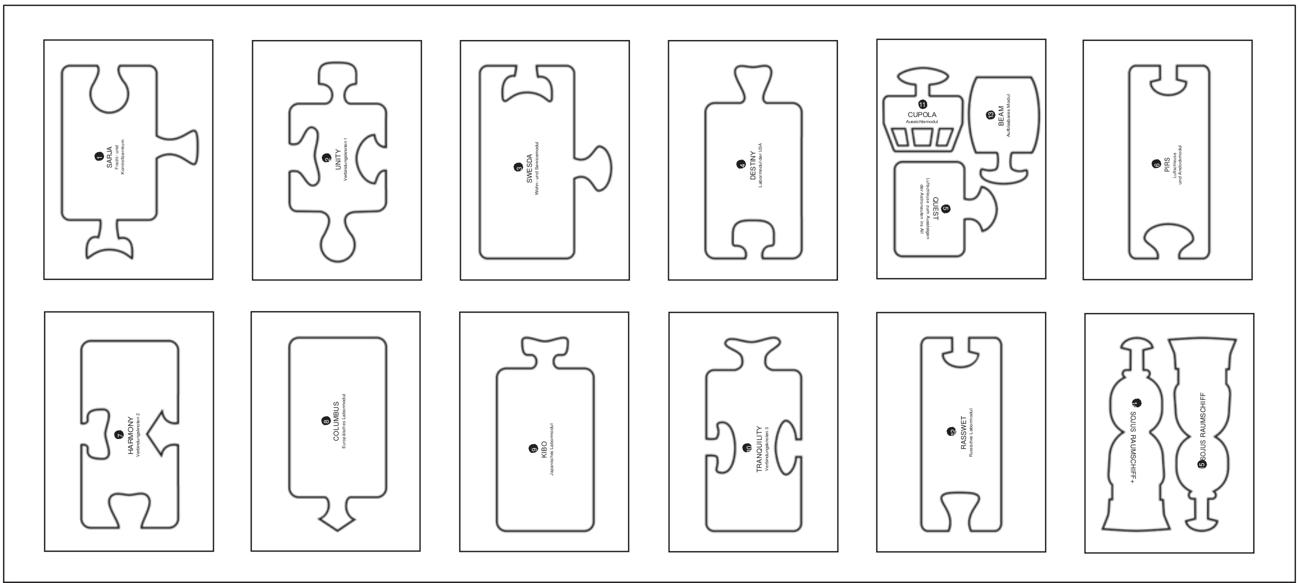
Colours of the puzzle pieces

Grey: Russian modules *Sarja*, *Swesda*, *Pirs* and *Rasswet*
Green: Russian *Soyuz*-space craft
Blue: US modules *Harmony*, *Destiny*, *Unity*, *Quest*, *Tranquility* and the expandable *BEAM* module
Red: Japanese module *Kibo*
Yellow: European *Columbus* module and the *Cupola* (located in the American part of the station, but manufactured in Europe on behalf of the USA)

Copy the specified template in sufficient quantity. The children should then cut out the pieces and colour them in with coloured pencils if necessary (write the colours for the individual segments on the board). The puzzle pieces are labelled with the name of the module and a number. The numbering of the individual pieces corresponds to the chronological structure of the ISS. The children put the small "table puzzle" with a partner or in a group.

Version B: The big floor jigsaw puzzle

Copy the parts so they are large enough to fit on an A4 or even an A3 page (either on white or coloured paper). Laminate the pages and cut out the parts (depending on the
laminator, the parts many have to be cut out first and then laminated; then the films should be trimmed again). This way, you get a large, stable and reusable "floor puzzle". The puzzle pieces contain information about the names and functions of the respective modules.



Template for the floor puzzle (large template see www.dlr.de/next/MitAstronautenInsWeltall).

Task 9: A 3D model of the *ISS* made from drainpipes

The modules of the *ISS* look like large "tubes". They are about 6 meters long and have a diameter of about 4 meters. Solar cells supply the *ISS* with electricity. Supply ships dock at the *ISS* so that the astronauts are provided with food, clothing and working materials at regular intervals.

You can build an *ISS* model with the children using simple materials available from a DIY store (approx. € 20). Pipes are pushed into each other or fastened with adhesive tape. Small "*Soyuz* spaceships" can be connected and disconnected at will.

Materials

- HT pipes (high temperature thermoplastic pipes):
- 4 times HTEA DN 50 / 50 87° and 4 times HTR DN 50 / 40 (cf. sketch)
- insulating tape in green, blue, yellow, red and white
- 4 black waterproof felt-tip pens (one per group)
- 1 blue balloon
- 2 small empty yoghurt cups
- self-adhesive Velcro tape (approx. 4 cm)
- 1 roll of transparent tape (5 cm wide)
- aluminum foil (dimensions: approx. 42 x 30 cm)
- 1 sheet A4 cardboard (e.g. the back of a writing pad)
- 2 long paper rolls (approx. 26 cm long, diameter: 4.5 cm, e.g. inside of kitchen roll)
- scissors

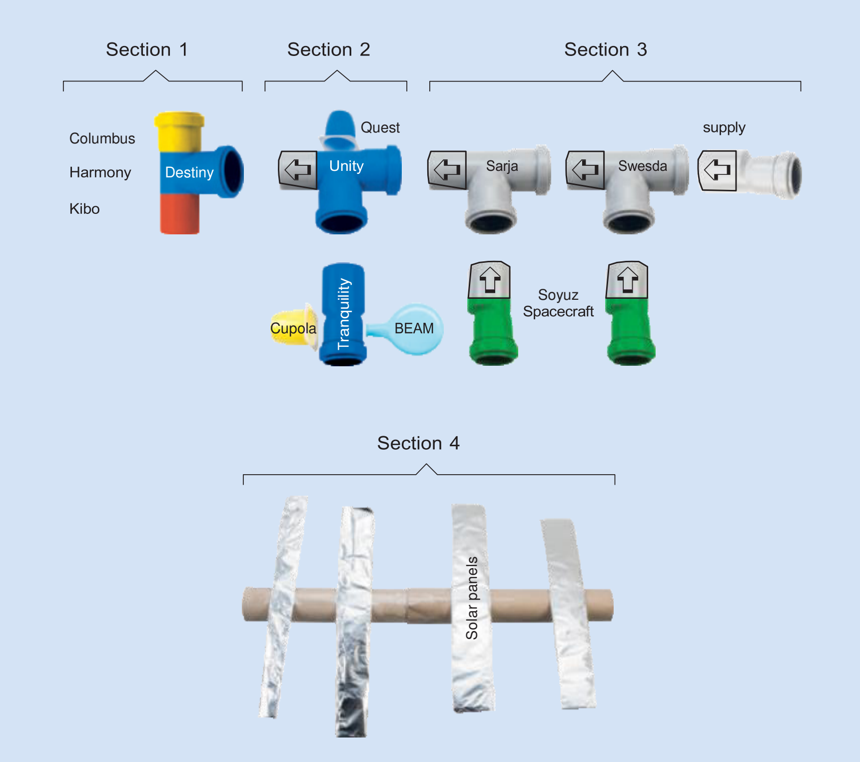
"Astronauts" and their own space station.
Picture: DLR/Timm Bourry

How it's done:

We have divided the *ISS* into four sections, each of which is built by a small group. The individual sections and the (again optional) colours of the various modules are shown in the layout sketch. If you opt for the coloured design: Each module gets its colour by wrapping coloured insulating tape around the pipes. The colours symbolize the countries from which the modules originate. The sections marked with arrows in the sketch are used to push the pipes together and should not be covered with adhesive. As soon as all parts are coloured, they are labelled with their respective names. The tubes are then pushed into each other; the yoghurt pot and the slightly inflated and knotted balloon are attached with adhesive tape to the places indicated in the sketch.

Didactics

- The children enhance their knowledge of the construction of the *ISS* by building a 3D model of the space station.
- The children train their skills in arts and crafts and practice teamwork



Sketch of the layout: Using these drainpipes and a few other ingredients, the children can assemble their own model of a space station.

The *ISS* is divided into the following sections, each of which is built by a group and then pushed together as shown in the layout sketch:

- **Section 1** contains the European module *Columbus* (yellow), the Japanese *Kibo* module (red) and the American modules *Harmony* (blue) and *Destiny* (blue).
- **Section 2** contains the American elements *Unity*, *Quest* and *Tranquility* (all blue) with the *Cupola* (yellow) and the expandable *BEAM* module (blue balloon).
- **Section 3** includes the Russian segment with the modules *Sarja* and *Swesda* (grey) as well as the two *Soyuz* spaceships (green), plus a supply ship (white).
- **Section 4** represents the truss structure–an outer grid structure to which the solar cells are attached.

The truss structure with the solar cells in made of four cardboard strips wrapped in aluminium foil (approx. 29 cm x 4 cm), which are fastened to two cardboard rolls with adhesive tape that are then inserted into each other. One half of the Velcro fastener is attached to the middle of the cardboard rolls, while its counterpart is mounted between the modules *Unity* and *Harmony*. This means that the solar cells remain mobile within the model, as is the case in reality. While the *ISS* orbits the Earth, the solar panels are permanently aligned exactly to the Sun in order to supply the space station with enough electricity. Finally, the Russian segment is rotated so that the two *Soyuz* space craft point downwards.

Task 10: The space station on the schoolyard

For your orientation: The proportional representation of the distances could look like this (depending of course on the scale you choose).

A flight into space–that always sounds like infinite distances. But the International Space Station *ISS* is not really that far away from Earth: As mentioned earlier, it orbits the Earth at an altitude of only 400 kilometres (while TV satellites orbit at an altitude of 36 000 km). Since the question often arises as to why the *ISS* does not fall to Earth from this low altitude, we will briefly take a moment to explain why: it is only thanks to its high speed of 27500 kilometres per hour that the space station does not fall to Earth like a stone, but "falls" permanently around our planet. If it were to travel more slowly or even stand still, it would be pulled downwards by gravity and fall to the ground. This is exactly what happens to a *Soyuz* spacecraft when it returns to Earth: after undocking, a short braking manoeuvre takes place, so that the spacecraft flies a little slower and its orbit height decreases automatically.

However, the following exercise is not about speed, but about the visual representation of distances–in the schoolyard.

Material

- Chalk
- Measuring tape

Didactics

- The children get an idea of distances in near Earth space (*ISS*, satellites, Moon).
- The children get to know scale representations as a form of visualization.

How it works:

A chalk drawing is created in the schoolyard: with the Earth, the ISS, satellites and the Moon. 1 meter in the sketch corresponds to 10,000 kilometres in reality. This results in:

- The Earth (approx. 12,000 km in diameter) is drawn as a circle with a diameter of 1.2 m.
- In the drawing, the *ISS* is a small dot–only 4 cm away from the Earth's surface (the edge of the circle).
- TV or weather satellites (approx. 36,000 km orbit) are drawn 3.6 m away from Earth.
- The Moon (diameter approx. 3,500 km, distance to the Earth approx. 400,000 km) is drawn as a 35 cm large circle–about 40 m away from the Earth.

Younger children should be told where to draw Earth, *ISS*, satellites and the Moon. Then the drawing can be is considered and discussed together. Older pupils should only be given the real distances and diameters as well as the scale and convert the data themselves. As an extra task, you can also have them calculate where the Sun would have to be located at this scale.

Solution: With a distance of approx. 150 million km, the Sun is roughly 400 times further away from Earth than the Moon, i.e. approx. 16 km away from the schoolyard at the chosen scale (all figures strongly rounded).

Hint: Instead of the chalk drawing on the schoolyard, it is of course possible to display all of this in an adapted scale on the board. Another alternative is the use of small balls and spheres in the classroom. With an Earth to Moon distance of only 4 m (instead of 40 m in the schoolyard drawing), the *ISS* is then only 0.4 cm away from the Earth, which can be represented by a sphere that is 12 cm in diameter (the model Moon then corresponds to a diameter of 3.5 cm).

4. Life on board the *ISS*

American astronaut Karen Nyberg's reflection in a hovering drop of water. Image: NASA

Our journey to space has just begun and it is getting ever more exciting! Life on board the space station is fundamentally defined by weightlessness, which is why, at the beginning of this chapter, we will present a series of hands-on activities that focus on its underlying physical concept.

Afterwards, we will once again slip into the role of an astronaut and will visualize several peculiarities that space travellers experience in zero gravity as well–by running experiments about dizziness as well as sampling "space jam".

One quite breath-taking experience is the view of the Earth extending beneath the space station: all astronauts enthuse about the experience! They are also quite eager to speak about how vulnerable our planet appears to them with its extremely thin atmosphere. Several short exercises on this topic are included in this chapter.

After dealing with the necessity of protecting our environment, and conserving our resources, we continue with an experiment that deals with the space station's very own recycling system. Just like on "spaceship Earth", it is crucial for astronauts living and working on the *ISS* to avoid wasting resources, albeit on a much smaller scale. The students will be able to test one of the many ways of recycling by building their own filtration system.

Good preparation is one of the most important prerequisites for a successful mission. This can be illustrated by a tricky task for which students will need only Lego bricks–and a lot of logical thinking.

The chapter will be concluded with the question of how to communicate with an astronaut from Earth. This topic can be dealt with by younger students, by constructing a simple tin can telephone, as well as by older students, who will discuss signal transit times.

4.1 The ‘crazy’ world of zero gravity

Fresh fruit is a welcome change on the menu. It is also used to show children and young people the effects of weightlessness with such photos. Image: NASA

Weightlessness has an impact on almost all aspects of everyday life: from eating and drinking to washing and sleeping. Even many of the movements that are taken for granted on Earth have to be changed in weightlessness. In addition to the information in the introduction (see pages 10 and 11), here are some examples ...

Even coffee comes out of beverage pouches. This image shows the French ESA astronaut Claudie Haigneré. Image: NASA/ESA

Food

Unlike in the early days of space travel, space food today no longer comes out of tubes. Instead, the on-board kitchen of the *ISS* offers a variety of dishes that are actually quite tasty. They are usually dehydrated after being prepared on the ground, packaged in retort pouches and sent to the space station on unmanned supply ships. Astronauts wishing to eat add warm water to the pouches, thus rehydrating the food, and voila! delicious pasta dishes or other meals are back on the menu. The table has special holders so that nothing floats away. Of course, watery sauces are not allowed: droplets could float through the station unchecked. For the same reason, drinks are only available in drinks packs with a straw. Interestingly, an astronaut’s sense of taste changes in weightlessness (see task 20 for explanations).

No "up" and "down," no "light" and "heavy."

Two astronauts are facing each other–one "normal" and one "upside down": Each of them could claim that he and not his colleague has his head "up" and his feet "down". Because this can easily lead to disorientation, the modules of the station are optically designed in such a way that they have a defined “floor” and “ceiling” (all labels are placed in a consistent direction within a module and all computers and instruments are aligned in this way). Since everything that is not affixed to something floats, every action must be carefully considered and prepared: A manual or laptop cannot be put aside for a moment, because it would simply float away. And if you want to loosen a tight screw with a screwdriver, you have to hold on to something: Otherwise you will only turn yourself and not the screw.

Claude Nicollier from Switzerland (left) and Jean-François Clervoy from France on a collaborative shuttle mission.
The picture shows: Each astronaut could claim that the other is "upside down".
Image: NASA/ESA

Sleeping

A normal bed would be quite unsuitable in weightlessness: One false move while sleeping would be enough to unintentionally move away from the mattress and float through the station. Instead, each crew member has their own cabin, where astronauts sleep in sleeping bags attached to the cabin wall. This allows at least some privacy during the several months of living together in a confined space.

In any case, getting a good supply of fresh air during sleep is important: on Earth, the carbon dioxide (CO2) we exhale sinks to the ground because this gas is heavier than normal air. As a result, new, oxygen-rich air is supplied to us almost automatically. But since there is no such thing as "light" and "heavy" in weightlessness, breathing would lead to a stable bubble of CO2 around an astronaut’s head and grow with every breath. This would have fatal consequences and lead, at the very least, to severe headaches. The on-board air conditioning system prevents this from happening.

Speaking of sleep: astronauts sometimes see "flashes" when their eyes are closed. To put it very simply, these light phenomena are triggered by tiny electrically charged particles of cosmic radiation or solar wind. They penetrate the ship's sides and occasionally trigger this reaction on the retina.

Italian ESA astronaut Samantha Cristoforetti in her small cabin with her sleeping bag on the wall.
Image: NASA/ESA

Excursion

Microgravity

At the beginning we mentioned that experts prefer to speak of "microgravity" rather than "weightlessness". Now we offer a short explanation. It is of course up to you whether you want to discuss this in class (with older students).

The term "microgravity" describes not a state of total weightlessness, but one that is as close to complete weightlessness as is possible. The reason for this is so-called residual acceleration: small disturbing factors that have a minimal but measurable effect on the “quality” of weightlessness. For example, air resistance slightly slows down a falling capsule, which influences its free fall and thus the weightlessness experienced within. Even if the air is pumped out of large drop towers, thus creating a vacuum, there are still minimal braking effects due to the few remaining air molecules. And even on the ISS, the friction of the Earth's residual atmosphere–thin as it may be at this altitude–influences the space station’s orbit: it ensures that the station is constantly slowed down ever so slightly. This is why the *ISS* loses a little height every day and occasionally has to be lifted to higher altitudes again by igniting the engines of docked supply ships.

Hands on: The paper test

To show the pupils the extent to which air resistance has a fundamental effect on free fall, you can conduct a simple experiment. Take a piece of paper and drop it on the floor. Then screw the sheet of paper into a ball, and drop it from the same height. The time difference is obvious, and it is also clear: both times the same sheet of paper fell to the ground, so its mass cannot have any effect on the duration of the fall. Rather, it is the air resistance that is crucial, and this is stronger or weaker depending on the shape of the falling object. A contrasting example would be to carry out the tests in a vacuum: then both would take the same amount of time.

The fact that the *ISS* still experiences "air resistance" even at an altitude of 400 kilometres is, of course, highly exaggerated. But at least there are still enough air particles in near-Earth space (even though many billions less per cubic centimetre than on the Earth's surface) to noticeably slow down the *ISS*.

It makes sense to talk briefly about the composition of the Earth's atmosphere. You can illustrate this on the blackboard with a graphic that shows the four layers of the atmosphere: namely, from bottom to top, the troposphere (0-15 km), stratosphere (15-50 km), mesosphere (50-80 km) and thermosphere (80-500 km). In our context, these are some interesting aspects that are worth mentioning:

- The highest mountains on Earth are over 8000 meters high. Most mountaineers that climb at this altitude require breathing apparatus because the air is so thin.
- Anyone sitting in an aeroplane at a typical cruising altitude of 10,000 meters already has more than two-thirds of the Earth's air mass beneath themselves: about 70% of the air mass is in the bottom 10 kilometres of our atmosphere.
- Weather balloons often rise to an altitude of 20 to 30 kilometres.
- Although the transition into space is fluid, it is generally considered to begin at an altitude of 100 kilometres (80 kilometres according to another definition).

The quality of weightlessness can be affected on the space station by other disturbing factors: every vibration results in an acceleration–even if only minimal–in one direction or the other. If a spaceship docks, this impulse is naturally transmitted to the entire station. If the *ISS* is lifted higher by igniting the engines of a docked supply ship, weightlessness is disturbed for the entire duration of this manoeuvre. The lifting does not result in an acceleration that is comparable to the acceleration experienced during the launch–but the principle is the same. And even an astronaut keeping fit using an exercise bicycle will cause minimal vibrations (though this effect is lessened by appropriate devices). All of this must be considered when particularly sensitive experiments such as crystal growing are on the agenda.

Hygiene

One of the most frequently asked questions by children is "How do astronauts go to the toilet?" In principle, the on-board toilet is comparable to an "earthly" toilet–with the difference that a slight vacuum ensures that no excretions whatsoever are released into the air. There are special adapters for urine depending on gender. Incidentally, it is collected and filtered and thus recycled into water (more on this in chapter 4.4).

Hygiene is of the utmost importance, as the immune system is weakened in weightlessness and astronauts therefore become particularly susceptible to infections caused by bacteria or fungal diseases. Personal hygiene is also very important, although there is no shower on board (earlier "space showers" proved to be too susceptible to technical errors). Instead, the astronauts clean themselves with wet towels. Tooth brushing is done the same way as on Earth, except that the toothpaste is spat into a cloth at the end.

Experiments and Exercises

Why is there weightlessness on the *ISS* at all? It's not because the space station is so far from Earth. It orbits our planet at an altitude of only 400 kilometres (as mentioned in the introduction and illustrated by the chalk image in the schoolyard), and even the Moon, which is a thousand times further away, is still influenced by the gravitational pull of the Earth. The reason is instead: The *ISS* is in free fall around the Earth. How do free fall and zero gravity come together? To help you understand, here are some examples that you can present to the students in a suitable context.

- **Thought experiment: the elevator**
  Imagine that you are in an elevator at the top of a high-rise building. You are standing on bathroom scales that show your weight. Suddenly the rope breaks and the elevator falls down. What do the scales show during the fall? Correct: They would read "zero". Because the ground beneath your feet is literally pulled away from you, you would no longer be able to put any weight on the scales from one second to the next. Instead, you would fall just as fast as the scales and the entire car. This is the principle of large drop towers (like in Bremen) and also the following experiments “the falling cup” and “the drop capsule”. And so, the *ISS* also falls around the Earth at breakneck speed–with the astronauts inside.

  Note: Since the idea of a falling elevator can be frightening, especially for young children, the jump from a three-meter board into a pool is an alternative thought model. With a little creativity, you have to imagine scales under your feet. On the top of the board, it shows the weight of the jumper before the jump. During the jump, the scales would read zero.

- **Roller coaster ride in the sky**
  During parabolic flights that are carried out in special aircraft, astronauts train for a stay in weightlessness. The aircraft initially climbs steeply upwards. In the exact moment that the pilot reduces the thrust, the aircraft follows a parabola practically without further propulsion: first it continues to travel upwards, then tilts forward and finally begins to fall down. During this time the occupants hover until the pilot intercepts the aircraft after about 20 seconds

Didactics

- The children develop and consolidate a basic understanding of the phenomenon of weightlessness through a series of experiments.
- The children learn about phenomena like surface tension and convection.
- With the help of the "sphere-particle model", students learn about the three states of matter, "solid", "liquid" and "gaseous".
- By carrying out an experiment, the students experience that warm air rises because it is lighter than cold air (and that hot water is lighter than cold water and floats near the surface).
- The children learn the basic procedures of science: experiment design, hypothesis building, experiment execution, evaluation/ interpretation of results.

A student floats during a parabolic flight. Image: DLR

and initiates the next rise to fly another parabola. On this "rollercoaster ride in the sky", phases of reduced gravity alternate with phases of increased gravity (in the "valley" of the flight path).

The *ISS* also follows such a parabola. The difference, however, is that here nobody has to stop the free fall and the space station does not go up and down all the time, because the station is so fast that it is in constant free fall around the Earth. Just imagine (only in theory, of course) that the pilot of the parabolic flight briefly injected thrust on the way up powerful enough to enable the plane to orbit the Earth– then you have made the mental arc from parabolic flight to the ISS.

Task 11: Galileo Galilei’s ball track

For older students you can precede the following experiments on weightlessness by an experiment dedicated to the topic of gravity (younger children might be confused by this, however, so that it is easier to enter the "world of weightlessness" directly). This references a wonderful "classic" from the history of science.

In the Museo Galileo in Florence there is an apparatus that is as simple as it is fascinating: a ball rolls down a track and touches several small bells along the way, which are placed close above the track. From the beginning to the end of the track, the distance between the bells increases, but the intervals of the acoustic signals do not change: if the ball rolls down, the intervals between the bells ringing remain the same.
Note: There is another experiment carried out by Galileo that deals with uniform acceleration, that involves weights attached to a piece of string. Feel free to choose whichever you prefer. Here, however, we concentrate on the Galilean ball track.

Material

- 1 u-profile (1 meter length)
- 1 glass marble
  (or similar ball of metal or wood)
- 1 smartphone with camera
  (or another camera)
- 1 metronome (or stopwatch app)
- self-adhesive small dot labels
- 1 measuring tape
- double-sided tape
- Stack of paper to set the track at an angle

Tipp: When buying the u-profile, take the ball with you to choose the correct size of the profile (or vice versa).

How it works:

The u-profile is placed on a table and one end raised to 2 to 3 degrees of inclination (for the recommended track length of 100 cm, one end should be placed on a stack of paper approx. 4 cm high). This gives us an inclined surface. Along the length of the track, either attach the measuring tape is with double-sided adhesive tape or transfer the centimetre scale to the track. Using a smartphone camera (which must be pointed at the lane and the scale and must not be moved) the run of a ball is filmed. The timer–a metronome–should be visible in the picture. The metronome should be set so that you can distinguish half seconds or thirds of a second (simply set to 120 or 180 beats per minute).

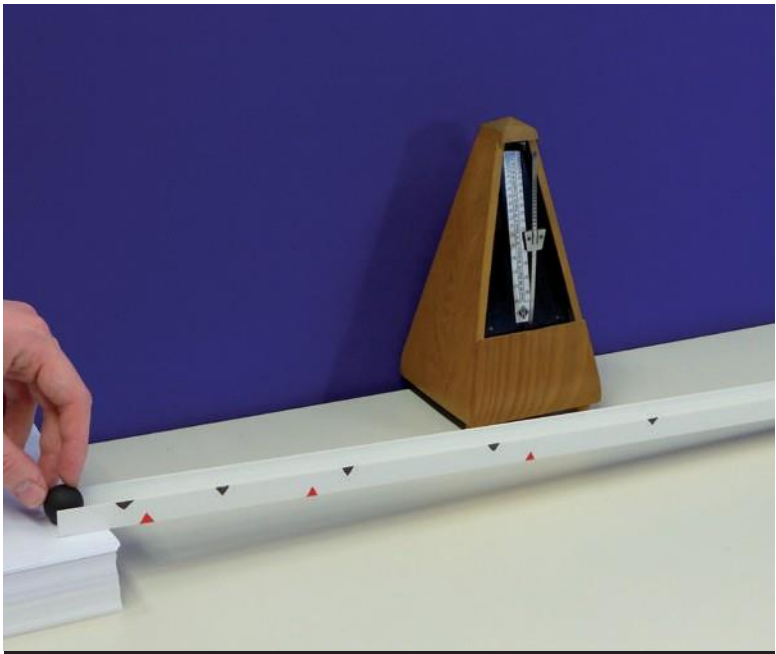
When playing back the movie frame by frame or in slow motion, it is important to determine the exact position of the ball at the turning point of the metronome and then mark its position with an adhesive dot on the track. When you consider the track with the dots, you will notice that the distances between the dots increase. This is because the longer the ball rolls, the greater the distance that is covered in the same time unit: It's getting faster and faster! This change in speed over time is called acceleration.

Half-second analyses (red markings in the photo) showed the following distances in our tests:

Time in sec.	Total distance travelled in cm	Distance travelled during the time interval in cm
0	0	0
0,5	5	5
1	15	10
1,5	30	15
2	50	20
2,5	75	25

Third second analyses (black markings) showed the following distances in our tests:

Time in sec.	Total distance travelled in cm	Distance travelled during the time interval in cm
0	0	0
0,33	3,7	3,7
0,66	9,8	6,1
1	17,3	7,5
1,33	27,2	9,9
1,66	39,2	12
2	53,2	14
2,33	69,3	16,1
2,66	87,4	18,1


Simple reconstruction of the historical marble run according to Galileo Galilei. Image: DLR

After the experiment, discuss the observations and results with the pupils. The experiment intuitively reveals the character of gravitational acceleration. The fact that the ball does not rush downwards at a constant speed, but becomes faster and faster, can be explained without using a formula as follows: The Earth's gravitational pull permanently affects the ball. That is why the ball starts rolling in the first place when you put it on the track. But if the Earth's gravity is constant and influences the ball–why does the ball not have a constant speed? The key is that however fast the ball travels on its path, the mass of the Earth continues to attract it and thus permanently increases the speed. The ball is fast, then faster, then even faster, and so on. At any given time, the ball has a certain speed on its way down and the Earth's gravitational pull always adds more to this speed. The following example can be given to the students as an analogy: Imagine the driver of a standing car steps on the accelerator and constantly pushes it all the way down. The car starts moving and gets faster and faster.

Interesting!

Weightless, but not massless!

Alexander Gerst on his spacewalk.
Image: NASA/ESA

An interesting aspect is often overlooked: In weightlessness, an astronaut can easily balance larger objects on her or his little finger, because after all, all these things do not weigh anything anymore. But of course, all objects retain their mass! If, for example, an astronaut caught a small and light screw that was slowly floating past during a spacewalk, this would be possible without any problems. The situation would be completely different if it was a satellite weighing several tonnes: Because of its mass, it could not be stopped even with all her or his muscle power.

Task 12: The falling cup

The following experiment shows that weightlessness exists in free fall. You hold a cup of water with a hole in it. The water flows naturally out of the hole. If you drop the cup, the video recording played back in slow motion or frame by frame shows: As soon as the cup falls, no more water flows through the hole. This is because it is falling at the same speed as the cup–very similar to what happens in the examples previously mentioned when the elevator falls or when someone jumps from a three-meter board. The *ISS* falls around the Earth following the same principle: with the astronauts inside.

Carrying out the small cup experiment is very simple and can therefore be left to the children. However, the explanation should be discussed together.

Note: Depending on the age of the children, the teacher should drill or cut the hole in the cup. And of course, the experiment can also be done without a camera!

The falling cup

If a cup is filled with water and has a hole, the water pours out–of course! But what happens if the cup is falling? Does the water then also pour out of the hole? Find out with the falling cup!

You need:

- 1 empty plastic cup (e.g. yoghurt carton) or paper cup
- Water (keep in a bottle)
- 1 bucket (so that the floor does not get too wet)
- 1 towel or cloth (for wiping up any spillage)
- 1 scissors

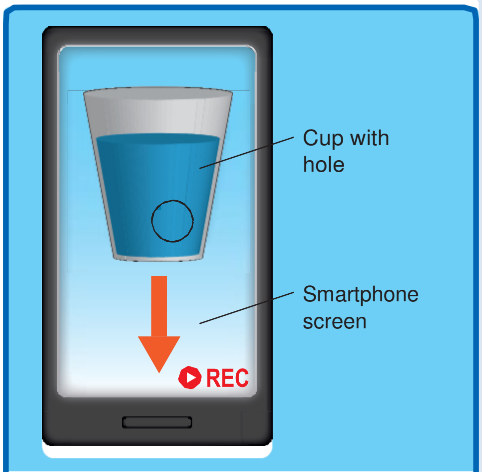
Attention: Do not carry out this experiment near electrical devices or sockets!

How it’s done:

Cut a hole into the side of the cup, near the bottom, and pour water into it. Keep the hole covered with your finger at the beginning so that the cup fills up. Now hold the cup up in the air–directly above a bucket standing on the ground (or even better outside).

As of this point, you need to film the cup, making sure that the hole below is clearly visible. The camera must not move (either use a tripod or hold still).

Tip: You should place the camera so that there is enough space beneath the cup in your frame so that you will be able to see the cup falling on screen.



This is what your camera screen should show before you start: The cup with a small hole is at the top of the frame, and then there's some space underneath.

Now remove your finger from the hole and immediately let go of the cup! What's happening? Film the cup until it falls out of frame.

Then evaluate the film. Watch it in slow motion or stop in between to look at single pictures! Discuss your observations with the teacher.

Task 13: Physics lessons in the gym

This hands-on experiment is about weightlessness and should be carried out in the gym. A trampoline is required (a small, round trampoline is also sufficient). The experiment can be done in two ways.

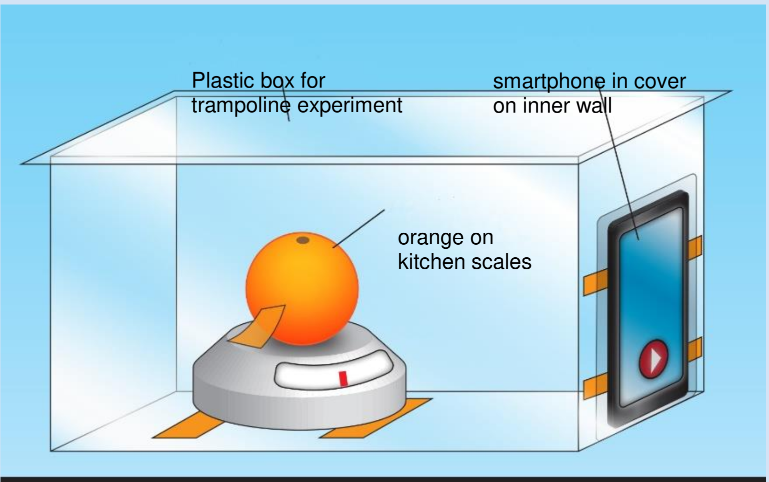
Version A: Using an acceleration app on the trampoline

Material

- 1 Trampoline
- 1 Smartphone with acceleration app

How it works:

First the children are allowed to jump around on the trampoline to get used to it. Then a smartphone which has an app for measuring acceleration is fixed to the body with a belt or similar (don't hold it in your hands, as the arm movements falsify the values when jumping). The analysis shows that acceleration drops to "zero" when the person jumping is in air. In other words: There are repeated periods of microgravity throughout the jump. In principle, you are as weightless as an astronaut! By the way: When the person jumping touches the trampoline and prepares for the next jump, the app shows increased acceleration. This is exactly the same effect that occurs during parabolic flights in the lowest points of the flight path (see page 37).



Sketch for version B: The weightless orange

Version B: The weightless orange

Material

- 1 trampoline
- 1 sturdy plastic box (preferably transparent)
- 1 orange, apple or other object with largest possible mass
- kitchen scales (analogue, not digital)
- 1 smartphone with camera function (or another small video camera)
- Velcro or double-sided adhesive tape, normal adhesive tape
- 1 pair of scissors
- 1 freezer bag or 1 transparent cover as cover for the smartphone
- 1 additional smartphone (with acceleration app)
- possibly small toy figures (simple version for younger children)

How it’s done:

Affix the kitchen scales (not digital, but a "classic" spring scale) to the base of a plastic box with Velcro or double-sided adhesive tape. An object (e.g. an orange or an even heavier object made of metal, for example) is placed on the scales and loosely (!) fixed there with adhesive tape so that it does not roll away. Now all that remains is to align the smartphone camera with the kitchen scales–depending on where the dial is located, either on the inside wall or inside the lid of the box.

Tip: If you use a smartphone camera, we recommend that you first attach a cover to the inside of the box with adhesive tape into which you cut a hole for the camera lens (e.g. a folded freezer bag or clear plastic bag).

Start recording directly before the experiment starts and place the smartphone into the case with the camera already running (without wobbling). The person carrying out the experiment then performs about ten jumps while holding the box and the running camera. Afterwards the video is analysed. When does the dial show the resting weight of the object on the scales? When does it show increased or decreased values? Why is this so?

Both experiments can of course be combined, so that you can compare the values obtained with the scales and the app. Interestingly, the free fall already takes place on the way up! This seemingly paradoxical situation of "falling upwards" is a continuation of the previous "cup experiment" and shows that things do not have to fall towards the ground to be in free fall! What is important is that the system itself is not affected by acceleration - no matter in which direction it moves.

Tip: For younger children, the trampoline experiments can be greatly simplified by using a transparent plastic box with objects such as small toy figures. The box represents the space station, the figures represent the astronauts. While jumping on the trampoline with the box in their hands, the astronauts "float" and "tumble" around in it, which is nice to see on the smartphone video.

Caution: The trampoline experiments must not be performed by children with balance problems.

Tip!

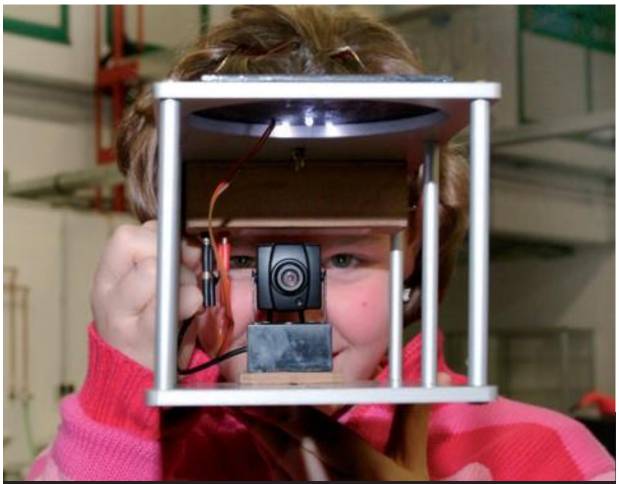
Avoid false explanations!

The fact that the *ISS* is weightless is often explained by the fact that the gravitational pull of the Earth and the centrifugal force cancel each other out due to the high velocity of the ISS. However, this explanation misleading. It cannot explain how weightlessness occurs during parabolic flights or in drop towers, as there is no circular motion involved. This explanation is also inadequate for all the experiments listed in this booklet–from the lift to the trampoline to the drop capsule. And the weightlessness on board a spaceship flying to the Moon or Mars cannot be explained in this way either.

Task 14: The drop capsule

Experiments with a small DIY drop capsule are much more demanding in their implementation and evaluation than the previous trampoline experiments and offer many possibilities for scientific experiments. In principle, the drop capsule works like a drop tower, in which weightlessness experiments fall from a great height into the depths. While real research involves several seconds of weightlessness, our drop capsule experiment lasts just over half a second. But that is enough to see some very interesting effects.

There are several ways to design and build the drop capsule. For school purposes we recommend a simple plastic box (for example from the kitchen). Inside the box a smartphone with video function (or another small video camera) is fixed on one side. It films the sequence of the respective experiment, which is placed on the opposite side in the box–for example a tightly closed glass containing water with some air, or a candle. How does the water-air mixture behave in weightlessness when the box drops a few metres?



Drop capsules can be constructed in various ways. This model consists only of a stable "cage" with a small camera and a light. Photo: DLR

How does the candle flame burn? Standing on a table, a pupil drops the box down onto a cushion lying on the floor. What happens in the phase of free fall is then evaluated frame by frame.

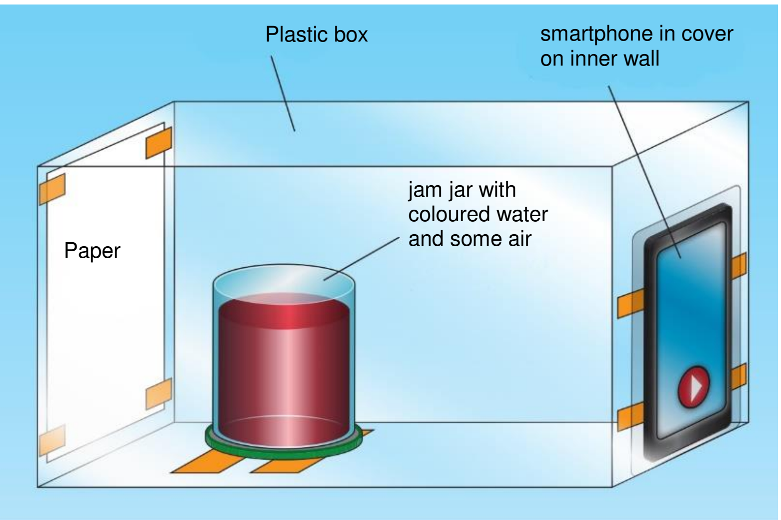
Materials for the drop capsule

- 1 stable plastic box (preferably transparent) with lid
- 1 smartphone with camera function (or another small video camera)
- Velcro or double-sided adhesive tape, adhesive tape
- 1 breakfast bag or transparent cover as cover for the smartphone
- 1 scissors
- 1 sheet of white paper
- 1 pillow as large as possible (to protect the capsule from impact)

How it works:

Building the drop capsule

To attach the experiments inside the drop capsule, double-sided adhesive tape or Velcro is stuck to the bottom of the plastic box in the appropriate places. A breakfast bag or a transparent cover with a hole cut in it can be made in advance and used as a custom-fit cover for the camera. The cover is taped to the inner wall of the box so that the camera stays pointed at the experiment. Immediately before the experiment you start the video and put the smartphone with the camera already running into the box (without wobbling during the jumps). The drop capsule is ready! Now to the experiments ...



Sketch of the drop capsule with the water-air experiment

Materials for drop test A and drop test B

- 1 empty jam jar
- water, possibly coloured with ink or food dye
- tin can
- brush
- black paint
- tealight (shorten the wick a little)
- matches

Drop test A: The water-air experiment

First, colour the water with food colouring or ink and pour it into an empty jam jar so that there is little air left in the jar. Close the jar well and stick Velcro tape on the lid of the jar. Now place the jar "upside down" in the box, where it is fixed to the bottom by the Velcro strips. To make it easier to see on video what happens inside in the glass, you can attach a white sheet of paper to the inside wall of the box behind it. Now the drop capsule is already ready for the first "drop test"!

Before the test begins, the students should formulate hypotheses: How will the water-air mixture react? They should also give reasons for their ideas. Next, it's time to switch on the camera and conduct the experiment. For this, a child stands on a table drops the box onto the pillow.

After the test (or several runs), the pupils analyse how the water-air mixture has reacted. Going through the results frame by frame shows how a round air bubble forms in the water! Afterwards you should discuss why this occurs.

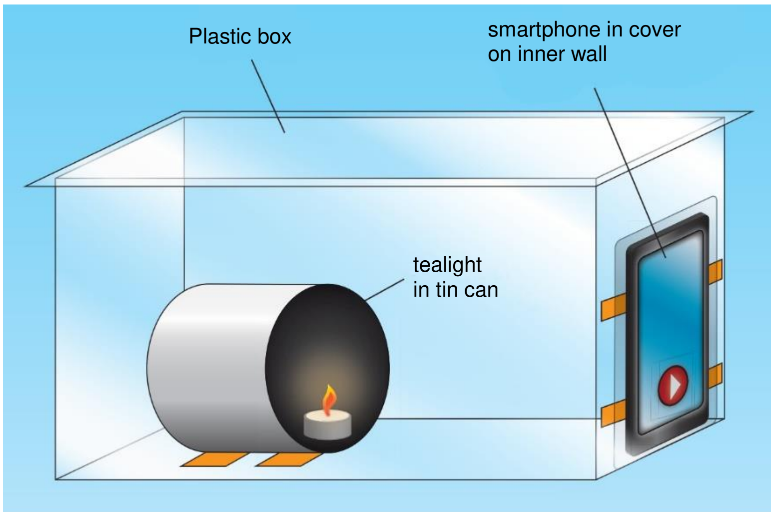
Explanation: As gravity is eliminated as the dominant force, another force becomes apparent–namely the surface tension of water. It "forces" the air into a spherical shape, while the water arranges itself around the inner walls of the glass–around the air bubble. This "mini experiment" demonstrates an essential principle of many *ISS* experiments: In weightlessness, physical effects can be observed and analysed that are "masked" on Earth by the omnipresent force of gravity.

Drop-Test B:
The strange candle flame

Attention: The experiment may only be performed under adult supervision because a candle flame is used. You should close the box with a lid shortly (!) before dropping the capsule so that the cushion (which absorbs the impact on the floor) does not catch fire. Do not touch the box immediately after the drop test, as it can be hot (danger of burns)!

First, paint the inside of a tin black (so the candle flame is visible more easily in the video). Then a tealight is glued into the tin (shorten the wick a bit). The tin is placed on its side with the tealight facing the camera in the drop capsule (fix it to the bottom of the box with Velcro or adhesive tape). The candle should only be lit immediately before the drop test so that the flame only burns for a short time and the can does not heat up too much. Start the camera and place it in the holder on the inner wall–and off you go with the second "drop test"!

Here too, students come up with hypotheses about the results in advance. The subsequent video evaluation shows that the candle flame is small, round and bluish. The cause should be discussed in a group discussion. In weightlessness there is no "light" and "heavy" and therefore no convection. Hot air is therefore not lighter than cold air in weightlessness. Thus, it does not rise, which is why hardly any new, oxygen-containing air can "move up". As a result, the flame burns blue under oxygen-deficient conditions. Note: This candle experiment can also be performed after the following experiments.



Sketch of the drop capsule with the water-air experiment

Task 15:
Convection–The sphere particle model and the aluminium spiral

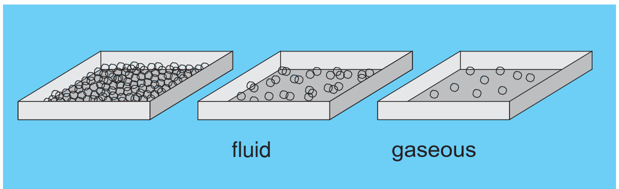
The following experiment can be carried out directly after the candle experiment in the drop capsule or can also be done in advance. The actual experiment with an aluminium spiral (see student worksheet) should be preceded by an explanation using the sphere particle model.

Materials

- 3 shoebox lids
- wooden beads (or crepe paper if you want to make the beads yourself with the children)

How it works:

Three shoebox lids contain a different number of balls: the first with balls very tightly packed, the second with balls arranged at a slightly greater distance from each other and the third with only a few balls and large gaps between them.



The sphere particle model: spheres of varying density are packed into three shoebox lids.

Use the model to explain to the students that all matter consists of tiny particles, which can be imagined as spheres. When the spheres are close together, the matter is solid. If the spheres are a little further apart, the matter is liquid. If the spheres are even further apart, the matter is gaseous. Illustrate what is said using the sphere-particle model. Arrange the spheres in the three lids in such a way that they represent the three aggregate states "solid", "liquid" and "gaseous". Give the children some examples of the states of aggregation–for example, wood for solid, orange juice for liquid and air for gaseous.

Note: Avoid ice, water and steam as examples, as there is the peculiarity that frozen water (i.e. ice) is lighter than liquid water (which is very complicated to explain), which is why icebergs or ice floes float on water.

In the following experiment, convection is made "visible", and the density shown in the spherical particle model plays a decisive role. The required materials are listed on the student worksheet.

Attention: The experiment may only be performed in the presence of adults, because a candle flame is used. Please make sure to use aluminium foil for the snail spiral and no other materials, as the foil is flame-resistant, and inform the children to maintain a safe distance from the candle.

After the experiment, use the sphere particle model again to explain the following principles: hot air has fewer "spheres" per units of space than cooler air. It is therefore lighter and rises upwards–as with this aluminium spiral or a hot-air balloon.

The final question on the student worksheet is now easy for students to answer: If there is no "light" and "heavy" in weightlessness because everything weighs "nothing", hot air does not rise. Here we come full circle from the candle experiment in the drop capsule. The following experiment is another that demonstrates that hot air is lighter than cold air under the influence of gravity on Earth.

Warm air is lighter than cold air

I'm sure you've seen a big hot air balloon in the sky. Maybe you have even been able to see the flame at the bottom of the balloon, which heats the air. But how is it possible that the balloon rises upwards even though it only contains hot air? The balloon rises because hot air is lighter than cold air. Verify this in this hands-on experiment!

You will need:
- aluminium foil (size of an A5 sheet of paper)
- 1 pencil (not too sharp)
- 1 tealight
- matches
- 1 thin thread (sewing thread) and 1 needle
- 1 jam jar lid

How it's done:

1. Cut off a piece of aluminium foil from the roll that is about the size of an A5 sheet of paper.
2. Draw a hand-sized spiral with a pencil on the aluminium foil.
3. Now carefully cut out your spiral on the aluminium foil along the outlines.
4. Attach a thin thread to the inner end of the spiral using the needle.
5. Place the tea light on the jam jar lid and light it with the matches.
6. Hold the thread with the spiral about 30 cm above the flame of the tealight. **Attention:** Do not come closer to the candle with your hand so that you do not burn yourself!
7. Observe and discuss what happens.

Question: Weightlessness exists on the ISS. In weightlessness there is no "light" and "heavy". Would your aluminium spiral spin there?

Task 16: The water mystery

Blue and yellow water: In one glass (right) they mix to make the water green, in the other they remain separated at first. Image: DLR

After you have explained the sphere particle model, perform this experiment in front of class– without telling them what it is about–because this is exactly what the children themselves are supposed to guess or conclude! After all, they are future astronauts and should be familiar with this after the previous experiments. In this experiment, you will deal with the distribution of water in two different set-ups: once at the same temperature and then at different temperatures.

Materials

- 4 (heat-resistant) glasses
- cold tap water (in a bottle)
- 1 kettle and 1 thermos flask for hot water
- 1 tablespoon
- 2 different food dyes (preferably blue and yellow).

How it works:

Announce to the class that you wish to perform a "trick" and get the students to figure out what's happening, and why. Note that you need to heat about half a glass of water (without the children being able to see this) in advance, dye it blue and fill it into a thermos flask. For the demonstration, place four glasses (two per round) on a table in front of you.

For the first round, fill two glasses half-full with cold water. In one glass you colour the water blue, in the other yellow. Now pour the blue water from one glass carefully into the glass with the yellow water. Result: Both liquids mix immediately and produce green water.

It that it? No! Now the real trick starts! Now pour the hot, blue-coloured water from the thermos into the third glass. Fill half of the fourth glass with cold yellow water. Visually, this starting situation is identical to the first round. Now slowly pour the hot (blue) water into the cold (yellow) water. To prevent it from mixing immediately, hold a tablespoon very close to the surface and pour the hot water over the spoon into the cold water. The separation between cold and hot water is immediately visible due to the different colours: The cold yellow water is at the bottom; the hot blue water stays above. Ask the children for an explanation. Also ask how the fluids would mix in zero gravity.

Note: In the first round it is not really necessary to pour the blue water over a spoon into the glass with the yellow water, because both are cold and therefore mix anyway. But so that the children don't think that the spoon is the reason for the different outcomes of the experiments, it is best to pour the water over a spoon into the glass during the first run as well.

Task 17: The fake hovering photo

Seemingly weightless: After his first *ISS* mission, Alexander Gerst met the winners of a school competition–and at the photographer's request, gravity was temporarily suspended here ;-) Image: DLR

This is a here is a fun suggestion for a more artistic examination of the topic of weightlessness: Who can produce the most original "fake photo"? The creative task: "Take a photo that makes it look as if you are floating in weightlessness." Pupils can form teams for this purpose–and, for example, show one person in the picture, while others assist just beyond the edge of the photo and hold seemingly floating objects in the photo. Of course, thin threads to which objects are invisibly attached or other tricks such as using appropriate image processing programs are also permitted.

Caution: Advise the students that they should avoid any risk of injury (e.g. use a soft mat on the floor as protection). For a really good photo, the necessary props should be carefully considered in advance. A tripod is also helpful.

4.2 Impact on the human body

Alexander Gerst floating through the *ISS* modules after work, when the normal lighting has already been switched off (hence the atmospheric lighting). Picture: NASA/ESA

Long before the launch, all astronauts go through a medical examination. Here is Alexander Gerst getting his eyes examined in the German Aerospace Centre. The data will be compared with the data collected during the flight and afterwards. Picture: DLR

Only those who are truly fit are candidates to go into space. For this reason, astronauts are subject to an in-depth check-up long before the launch. In microgravity, they develop symptoms that mirror earthly diseases. The amount of calcium in their bones decreases–similar to symptoms apparent in cases of osteoporosis. The immune system lacks in efficiency. Bodily fluids like blood are normally evenly distributed throughout the body on Earth; however, they shift to the upper regions of the body without the force of gravity. This process leads to circulation problems, increased intraocular pressure and other effects. The unfamiliar environment of microgravity can also result in an imbalance. After landing back on Earth however, all symptoms regress. Medical scientists are able to study the organismic processes under controlled circumstances and draw conclusions for terrestrial practices. This section will present some harmless exercises that deal with these issues.

Didactics

- Children learn about their of sense of balance in a playful manner (this will be dealt with in greater detail later).
- Children construct a spine model to learn about the impact of gravity on the spine. They make themselves familiar with models as an instrument of visualisation and demonstration.
- Children experience the effect of microgravity by testing their sense of taste using the “jam test” (and are introduced into the logic of empirical studies including control groups).

Experiments and exercises

Task 18: Feeling dizzy

“Having arrived at the station I flew through the first connection node”, says the German ESA astronaut Thomas Reiter. “It’s like an intersection where several modules branch off, leading in different directions. I looked into the long tube below me and thought spontaneously: That´s really deep! Better not to fall!” The transition of living on Earth to staying on board the *ISS* is a serious change. It takes time until all reflexes adjust to it. Glancing out of a

Materials

- 1 piece of cloth (for blindfolding)
- gym mats or alternatively 1 rotating chair

window one can see the Earth deep below–but a slight body rotation means that you the planet high above. In playful experiments, the students can experience the phenomenon of spatial disorientation themselves.

How it works:

Some astronauts suffer from it, others don´t. Space sickness includes disorientation, dizziness and nausea. These symptoms are similar to seasickness and abate after a few days of acclimatisation. In order to experience similar effects, we suggest carrying out an exercise we all know from children´s birthday parties: “Blind man’s bluff”. To avoid any injuries, it´s best to play the game on mats in the gymnasium. One after the other, volunteers are spun around their own axis. The one who is able to run a straight line the best, belongs to the “tougher” astronauts. Without access to a gym or mats, this game works also well with a rotating chair in the classroom: Where is the board? Who can point in the right direction after several turns with closed eyes?

Attention: Children with balance problems should not be challenged to do this!

The same picture of the German ESA astronaut Thomas Reiter and his *ISS* crew is shown twice. On the left side, Reiter can be seen at the bottom. But where is the “bottom” in space? You can also turn the photo upside down, as we have done–and Reiter can be seen in the upper half of the picture. Picture: NASA

Task 19: In the morning we are taller than in the evening!

Rigid vertebra and elastic intervertebral discs: Children recreate a model of a spine to understand the reason why people are taller in the morning–and why astronauts get taller in space. Image: DLR / Timm Bourry.

Did you know that you are taller in the morning than in the evening and that astronauts "grow" by a couple of centimetres in microgravity? Here are two suggestions to deal with this phenomenon. We will begin by doing a little homework.

Materials:

- 1 measuring tape
- 1 book
- 1 pen

How it works:

During the night the spine is relieved of pressure by lying down and during the day, while standing, it is compressed due to the effects of gravity. The children can test this on themselves as a homework exercise: Right after getting up, they should measure their body height as precisely as possible by marking the wall with a line, and repeat this right before going to bed. For best results, parental help is essential as well as a book on the head for comparable angles and reliable data–because the difference is just a few millimetres.

Additionally, here is a recommendation for building an explanatory model: By constructing a simplified model of the spine, the impact of gravity on body height can be illustrated. The comparison of "standing" and "lying" makes the effect of gravity on spinal discs clear: The difference is approx. 1 cm in the experimental setup presented here.

All materials and steps are described on the exercise sheet. Jam jars are used in order to visualize vertebrae and paint pads to illustrate discs. Both are piled alternately in a tube composed of two PET bottles. Next, the length of the "jars-pads tower" is measured when the tubes are positioned vertically and horizontally.

Tip: First, test if the effect is clearly visible. The success of the experiment depends heavily on the elasticity and thickness of the pads as well as the weight of the jars, so that it might be necessary to increase the number of "ingredients". Second, cutting or drilling tiny holes into the bottles makes it easier for children to start cutting the PET bottle. Third, here is an explanation for the additional question on the exercise sheet: As astronauts are frequently in microgravity for more than several months, their spine is permanently relieved of load and they grow approximately 2 to 3 cm (back on Earth they will shrink to their "normal" size).

In the morning we are taller than in the evening!

If you feel along your back from your neck downwards, you can feel your spine. If you are agile, you can do it by yourself–otherwise, ask fellow pupils. In order to move freely, we rely on the so-called intervertebral discs that are located between the vertebrae. The vertebrae are hard and rigid, whereas the discs are soft and elastic.

In the morning, immediately after getting up, we are taller than in the evening. How is this possible? Figure it out by yourself and build a spine model! The hard vertebrae are represented by jars previously filled with sand. The soft discs are represented by small pads put between the “vertebrae”. To prevent this tower of jars and pads from falling, put it into a tube crafted out of plastic bottles. You can try out what happens to your back while standing or lying down.

Materials:

- 4 jars with caps (diameter: up to 8.5 cm)
- 3 pads (diameter: approx. 7 cm)
- 3 transparent PET bottles (1.5 litres)
- 1 pair of scissors
- 1 ruler or measuring tape
- 1 waterproof pen
- sand (1 or 2 buckets, the exact amount depends on size and number of jars)

How it works:

1. Cut off the upper and lower ends of two of the PET bottles, so that you can use the middle parts as two “tubes”.
2. Only cut off the upper end of the third bottle with the cap.
3. Use transparent tape to affix all three parts and make them into a “tower”.
4. Fill the jars with sand and close them firmly.
5. Lay the tower horizontally on the desk. Fill it with jars and pads in an alternating order. The jars filled with sand represent the vertebrae, the pads the discs.
6. Mark the position of the cap of the last jar with a waterproof pen.
7. Now raise the spine model into vertical position and hold onto it.
8. Measure the position of the last cap again. What has happened?

Here is an additional question: Microgravity is evident on board the ISS, so astronauts do not weigh anything anymore. What happens to their spine?

Task 20: The jam test

How it's done:

Now follows a way to test your sense of taste. Astronauts have swollen nasal mucosa membranes due to the shift of bodily fluids into the upper halves of their bodies. The way this effects the sense of taste is comparable to having caught a cold. To mirror this, the students merely have to hold their noses. Then they try tasting two small amounts (always just a tiny tip of the spoon) of different types of jam (always use clean spoons or wooden spatulas). Of course, this should be done blindfolded so that one cannot determine the different types of jam by colour. For the sake of comparison, one reference group has to do the test without holding their noses closed. Which groups will get the best results?

Tip: For valid results, you may divide the pupils into three groups: one with their noses held closed, one as a reference group without holding their noses (both with an identical number of participants) and one group helping the others to survey the test data (taking notes of successful identifications). To ensure that the test is not biased, the children should not know what kind of jam has been chosen before completing the test. to this end, all "testers" gather in one corner of the room and are led to the desk with the jam jars blindfolded. They whisper their results so that the other students can record the successful hits.

Attention: Children with food allergies or other illnesses requiring limitation of food should not take part as "testers" but rather record the results.

Materials:

- 2 jars of jam that taste as different as possible (1 jar each)
- enough spoons or wooden spatulas
- piece of cloth to blindfold appropriate testers
- paper and pen for recording

This is what astronaut food looks like: vacuum-packed food such as dehydrated spinach (in the upper right corner). On board the space station astronauts add hot water–the meal is ready on the spot. Picture: NASA

Dinner on board the ISS. Here the crew of a space shuttle is visiting so that there are more members on board the actual space station than usual. Since there is not enough space at the table, one astronaut takes a seat on the ceiling. Picture: NASA

4.3 A view of the Earth

Astronaut Tracy Caldwell Dyson enjoying the view of the Earth. Image: NASA

"For the first day or so we all pointed to our countries. By the third or fourth day we were pointing to our continents. By the fifth day, we saw only one Earth." This quote from an astronaut who was a member of an international crew shows that the view of the Earth can be quite unifying and has a political dimension. In addition, astronauts repeatedly report on how vulnerable and worthy of protection our home planet appears from a distance– this is certainly a political message with regard to our treatment of the environment.

At the same time, the beauty of the "Blue Planet" is a magic that hardly any astronaut can escape. Since many modules on the *ISS* have no windows, the Cupola–a "mini-module" with a panoramic view–is the best place to enjoy the view of the Earth in your free time.

First of all, for you as a teacher, consider this: At an altitude of 400 kilometres you are, of course, still quite close to the Earth, so you cannot see the entire globe at a glance. Nevertheless, areas about the size of Western Europe can be captured in photos taken by astronauts. Only by using a telephoto lens can details such as buildings or streets be seen.

Exciting!

Your own city as seen from space

If you or your students would like to search for your own city, we have a special link here. NASA's online image archive contains millions of photos of the Earth taken by astronauts: https://eol.jsc.nasa.gov/

You can also use the search function to find a major city near you. With a bit of luck, your home region might be visible in one of the pictures.

And because people keep asking: The Great Wall of China can only be seen as a very thin line–and only if you know exactly where to look for it.

Didactics:

- The children get to know landscapes of the Earth in an easy geo-quiz.
- Older students train their logical and three-dimensional thinking by using the example of the *ISS* orbit.
- The students develop a first basic understanding of light and atmospheric phenomena.

A crew member in the Cupola. From here, the astronauts can see and control the robotic arm mounted on the outside of the station–for example, to capture unmanned cargo ships. But of course, they also use the "observation dome" to get a view of our planet. Picture: NASA

Experiments and exercises

Task 21: The Geo-Quiz

The following student worksheet shows photos taken by astronauts from different regions of the Earth. Who can identify the regions in the pictures?

Clues: Depending on the age of the students, you should give tips, for example by naming the regions concerned and having the students assign the appropriate pictures. When looking at the photos, also bear in mind that, depending on the viewing direction, north is not always at the top of the picture (the photos cannot always be "northerly" because of the perspective).

Solutions: The pictures show the following regions:
1. Europe at night (Germany in the middle, Scandinavia on the left). On the horizon you can see northern lights.
2. The Sinai Peninsula with the Red Sea (right) and the Mediterranean Sea (left at the edge). Below, the Nile is partially visible.
3. Northern Germany and Denmark.
4. Berlin at night (May 2012). The different colours of the street lighting in West and East are striking.
5. The western Mediterranean with Spain (left) and Mallorca (centre).
6. The Bosporus (above the Sea of Marmara, below the Black Sea).
7. Italy, France and the Alps.
8. Hamburg.

Pictures: NASA and ESA

Take the geo quiz!

Astronauts are always amazed at how beautiful the Earth looks. In their free time they look out of the window and take numerous photos. Here are some of these photos. Try to find out which regions the pictures show!


5


6


7


8

Task 22: The space station's orbit around the Earth

The orbit of the *ISS* is displayed as a so-called "Groundtrack", as it is often seen on the screen in space control centres. Such a projection of the *ISS* trajectory on the Earth's surface can be found on the following student worksheet (only suitable for older students). Two special features stand out here:

- First of all, the track seems to be sinusoidal, always high above the equator to the north and then down again to the southern hemisphere.
- Secondly, the orbits are slightly offset from one rotation to the next (the graph shows several rotations).

hat is the reason for all this? Discuss and explain this using the following student worksheet.

Here are the **solutions:**

- Firstly, of course, the *ISS* does not fly around the Earth in "sinuous lines". It only looks that way on a two-dimensional map. Rather, one can imagine the orbit of the *ISS* as a ring, which, however, does not run around the Earth exactly above the equator, but is inclined at an angle. This tilt to the equator is called inclination. On the *ISS* it is 51.6 degrees. This also means that the *ISS* does not fly over regions beyond this northern or southern latitude. For example, the orbit just passes Dortmund, but not Hamburg (which you can never see from the *ISS* exactly below you, but only at an angle).
-

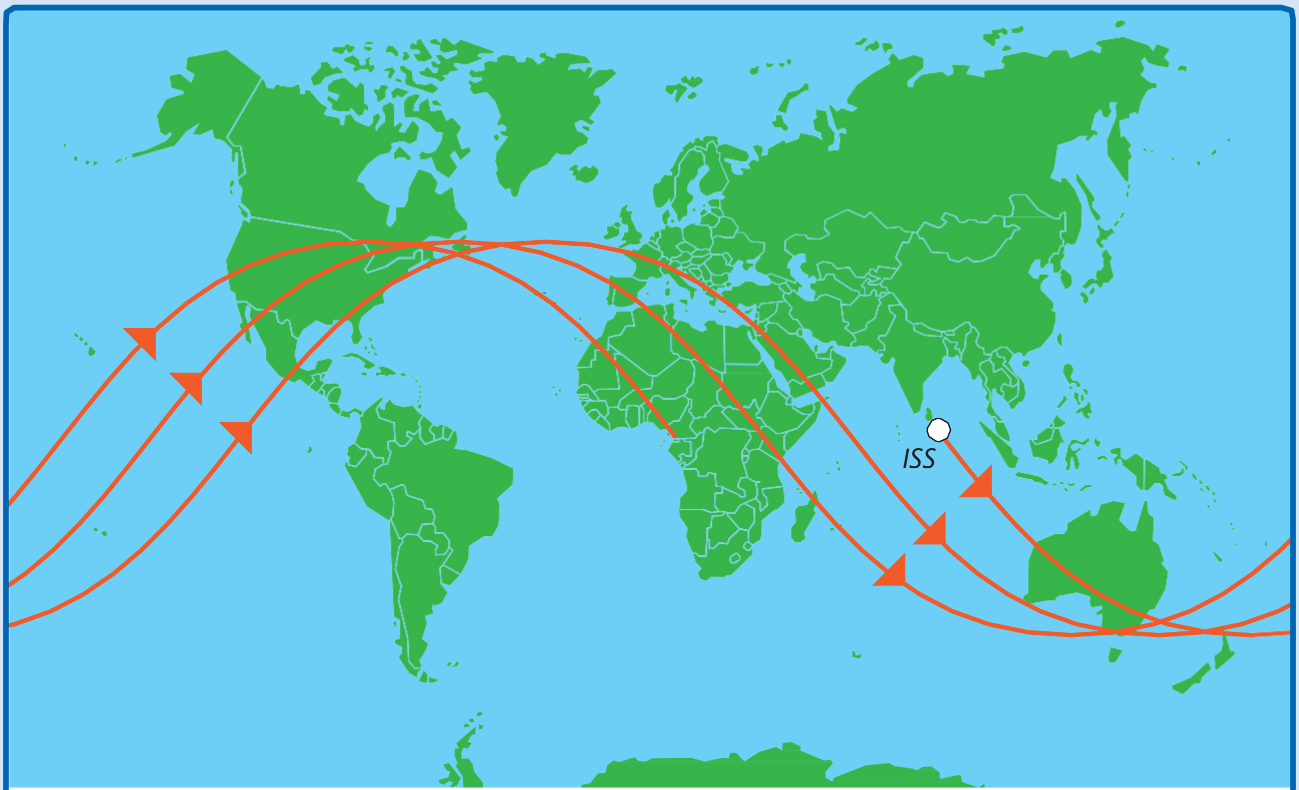
Secondly, because the Earth continues to rotate under the *ISS* orbit, the *ISS* does not fly over exactly the same region after 90 minutes. Instead, each orbit is offset to the west by exactly the same distance that a point on Earth has travelled in the meantime to the east as the Earth rotates. The following applies: The *ISS* needs about 90 minutes for one orbit around the Earth, i.e. it completes 16 orbits in 24 hours During each orbit, any point on the Earth moves forward by one-sixteenth of the distance it travels in 24 hours. A point on the equator travels about 40,000 kilometres in 24 hours–corresponding to the circumference of the earth at the equator. One sixteenth of that distance results 2,500 kilometres of displacement westward (less at north or south depending on degree of width). Depending on the age and performance level of the students, you can demonstrate this qualitatively with a globe or a ball or even have it calculated.

Interesting!

Live display of the current position

There is a whole range of apps–including one from the youth portal DLR_next–with a live display of the current *ISS* position. For the PC view, you can find such a live map e.g. at
www.lizardtail.com/isana/tracking/

The space station's orbit around the Earth



A world map with the space station's orbit ...

This map shows the orbit of the International Space Station *ISS* (shown in red lines) along the surface of the Earth. Do you notice anything? The *ISS* seems to fly strange curves around our planet! Of course, this is not really the case. But why do these strange curved lines appear on the map? Try to explain that!

Take a good look at the graphic again. The orbit of the *ISS* is shown here in three red lines–starting from its current position for the next three orbits of the Earth. Where the orbit stops on the right-hand side of the chart, it continues on the left-hand side. If you follow the path of the *ISS*, which always flies from west to east, along the red line, you will see that the *ISS* always flies from west to east: the orbits are slightly offset. In other words, the *ISS* does not fly over the same areas again after one orbit of the Earth, but the lines of the second and third orbits run to the left (i.e. west) of it. But why does the orbit of the *ISS* shift slightly from one Earth orbit to the next? Find an explanation for this too.

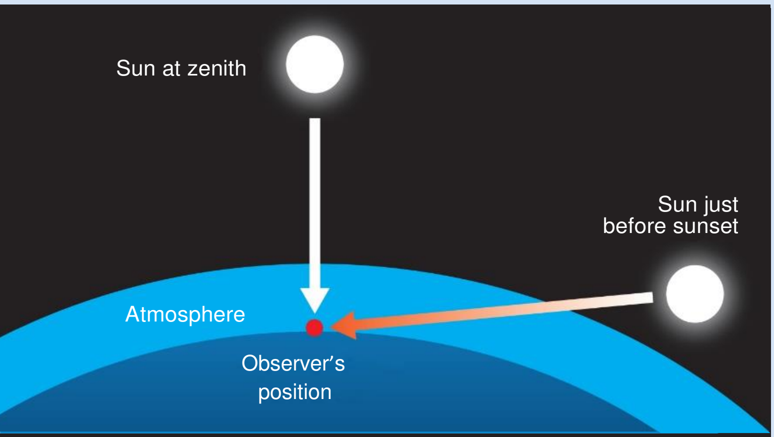
Task 23:
The "blue planet" and a red sunset in a glass

The blue shimmering ribbon of the atmosphere (on this photo with the moon in the background).

Astronauts report how the atmosphere appears as a thin, blue layer when viewed from space. And even if we look up from below from the opposite direction, we see the sky in shades of blue during the day. But why is it actually blue? Here is an explanation for one of the most popular questions asked by children, followed by an equally simple and fascinating experiment.

Sunlight appears white, but consists of many different colours, each of which has a different wavelength. You can easily recognize this in a rainbow or by using a prism.

Tip: For this purpose, you can already conduct a first "mini experiment" here, in which you hold a CD with the reflective side into the sunlight: On a light-coloured wall, which should be in the shade if possible, you can see an artificial "rainbow", because the CD breaks up the white sunlight into its constituent spectral colours.



The illustration shows: If the sun is above an observer at the zenith, the path of light through the atmosphere is shorter than at sunset (or of course at sunrise).

What exactly happens when sunlight, which is composed of different wavelengths and thus colours, penetrates the atmosphere? From the direction of the sun we obtain the complete "mixture" in the form of white light. But if we look at the rest of the sky away from the sun, we see light that only reaches our eyes in a roundabout way: On its way to us, this light first hits air molecules and is deflected by them (we also say "dispersed"). The peculiarity is that the shorter the wavelengths, the more intense the dispersion: While the long-wave reddish light components are hardly dispersed at all, the short-wave blue light components are dispersed much more strongly in all directions by the air molecules–even in our direction towards the ground. Wherever we look at the sky: Blue light from hits our eyes from every direction.

It is also interesting to consider why this changes at sunset: First, imagine the path of light through the atmosphere. When the sun is at its zenith, the rays of light take the shortest path through the atmosphere to your eye. If, on the other hand, you see the sun just above the horizon, the light travels a much longer path "diagonally" through the atmosphere until it reaches you. On this long path, the blue light hits molecules so often that hardly any of it reaches you. Now the long-wave light in the form of the yellow and red colours has its big appearance: Since it is dispersed less often, it dominates over the blue light.

How it works:

Explain the relationships described above to the students in simple words, using the image on page 62 on the blackboard as a guide. And then you present a very special experiment! A mixture of water and some low-fat milk in a glass represents the atmosphere and a flashlight replaces the sun. Hold the flashlight against the glass in a darkened room so that the water-milk mixture is illuminated from below. If you now look into the glass with the children from above, you can see a reddish shimmer there. These are the red light components that penetrate the "atmosphere" almost "straight ahead" and with little dispersion (this corresponds to the situation at sunset).

Tip: If you place the flashlight under an empty glass and then slowly pour in the water-milk mixture from a bottle or jug, you can see very nicely that the colour gradually increases from yellow to orange to red. As in the minutes before a sunset, the way through the "water-milk-atmosphere" becomes longer and longer. In the end everyone is amazed: The white light of the table lamp appears red when viewed through the actually white water-milk mixture!

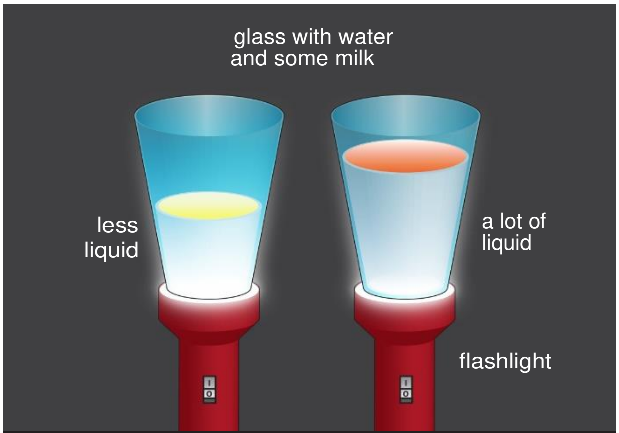
A further surprise effect is added when looking into the glass from the side: from this angle the contents shimmer white to slightly blue. This is because the shorter-wave blue light is scattered to the side by the fat droplets in the milk, which represent the air molecules, while the longer-wave red light makes its way "straight ahead" through the glass and is therefore missing when viewed from the side (just like in the atmosphere).

Notes: This is not a typical "hands-on" experiment that the students could implement and understand on their own. Therefore, please present the experiment to the class, though the children can of course help with its construction and execution. In any case, conduct your own tests with different water-milk mixtures (there should be significantly more water than milk).

Attention: As with all experiments on the subject of the sun, you should point out to the students right at the beginning that you should never look directly into the sun, otherwise they may suffer serious eye damage!

Materials

- 1 tall glass (colourless)
- (low-fat) milk
- water
- 1 flashlight (best with conventional light bulb)
- 1 bottle or jug



The more milk-water mixture there is in the glass, the more red the light of the flashlight appears when viewed from above.

Interesting!

The sky on Mars

Sunset on Mars Picture: NASA / JPL-Caltech / MSSS / Texas A&M Univ.

On Earth, the sky is blue during the day and red at sunset. On Mars it is exactly the opposite: During the day, particles of red sand and dust in the atmosphere give the sky a red colour, at sunset they scatter the light in such a way that the sky around the sun appears slightly blue.

4.4 Economical use of resources!

The international space station is high above Earth. Since supply ships only bring supplies from time to time, it is important to be economical in the use of resources.
Picture: NASA

What does a space station have to do with environmental issues and the sustainable use of natural resources? Or a sewage treatment plant? Here are the answers ...

Every kilogram that is to be transported into space is a cost factor. Unmanned supply ships deliver supplies to the *ISS* at intervals of several months, but their transport capacities are restricted to a few tons. These limitations make the economical use of resources on board the *ISS* a top priority. One example is the reprocessing of water, which is a precious and limited resource not only on the space station but also in many regions of the world. On the ISS, the moisture is filtered out of the air and water is even recovered from the urine.

Didactics

- The children develop an awareness of environmental resources and the maxim of sustainability.
- Students practice taking part in a discussion.
- The children learn how to set up a "mini sewage treatment plant" and practice their technical skills.
- The children understand that there are different stages of purification in a sewage plant; here: mechanical and chemical separation processes.
- The children learn that mixtures of substances can be separated into individual substances by filtration.

Experiments and exercises

We recommend an introductory discussion on this topic, followed by a more technical hands-on experiment.

Task 24: Spaceship Earth–water, air and energy

As an introduction into the topic, you can draw astonishing parallels to Earth and discuss what can be learned from the operation of a space station with regard to the economical and sustainable use of resources on Earth. This does not only apply to the topic of water, which will be dealt with in detail in the subsequent hands-on experiment. Air is also a good example: Since it circulates constantly on the ISS, it cannot hold any toxic substances; otherwise they would circulate over a long period of time. You can't just open the window and air out the station as you would at home. Therefore, all materials, including the clothing of the astronauts, must be tested for non-toxicity beforehand. Even some textiles can contain toxins as a result of the dyeing process or a chemical treatment and thus contaminate the air. The *ISS* is also exemplary in terms of energy supply: it draws its power from the solar cells attached to the outside of the grid structure. This power supplies the on-board computers, the scientific experiments and also the life-support systems of the station–including the lighting, so that the astronauts do not have to float through the modules in the dark.

Water, air, energy–the examples show: What applies on a small scale to the space station can be a model for the Earth on a large scale. Since the resources on our planet are limited, too, we sometimes call it "Spaceship Earth".

Tip: First, explain to the pupils in a few sentences how water, air and energy are handled on the *ISS*: Water is purified and can be reused, air must be clean and free of harmful substances, and electricity is generated via solar cells. Then initiate a discussion about what we can learn from the *ISS* for life on Earth. What are the problems here regarding water, air and energy? What needs to be improved? Irrespective of content, make sure that you have fair discussions: Let everyone make their point, respect other opinions and formulate criticism objectively.

Task 25: A DIY filter tower

Every person needs several litres of water every day. For a crew of six, this adds up to more than could be transported to the station by supply ships. For this reason, the water on the *ISS* is recycled. The so-called "Water Recovery System" cleans more than 90 percent of the water via several mechanical and chemical stages. Water is filtered out of the humidity of the air and even recovered from urine. Microorganisms and other organic contaminants are killed by high temperatures and removed from the wastewater.

Water polluted according to a "recipe" is poured into the filter tower. Picture: DLR/Timm Bourry

The self-built water treatment plant.
Picture: DLR/Timm Bourry

In this experiment, the students construct a "mini water treatment plant" using, among other things, PET bottles, filters and sieves. The filter tower allows the cleansing of water that has previously been contaminated in a controlled manner according to a given "recipe". Using their self-made equipment, the children learn about different separation processes. First, the large particles are removed from the water by two filters of different pore sizes using physical (purely mechanical) separation. In the second step, a chemical separation process is demonstrated by adding citric acid (whereby, strictly speaking, citric acid only visually brightens the water previously coloured with black tea, as the colour depends on the degree of acidity and the dark dye itself remains invisible in the water).

Attention: The water, which comes out of the water treatment plant "clarified", looks clean, but can still be contaminated by microorganisms and other small particles. So it is not drinking water. This must be pointed out to the children!

Tip: Drill holes into the PET bottles so that the children can cut them easily with scissors (the sketches in the student sheet indicate where the bottles should be cut apart and therefore the holes should be made).

The recipe for "dirty water":
Prepare a cup of black tea (brewing time: 10 minutes) and let it cool to room temperature. Together with the children, mix the "dirty water" by pouring 100 ml of this tea into a measuring cup, adding 3 tablespoons of sand with small stones (max. size 2 cm). Stir well.

Excursion

From the sewage treatment plant to plastic waste

If you want to go into the subject in more depth, there are many starting points–from visiting a sewage treatment plant to discussing how much water we all use every day. Related topics are also the handling of the "resource" air (keywords are emissions, fine dust, climate change etc.) or mineral resources such as crude oil (which we burn to a large extent or transform into plastic waste). At the end of the discussions, sustainability can be introduced as a maxim in the classroom.

Everything is recycled– even the "pee" in the toilet!

After we've been to the toilet and flushed–where does everything go? It flows through underground channels into a sewage treatment plant. Various processes help to clean the water of all pollutants. It becomes clean and is discharged to the rivers.

On the International Space Station, water is a precious resource, because it is not possible to transport a lot of fresh water from the Earth to the International Space Station very often. Therefore, every drop must be collected and cleaned so that the astronauts have enough fresh water every day. Water is even extracted from the air they breathe and from their urine.

The water treatment plant

On the space station this is done by a very complex system with many filters. In this experiment, you can build your own "Mini Water Treatment Plant" to clean dirty water. But attention: The water that comes out of your plant is not drinking water! Just because water looks clean doesn't mean it's really clean! There may still be impurities and bacteria in the water that you can't see with your eyes.

You need:

- 2 PET bottles (1,5 l)
- 1 scissors
- 1 ruler
- 1 coffee filter
- 1 fly screen made of fiberglass (from a building supplies store)
- tape
- 1 large jam jar
- 1 measuring cup
- lemon juice

That's how it's done:

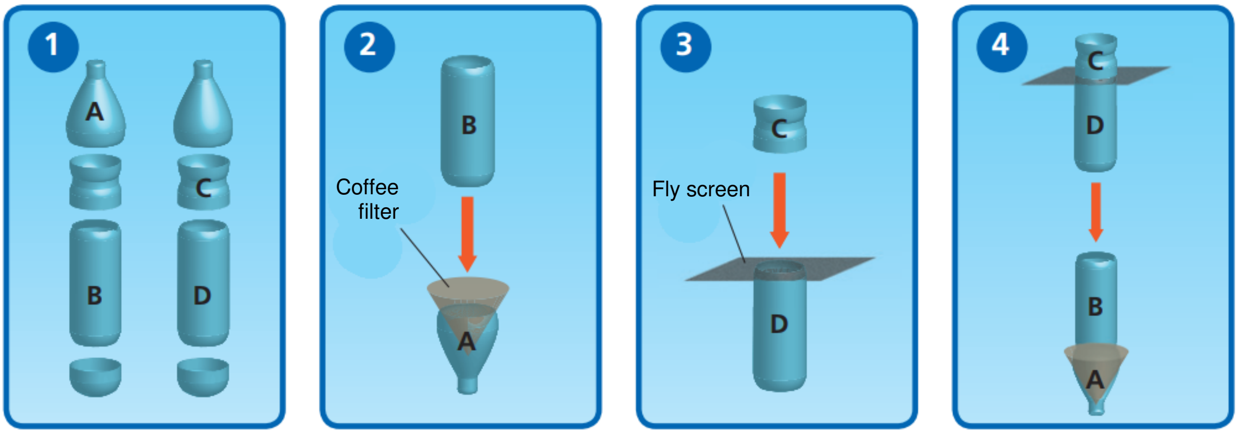
Construction of the water plant:

Step 1: Cut both bottles apart where your teacher drilled small holes in the bottles before. You will receive a total of 8 pieces. For the construction you only need the 4 parts which are marked with letters below.

Step 2: Affix a coffee filter to part A with adhesive tape. Then put part A and part B together.

Step 3: Cut out a 11 cm x 11 cm square of fly screen and tape it into part D. Then put part C and part D together.

Step 4: Now join part B and part D together by cutting the bottles a little bit at the edge (so that you can insert the bottle parts into each other better). Finished.



How to clean water with your plant:

Your teacher has made "dirty water" according to a special recipe, which you can now clean with your system. Place the system in an empty jam jar and hold it tightly. Slowly pour the "dirty water" from above into the plant. The water will pass through the different filter stages. At the end a liquid will trickle into the jam jar. Then add 4 drops of lemon juice.
Observe what happens now and discuss it with your teacher.

4.5 The astronaut's timetable

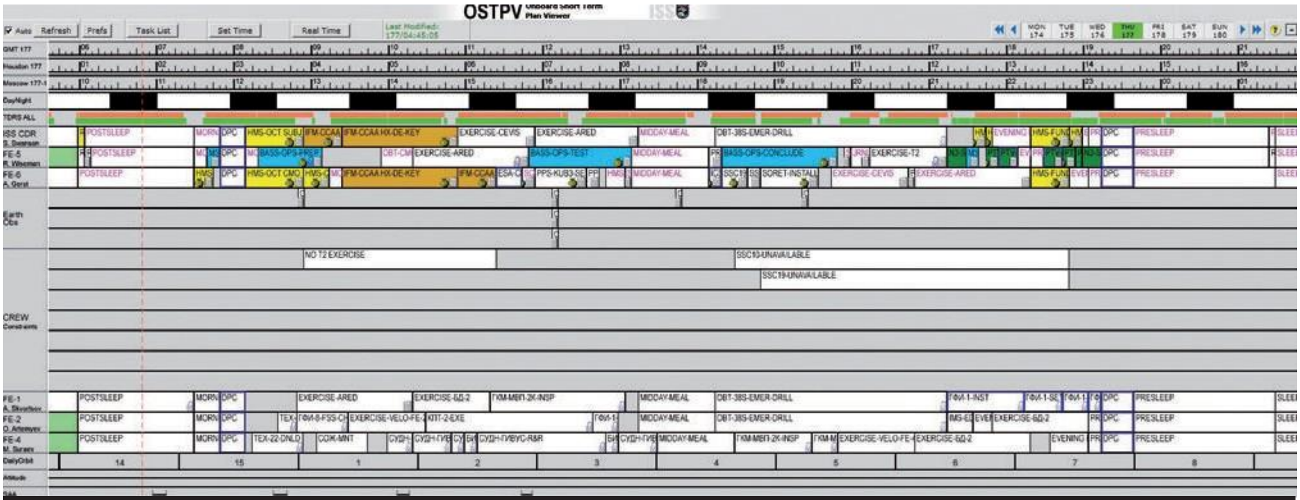
In the control centres–here Oberpfaffenhofen near Munich–staff compile the on-board timetables for the ISS crew and monitor the work at the station remotely. Picture: DLR

Generally speaking, there are always six astronauts on board the *ISS* (apart from short phases in which only three crew members are on the station until the next "shift" starts). In order to ensure that work runs smoothly, an on-board timetable is drawn up well in advance. This so-called timeline lists the upcoming activities of each crew member: from getting up to the planned experiments to meals, sport, leisure time and bed rest. During the planning phase, care must be taken to ensure that tasks are not disturbed by parallel activities.

The daily routine is as follows: The astronauts all sleep at the same time, no one keeps "watch" at night (because all important functions of the *ISS* are monitored from Earth). Every morning there is a short conference with the control centres in Houston and Moscow as well as Oberpfaffenhofen (where the DLR site is located near Munich), where the daily plan is discussed. A large part of the plan is dedicated to scientific experiments and maintenance work. The astronauts also have fixed mealtimes. In addition, there is physical training to keep fit and to counteract the degradation of muscles that are less stressed in weightlessness.

An American astronaut at work (in the background a Russian colleague). By the way, there is an emergency exercise on the board schedule. Picture: NASA

And at the weekend, the *ISS* has to be cleaned: Cleanliness is very important because otherwise filters could be clogged by dust and bacteria or fungi could settle on surfaces. Unforeseen events can lead to a change of plans at short notice. In the evening, there is another conference with the ground stations. Leisure time and bed rest are also included in the on-board timetable.



This is the timeline of the *ISS* crew. Picture: NASA/ ESA

Experiments and exercises

Task 26: The on-board timetable made of Lego bricks

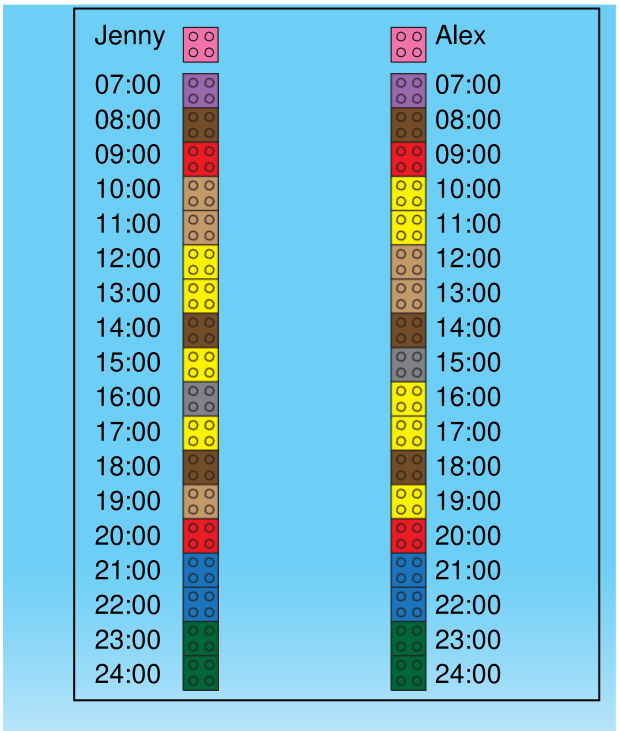
In this exercise, students create the on-board timetable in groups. With the help of Lego bricks, each group plans the timetable of two crew members for one day on board the ISS. The student worksheet contains the instructions and a table. The Lego bricks and pegboards may be brought by the children from home in the appropriate numbers and colours (according to the table on page 72). The stones should be "four-notch"-bricks.

Note: If there is a lack of Lego bricks, you can also work with coloured cardboard or sheets of paper (all of the same size and in the corresponding numbers). For clarification, write the activities which have to be put into the correct order on the sheets (see also student worksheet). Depending on the age of the children, the task can be simplified.

Materials

- Lego bricks of given number and colour
- 1 large Lego pegboard (1 pegboard per group table)
- dark-coloured pens (1 pen per table)
- alternatively, instead of the Lego bricks, sufficiently coloured cardboard or paper (plus scissors for cutting out)

Solution:



Didactics

- The students get to know the daily routine of astronauts.
- The students understand that careful planning is important in complex processes.
- The students practice working with tables, logical thinking and mental arithmetic.

Like at school: The astronauts' timetable

Six astronauts live on the International Space Station. The astronauts follow a timetable so that there is no crowding and they don't argue about who is allowed to go to which device first. It has a similar structure to your school timetable. It tells you what each astronaut has to do at what time. In addition to the experiments, meals, sports or sleeping are also recorded.

Create your own timetable for the astronauts!

You need:

- Lego bricks in different colours, as given in the table
- 1 Lego-pegboard
- 1 thin felt-tip pen

How it's done:

Your task is to create the timetables for Jenny (an astronaut from the USA) and Alex (an astronaut from Germany). For this you need to use the Lego bricks that you brought from home.

1. First place a long row of 18 white bricks on the pegboard for Jenny and next to it for Alex. This is the timeline. **Important:** 4 points on the brick stand for 1 hour. Write the times on the side of the brick with the pen. Both timelines start at 7 o'clock in the morning–this is your first white brick. The brick that follows stands for 8 am and so on. The last stone represents the hour which starts at 12pm (midnight). Count again at the end: There should be 18 stones in each of the two rows, each with 4 points.

2. The two timelines–one for Jenny and one for Alex–should be arranged exactly next to each other. Write the names of Jenny and Alex on 2 pink Lego bricks (a different colour works here too, of course), so you know which timeline be-longs to whom.

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3 Now put coloured "activity stones" on top of the white timelines. Each colour represents a certain kind of activity, for example brown for food, yellow for experiments or orange for sports. The following Lego bricks–each with 4 points, so always 1 hour–are at your disposal for Jenny and Alex:

Meaning	Colour	Number of 4pt bricks for Jenny	Number of 4pt bricks for Alex
Timeline	white	18	18
Name indicator	pink	1	1
Getting up (brushing teeth, washing, dressing)	purple	1	1
Food (breakfast, lunch and dinner)	brown	3	3
Conference with control centres	red	2	2
Repair work	grey	1	1
Experiments	yellow	4	5
Sports	orange	3	2
Leisure time	blue	2	2
Sleep	green	2	2

But attention, please! There are many things to consider:

Jenny and Alex both get up at 7:00am, wash and get dressed. This takes 1 hour and planning is still simple: One purple brick each for Jenny and Alex is placed on top of the white 7 o'clock brick.

Jenny and Alex also take all meals (always 1 hour) together. Breakfast is at 8 am, lunch at 2 pm and dinner at 6 pm. Put the brown bricks, which mean "food", on the corresponding places of your timeline.

At 9 o'clock in the morning and at 8 o'clock in the evening, a conference takes place at which all astronauts must be present and talk to the control centres on Earth by radio. You'll quickly find out where the red stones on your timeline are going. But beware: Now it's getting really complicated …

At the 9 o'clock meeting, Jenny and Alex learn that they are each assigned 1 hour for repair work because something is broken. Alex is to start with his hour of repair work and starts right after lunch; immediately after that Jenny replaces him.

All astronauts have to do sports for 2 to 3 hours a day, because otherwise the muscles would be reduced in weightlessness. Jenny completes 2 hours of training in the morning, directly after the conference. Alex starts training as soon as Jenny is finished. Jenny trains for 1 hour longer than Alex today, who has to train between dinner and the conference in the evening.

Jenny has to carry out experiments for 4 hours during the day; Alex has to experiment for 5 hours. An experiment that lasts 1 hour must be done together before dinner. One of the experiments Alex has to conduct for 1 hour is particularly sensitive and needs absolute quiet. So, Jenny cannot not do any sports during this time, because that would lead to vibrations that could disturb Alex's experiment. All experiments must be completed before the conference in the evening.

Alex likes to take pictures of the Earth in the 2 hours of free time allocated to him. When does he have time to do this it if he goes to sleep at 11pm?

In the evening, Jenny talks with her family on Earth for 1 hour before going to bed and reads a science fiction book in the second hour of her free time.

4.6 Communication: How do you speak to somebody in space?

Communications satellites transfer signals for both visual and auditory information. Image: Eutelsat

Do you know the situation? You're watching a football match on TV on a warm summer´s night with the windows wide open, and you suddenly hear your neighbours cheering for a goal that has not been scored on your screen yet. Several seconds later, the ball goes past the goalkeeper on your own TV. This time gap can be explained with the differences in signal paths and delays in the processing of the signal. Whether it´s a satellite dish, cable TV or even an online livestream service; things are never really 'live,' as a signal always needs a certain time span to reach its receiver–even if that time span is only a split second. At the beginning of the era of telephoning across the Atlantic Ocean, those delays often led to dialogue partners repeatedly interrupting each other. Even today, delays can be noticed when foreign correspondents report from distant regions on the news.

The audio and video signals from the *ISS*, too, have to cover quite a long distance, though the altitude of the station's 400 km orbit is not the biggest problem. Usually, one or even several tracking and data relay satellites that orbit the Earth at around 36,000 km are involved in signal transmission. Whenever a reporter or a politician talks to the crew on the ISS, the delays between question and answer give you a good estimate on how long it takes to send signals from the *ISS* to Earth, and vice versa.

Several tasks and exercises are suitable for discussing the topic of communication in class. You will find attached a few suggestions on how to interest your students.

Experiments and exercises

Task 27:
The tin can telephone–sending gibberish on a journey

Materials

- 2 medium large plastic cartons (e.g. yoghurt cartons)
- string (3-5 metres)
- thin adhesive tape
- scissors or a knife
- a horse
- no cucumber salad

You've probably noticed; the horse and also "no cucumber salad" are not really required for this classic student experiment. The reason for it being on our list nevertheless (with a little smirk, of course) can be found in the following tale of technological history …

How it's done:

Especially for young children, the "tin can telephone" (plastic cups will work, too) is an easy way into the subject of communication and transmission of signals; simply slit open the bottoms of the empty cartons, push the string (3 to 5 metres in length) through the slits and tie a knot into each end on the inside of one cup (or use sticky tape)– and you´re done! Now when the string is pulled tight, it will even transfer words that are whispered into a cup very quietly. Students can test how well the "transmission" works by either lining up in a row with several tin can telephones between each other or by taking turns using a single tin can telephone. They could even start with the first words that were ever be spoken through a telephone. Do you know what was said? "Das Pferd frisst keinen Gurkensalat," meaning "the horse does not eat cucumber salad." These were the words that German physicist and inventor Philipp Reis spoke into the newly invented device on 26 October 1861. He chose gibberish phrases to ensure that the person he was speaking to actually understood his words and would not be able to put together a sentence just by understanding small fragments of it.

Task 28:
Clapping from a distance–see it before you hear it

Sound waves spread through air at a certain velocity; depending on air humidity and temperature, the average speed of sound lies at around 340 metres per second. A task where students line up at both ends of a 100-metre track will show this visually; if one student claps his or her hands, the students on the other side of the track will see the clap about one third of a second before they hear its sound. Apart from clapping, the popping of a balloon will also do the trick. With the help of louder sounds such as the playing of a drum or a track and field starting flap you could even increase the distance between the children and the origin of the sound. The reason for seeing something before being able to hear it is quite simple; light, just as sound, travels at a certain speed.

This speed, however, exceeds sonic speed by far. The speed of light amounts to 300,000 kilometres per second. The same holds true for radio waves. They are electromagnetic waves, just like light. Long story short: all signals come with signal delays.

Didactics

- Students learn about transmission of signals and the spreading of sound waves.
- Students learn about the phenomenon of signal delays.

Task 29: An alarm clock and an electric bell in a vacuum

Materials

- 1 vacuum bell jar with pump
- 1 old analogue alarm clock with bell
- 1 electric bell

How it's done:

In order for sound to be transmitted, it needs a medium it can travel through. With the tin can telephone, the transmitter is a string, meaning a solid object. In normal conversation, or generally in everyday life, sound is transmitted through air. This can easily be demonstrated if you place an alarm clock inside a vacuum bell and let it ring. At first, everything appears to be normal and the alarm clock can still be heard, but once the air within the bell jar has been evacuated, the ringing of the alarm clock is inaudible. No air means no sound. For this experiment it is best to use an older alarm clock with a mechanical bell so that the students will be able to still see the ringing–even if they cannot hear it anymore. The conclusion should be: sound waves cannot be transmitted when there is nothing to carry it, like air.

Young guests experiment with vacuum pump in one of the DLR_School_Labs. Image: DLR

This standard experiment could be concluded here. But there is one more remarkable thing to discover; while sound waves need a transmitter, radio waves (electromagnetic waves) do not have this restriction; they can be transmitted through a vacuum as well as through air. If that were not the case, one would neither be able to see the alarm clock under the evacuated bell jar, nor the light from the sun and stars that travels towards us through the vacuum of space.

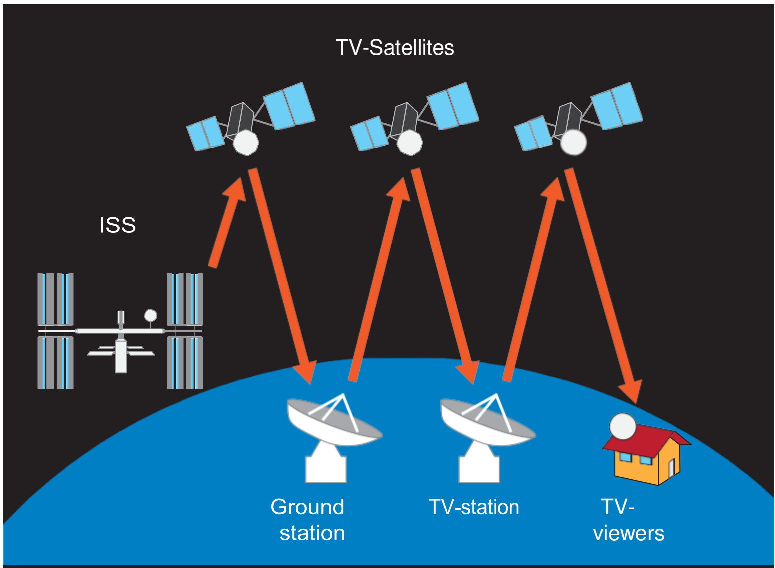
To illustrate, you could direct a beam of light from a torch through the evacuated bell jar. However, this requires the students to know about the similarity of radio and light waves and that both are electromagnetic waves. Another way of clarifying this phenomenon for younger children could be the operation of an electromagnetic device inside the bell via remote. Mobile phones are such devices, but due to the danger of damage the vacuum could do to a mobile phone, this is not recommended. It is much better to use a wireless doorbell that has an LED to signal when it is ringing (such bells are available from around 10 €). Once the air has been evacuated, no sound will be heard, but the LED will still light up. This shows that, unlike sound waves, radio waves still travel through a vacuum. Another possibility is to fly a small drone underneath the bell jar while it still contains air. Without air, it will not be able to fly anymore, but can still be switched on and off via the remote. All these experiments demonstrate that radio waves are able to travel through vacuum and hence, through space, which is the basis of communication between the *ISS* and mission control.

Task 30: Signal delays– Blackboard illustration and tasks for thinking and calculating

The term ‘signal delay’ describes the time span a signal needs to travel from transmitter to recipient. So let us neglect delays that occur in on-board computers of satellites and look at two scenarios that can be explained to (older) students.

First, we will look at how an amateur signal travels from a school to the *ISS* in order to speak to the on-board crew. Recordings of such amateur radio conversations can be found here: www.DLR.de/next/ISSFunkkontakt. For educational purposes concerning the studies of radio waves, schools can apply to take part in the ARISS program (Amateur Radio on the International Space Station) in order to contact an *ISS* crew member. For the establishment of radio contact, the *ISS* is targeted directly from the surface of the Earth, meaning that the signals merely have to cover the linear distance of 400 km between Earth and the *ISS*. During this procedure, it is crucial for the antenna to be pointed at the *ISS* continuously, which is why the support of an experienced radio amateur can be helpful, since the *ISS* moves rather quickly across the sky and will vanish after several minutes, resulting in the end of radio contact.

This begs the question: how do radio and video signals travel when a TV station interviews an astronaut on live TV? Obviously, not with the help of amateur radio operators, but instead, the signal is sent to one of the many tracking and data relay satellites that orbit the Earth at an altitude of 36,000 km, and from there to the ground station of a space agency. The agency then sends it up 36,000 km to another relay satellite for the broadcasting company to access the signal from Earth so that they, in a final step, can broadcast their show with the help of a third relay satellite for the viewers to access with their satellite dishes. You could draw these signal pathways on the board as you explain the process. You might also want your students to calculate the signal propagation delay, for which you can give an estimate of 200 000 km for the travel distance; that way, it is easier to achieve rounded



The path of sound and video signals from the *ISS* to a TV audience.

values (the signals travel at the speed of light, which is 300,000 kilometres per second). The result: neglecting delays caused by on-board computers and so forth, we will always see and hear astronauts with a delay of two thirds of a second during an interview, caused solely by propagation delay.

Another interesting question could be why satellite dishes–unlike the antennae that have to be aimed at the *ISS* continuously–do not have to follow the movement of the satellites in order to get an uninterrupted signal. Let your students ponder on it for a while before you explain: the TV broadcasting satellites are located in geostationary orbit 36,000 km away from Earth, meaning that they orbit our planet exactly once within the time span of 24 hours, at the velocity of Earth’s own speed. As a result, when looking up from Earth, the satellite is ‘set’ in one spot so that, once the satellite dish is targeted at the satellite, continuous signal transmission and reception are ensured.

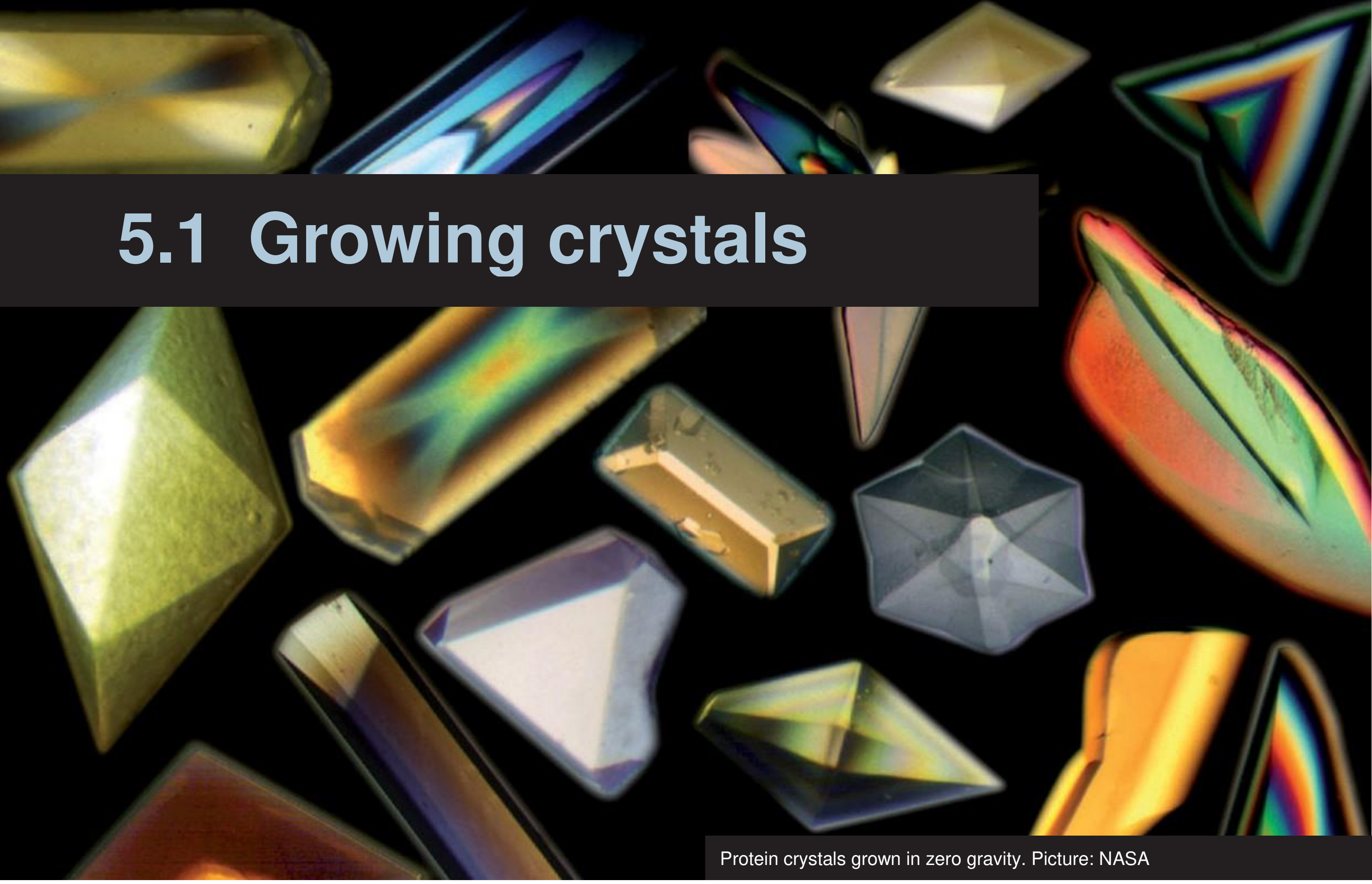
5. Research on the ISS

German astronaut Alexander Gerst pictured in one of the *ISS* laboratories while working with one of the many instruments for scientific research. Image: NASA/ESA

Your students have come a long way already: they trained, took off, and have now arrived on board of the *ISS*. They are aware of and informed about several significant technical components of the space station as well as the fundamentals of an astronaut's everyday life in space. But why did they come to the space station in the first place? For research of course. So let's not waste any more time and get to work!

Usually, there is a long list of experiments to perform during a mission. For example, German ESA astronaut Alexander Gerst took part in around 100 scientific experiments during his first mission to the *ISS* in 2014. In order for your students to gain insights into the different areas of research on the ISS, several of these areas will be looked at over the course of this chapter, meaning that your students will be able to participate in several experiments on crystal growing, human medicine, plant growth and material science.

5.1 Growing crystals



Protein crystals grown in zero gravity. Picture: NASA

Crystals are solid substances with particles that are arranged in a regular pattern, like salt or sugar. Their structure can be examined by X-ray analysis. This requires crystals that are as large and evenly grown as possible. On Earth, however, gravity (with sedimentation and convection as consequences) often interferes with the formation of such crystal structures. This is why crystals grown on the *ISS* in zero gravity are of great value for research. This also applies to protein crystals. Proteins are vital building blocks in the cells of all living organisms. The more we know about them, the better we can understand the biochemical processes in a cell and thus in an organism.

Experiments and exercises

Task 31: Crystal explorers in action!

The following experiment introduces the students to the world of crystals and even lets them grow their own crystals. In two separate experiments, table salt and Glauber's salt (sodium sulphate) are added to water while stirring continuously until nothing more dissolves. Salt that can no longer be dissolved in water sinks to the bottom of the vessel. This is called a "saturated solution". For the types of salt in these two experiments, you should reach this state after about 3 teaspoons per 30 ml of water. After filtration, the solution is poured into a jam jar lid and left to stand for a few days. The water slowly evaporates and crystals appear.

Students growing crystals. Image: DLR/Timm Bourry

Growing crystals in class: impressive results!
Pictures: DLR/Timm Bourry

Didactics

- The students discover that salts are crystals.
- They learn about filtration as a separation method.
- The students deepen their ability to experiment in a team.

The students recognize differences between the crystal lattice structures of both substances: common salt forms cubic crystals, while crystalline Glauber's salt is comprised of larger and more complex structures. Crystals of Glauber's salt are formed faster through evaporation than those of common salt. In contrast to solid table salt crystals, they are porous and fragile. From this you can see which substance was dissolved in the water.

Tips: All necessary materials and the procedure are described on the student worksheet (since rock sugar is also mentioned there as an example, you may want to bring a few pieces with you for demonstration purposes). To measure the water, you need a syringe (5 ml or 10 ml) which will need to be drawn up several times. The funnel should have a diameter of approximately 14 cm, so that a coffee filter fits well. One of the jam jars that the children should bring from home must be high enough to allow the funnel to fit comfortably inside. The Glauber salt and the plastic syringes (without needles!) are available at pharmacies for low prices. If you want, you can dye the crystals with ink. This way you get coloured crystals instead of translucent whitish crystals. Please make sure that disposable gloves and aprons are worn and the table is protected because of possible colour stains.

Attention: The two types of salt listed, table salt and Glauber's salt (sodium sulphate), are basically harmless substances, but we strongly advise against any consumption! Glauber's salt has a strong laxative effect and an excessive intake of table salt can lead to cardiovascular problems.

Divide the children into groups (4 to 6 children per group). The groups can each experiment with one or two types of salt (the following student worksheet contains materials and instructions for one type of salt). Assist the children with the quantities and with the implementation.

Let’s grow crystals!

Do you know rock sugar? It's sometimes used in tea. Take a closer look at the sugar grain. It's special because of its square shape. This regular structure is called a "crystal". The frost patterns that cover cars or windows on cold days, snowflakes and some other things have such a crystal structure. On Earth and on the International Space Station, crystals are studied to find out more about the properties of these substances. In microgravity, you can grow particularly regular crystals grow. This helps in the investigation.

Rock sugar. Picture: Wikipedia / Genesis12

In this experiment you can grow your own crystals!

You need:

- 3 jam jars with lids
- 2 teaspoons
- 1 funnel
- 1 coffee filter (approx. 14 cm diameter)
- 1 plastic syringe (5 ml or 10 ml)
- table salt or Glauber's salt
- water (for half a jam jar)
- 1 waterproof pen

How it's done:

1. Fill the first jam jar about halfway with warm water. Using the syringe, transfer 30 ml into a second jam jar.
(The remaining water is no longer needed.)

2. Dissolve as much salt in the 30 ml of water, stirring continuously, until there is some salt left at the bottom of the jam jar which will not dissolve.
Note: Always use the same spoon for stirring and a different, dry spoon for adding salt!

3. Place the coffee filter in the funnel.

4. Place the funnel in a third jam jar.

5. Pour the salt solution into the filter so that the liquid solution drips into the jam jar at the bottom (this is called "filtrate").

6. Half fill a jam jar lid with this filtrate.

7. Label your lid (your name, salt type, date) and place it in a quiet place– preferably on the heater or on the windowsill so that everything evaporates faster.

8. Look and see what happens from time to time for a few days!

5.2 Medicine

Alexander Gerst during his daily workout on board the space station. Only by training sufficiently is it possible to counteract the degradation of muscle mass in microgravity. Picture: ESA

Much of the research in weightlessness is devoted to human medicine. Of the many questions that guide the research, we have selected two aspects that are suitable for simple experiments: Firstly, the topic of balance and orientation and secondly the topic of "fluid shift", i.e. the displacement of fluids in the human body as a result of weightlessness.

Experiments and exercises

Task 32:
The rotating cocoa cup and the brush with stones in your ear

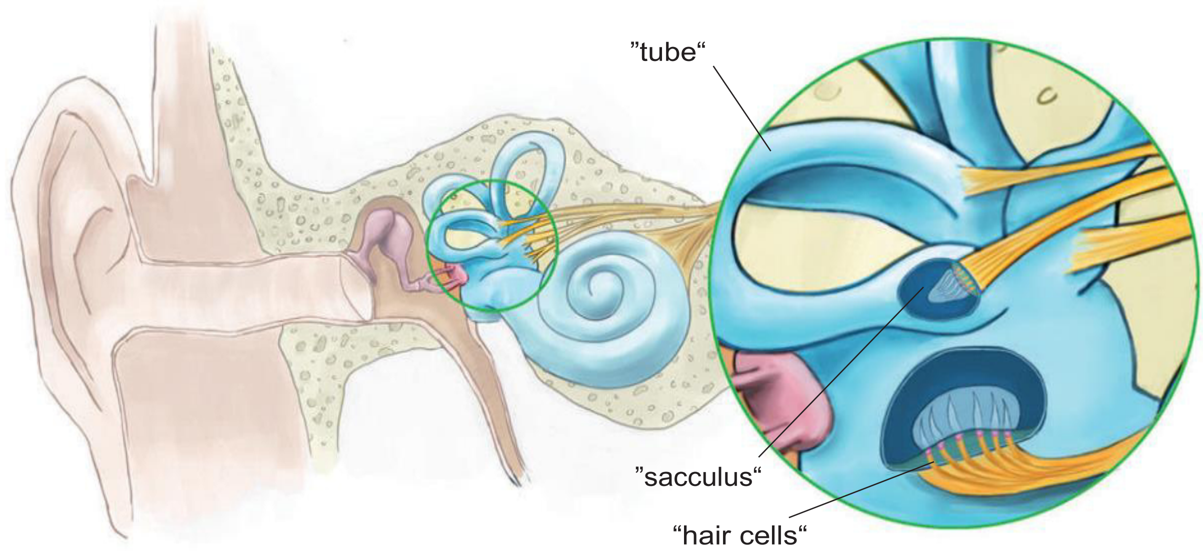
A brush with stones in your ear? Yes, this simple model illustrating the organ of balance shows what happens in our inner ear when we tilt our head sideways. What does all this have to do with cocoa? We explain this at the beginning of this "double experiment" on the subject of the organ of balance (suitable for older pupils). It ties in with the exercises described on page 51 on dizziness (blind man’s bluff).

What do cocoa, a brush and stones have to do with our ear?

Even when we close our eyes, our brain notices whether we are standing still or whether we are beginning to move. It also senses whether we are holding our head straight or crooked. But how does this work? Here are two attempts at explaining to you what happens in your ear. In the ear? Yes, because that's where the human organ of balance is located.

- The organ of balance consists of thin curved "tubes". (they are called "semicircular ducts"). These tubes are our "motion detectors".
- In addition, the organ of equilibrium has several protrusions, which can be imagined as "little bags" (sacculi). These indicate “up” and “down”.

There are fine "hairs" (to be exact they are "hair cells") in these tubes and sacks. As you will soon learn, they are particularly important!



These two graphs show our organ of equilibrium in a very simplified way. On the left you can see the outer and the inner ear, on the right the green circle is enlarged. You can see the small tubes and the bags in which the hairs cells are located.

1. The cocoa experiment

You need:

- 1 cup cocoa (simply mix milk and some cocoa powder)
- chocolate sprinkles
- 1 spoon

How it's done:

Dissolve the cocoa powder in milk and mix like a normal cup of cocoa. Scatter additional chocolate sprinkles on the cocoa. Leave the cup on the table until the cocoa no longer moves. Then carefully rotate the cup on the table: the cup starts to rotate, but the cocoa doesn't rotate with it. You can see this by watching the chocolate sprinkles.

Now put a spoon in the cup, wait a while and turn the cup again: You can see how the spoon begins to rotate together with the cup, colliding with the liquid that is swirled by it.

What does that have to do with the equilibrium organ in the ear? No, of course, there is no cocoa with chocolate sprinkles in your ears! But in the organ of equilibrium, the small tubes are filled with liquid. When you start moving your head, the liquid initially stays still–like the cocoa in the cup. This causes the hairs of the hair cells in the tube to bump against the liquid–like the spoon against the cocoa. These hair cells are sensory cells: They "notice" when they hit against the liquid and immediately pass this stimulus to our brain. So the brain learns about it and we feel this as acceleration or deceleration.

So with the tubes, we notice when we start to move (or stop moving again). But they cannot help us determine what direction is "up" or "down". For this we have small "bags" under archways in which there are also hair cells. Many small calcium crystals lie on these thin hair cells. And what happens there is shown in the second experiment …

2. The brush experiment

You need:

- 1 book
- 1 brush
- 1 flat stone

How it's done:

Place the brush on the book (bristles up) and the stone on the brush. If you carefully lift the book (and with it the brush) on one side, you can see how the stone slides to the side and bends the bristles.

In our organ of equilibrium, things are similar: If we hold our head crooked, the calcium crystals slip to the side a little and bend the hairs of the sensory cells. The cells report this to our brain. So we know that our head is inclined at a certain angle (and that the "top" is not exactly above our head, but a little bit diagonally above it).

Task 33:
Handstand photos and measurements on forehead and calf

Measurement of head circumference on forehead. Picture: DLR/Timm Bourry

When we stand upright, our bodily fluids distributed evenly throughout our body. However, when the downward gravitational pull is suddenly missing, bodily fluids shift in the direction of the head. Astronauts therefore have somewhat puffy faces and thin "chicken legs", as they sometimes call them themselves, in weightlessness. This effect can easily be demonstrated by two comparative photos: In the first photo, photograph the face of a person standing upright, then, with as similar a picture composition as possible, photograph the person doing a handstand (preferably against a wall and with the support of classmates holding their legs). If you turn the handstand photo by 180 degrees, you may see the differences (with the help of image processing programmes, you can overlay both photos semi-transparently and see the effect even better).

On the following pages there is a student worksheet on the effects on the body with suggestions for more precise measurements. This means measuring the circumferences of calf and forehead, which are measured first when standing, and then when lying down (legs slightly raised on a chair).

Test measurements with 14- to 19-year-olds have shown: The circumference of the calf increases in the person lying down by 1 to 2 cm, the circumference of the head by 1 to 2 cm too. During the subsequent comparison of the values, you should once again recapitulate with the children the background of these fluid shifts in the body (it was already mentioned on page 55 as part of the “jam test”).

What is also interesting about this simple experiment is that since a low head position simulates the situation in weightlessness, large research studies also use this technique. The test subjects lie in an "inclined" bed, with the head slightly lower than the legs, for several weeks under medical supervision.

Weightlessness: What happens to an astronaut's body?

The human body consists, for the most part, of water. Most of it is in the cells, but I'm sure you've heard of the bloodstream. When we are standing upright, these fluids have to be transported towards our heads against the pull of gravity. This is done by a "pump", namely our heart.

Normally all this is evenly distributed throughout the body: Gravity pulls downwards, the heart pumps upwards. But when astronauts are weightless, gravity no longer pulls down. But since the heart keeps pumping and pumping and pumping–what happens? Exactly: Now more fluids accumulate in the upper half of the body. The consequence: The astronauts get a "thick head" and thinner legs, because there is too much liquid in the head and too little in the legs.

In this experiment, you can imitate this situation.

You need:

- adhesive dots
- 1 tape measure
- 1 chair
- 1 blanket

Here circumference of the head is measured while lying down. Picture: DLR/Timm Bourry

How it's done:

Does the head really get thicker and the legs thinner in weightlessness? This is what we will measure in this experiment. Since we cannot switch off gravity, we use a "trick": The test subject simply lies down with his or her legs raised slightly. Then the same thing happens to the distribution of fluids that happens in weightlessness. To ensure that we measure at the correct points, the test subject is first marked with several adhesive dots on his or her forehead and calf (roll up your trousers). Then the test person remains still for 5 minutes. With a measuring tape, we again measure the circumference of the head and calf at the marked points.

Note: The measuring tape should be close to the skin, but should not be constrictive!

Now the subject stretches out on the floor, with their feet slightly raised on a chair. If possible, the test person should not move (it is best to place a blanket underneath). After 10 minutes we repeat the measurements in exactly the same places as before.

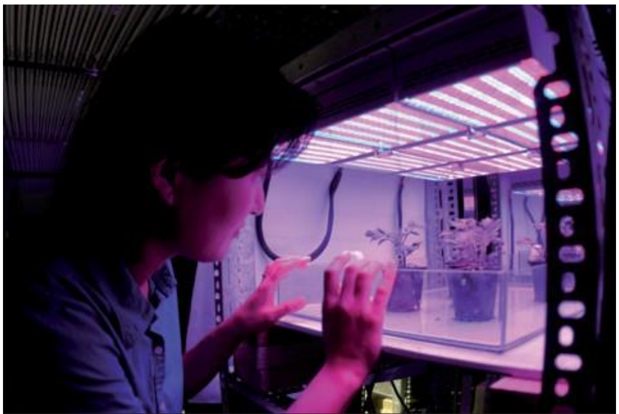
Now compare the values while standing and lying. What happened? Why?

	head circumference in cm	**calf** circumference in cm
standing		
lying		

5.3 Biology: Plant growth

This flower was grown in microgravity on the ISS. The growth of lettuce, cress and other plants is also tested on the space station. Picture: NASA

How do plants "know" which direction to grow in? Do they grow towards the light? Or do use gravity as orientation and grow in the opposite direction? Which of these two factors "tells" the plant to orient its roots downwards and its shoots upwards, and where downwards and upwards are at all?



Scientists are also researching which light lead to the best plant growth. Picture: NASA

These questions were explored by the Dutch ESA astronaut André Kuipers in an experiment for children on the *ISS* in 2004. His objects of investigation were rocket plants. At the same time as the experiments were being carried out on the *ISS*, pupils on Earth observed the growth of rocket plants. On both the *ISS* and Earth, the plants were grown with and without light. The result: whether in microgravity or on Earth–if there was a light source, the plants always grew in this direction. Light is therefore the dominant factor. When there is no light, gravity also has an effect: On Earth the rocket grew upwards in the dark (albeit not particularly well). The rocket which was kept in the dark on the space station grew randomly in all directions.

Experiments and exercises

Task 34: What do plants need to grow?

Cress seeds are used in this experiment because the germination time of cress is very short. The first plants can be seen after approximately 24 hours. You can observe the growth over four days with the students.

Attention: The cress bred in this experiment is not suitable for consumption as mould can develop in the dark boxes! When the experiment is completed, throw away the plants and soil! Of course, the clay pots (see below) can be reused.

In the course of the experiment, students will find that plants grow best when they are in full light. Cress plants bred in darkness and half-darkness will have yellowish leaves instead of an intense green colour, because plants do not produce green leaf pigments in the dark. Great effect: If you move the plants bred in darkness into light, the leaves will begin to turn green after a few hours (the light stimulates the production of chlorophyll).

All information about necessary materials and the procedure can be found on the student worksheet.

Students preparing the cress experiment. Image: DLR/Timm Bourry

Didactics

- The children learn how to sow seeds and cultivate and care for plants (e.g. watering regularly).
- The children practice exact observation over a longer period of time as a scientific procedure.
- The children learn that light is essential for plants to thrive well.

What do plants need to grow?

If you forget to water a plant, it will dry up. Therefore, plants are reliant on water. What else does a plant need to grow well? And how does a plant "know" in which direction to grow? This is something that is also researched on the space station, because astronauts are supposed to grow their own fresh food on the space station, for example lettuce. In the following experiment, you can find out several things about the growth of plants by yourself!

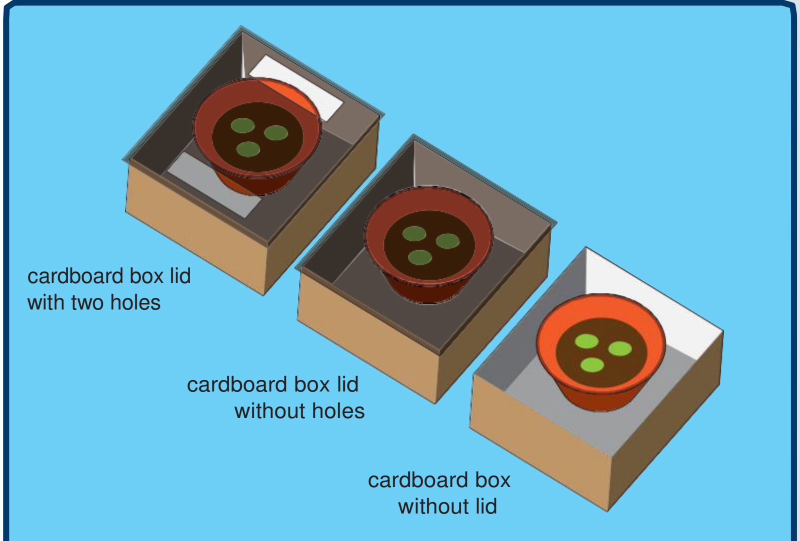
You need:

- 3 cardboard boxes with lids
- 1 pair of scissors
- 1 Geo triangle / ruler
- 3 small flowerpots (about 6 cm high) and saucers
- cress seeds
- garden soil
- 1 tablespoon
- 1 teaspoon
- 1 watering can with water

This experiment is about cress plants.
Image: DLR/Timm Bourry

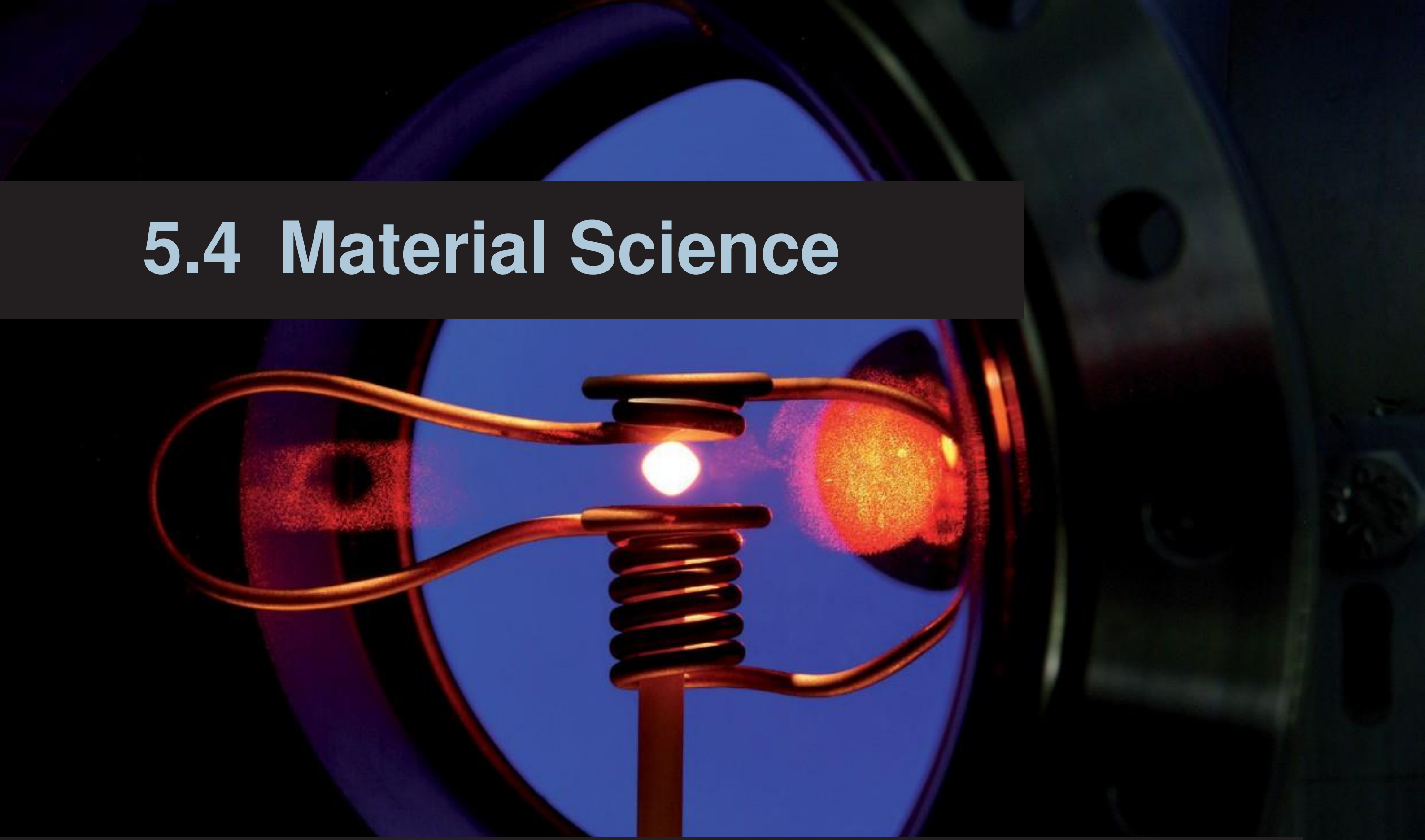
How it's done:

1. Fill each flower pot with 3 tablespoons of garden soil. Press the soil down gently.
2. Sprinkle half a teaspoon of cress seeds on the soil and press the seeds into the soil gently.
3. Water the soil so that only a little water flows into the saucers. Pour away excess water!
4. Cut two holes measuring 14 cm x 7 cm into the lid of one of the cardboard boxes (not in the middle, but rather towards the edges). Leave the other cardboard lids intact.
5. Place the pots in the centre of the cardboard boxes and put them on a windowsill. Cover two boxes with the lids (one of the lids has the two holes in it). The third box remains open.
6. Water the pots regularly, because the soil must always be kept slightly moist.
7. Observe the growth of the cress in the boxes over a period of 4 days.



Three cardboard boxes with cress pots: the left-hand box has two holes in its lid, the middle lid has no holes, and right-hand is left without a lid.

5.4 Material Science



A hovering metal sample is being held and heated by a magnetic coil. Experiments like this can also be conducted on Earth, but performing them in zero gravity leads to much better results. Image: DLR

Materials are constantly being refined in order to meet all kinds of requirements depending on their use. For example, in the development of different metal alloys, many different parameters have to be taken into consideration; the surface tension of the melt, the impact of temperature on movement inside liquid metal, and so forth. Each of these parameters come together to influence the final quality of the material. However, precise measurement results of such effects are rather difficult to attain due to the distorting effects of gravity. Instead of meaningful results, experiments will mainly show interfering side effects such as sedimentation and convection. In contrast, carrying out the same experiments in zero gravity will mostly result in impeccable displays of said effects and can help to gain detailed information as well as further knowledge, which in turn can help to optimise industrial manufacturing on Earth.

Experiments and exercises

Task 35: Hard or soft, rough or smooth?

How it's done:

As an introduction into the topic, let your students test out different material characteristics. To do this, divide the class into five groups to work on five tasks. Each task is set at one 'station'. Each group will have a time slot to work on one task until they are sent to the next station (rotation of workspace). In the end, each group should have spent the same amount of time on each task. Working at every station, each group will have the same selection of materials that will be the overall topic of the assignment. Taking them from station to station, they will be able to experiment on different features of their materials using a variety of tools that differ depending on the task at each station and are hence to be kept at each station for the next group.

The first task makes use of an object that is often used on the *ISS* for experimental purposes: a glovebox. Its advantage lies in the option to work with an object without having to touch it with one's bare hands. This task should be the first that every group works on in order to feel the different materials before taking them out of the glovebox to work with them at the other four stations.

The glovebox can be made out of a shoe box or something similar; simply cut two circular holes with a diameter of about 10 cm into the longer side of the box. Now attach a pair of disposable gloves (or small plastic bags) to the openings so that they can be put on to reach inside the box.

Tip: This can be made even more interesting for the students if each group builds their own glovebox with assistance from the teacher.

Once every group has finished building their box, they will receive a set of the selected research materials and a copy of the worksheet found on pages 97-98. Prepare a table for each task by placing the required 'tools' according to each assignment and mark which station can be found where.

Children testing the glovebox inside the simulator of the Columbus laboratory (located in the European Astronaut Center of the ESA in Cologne). Image: DLR"

The five stations are:
Station 1: The surface of materials
Station 2: The appearance of materials
Station 3: The sound of materials
Station 4: Magnetic properties of materials
Station 5: The hardness of materials

Didactics

- Students develop general understanding of different criteria of material characteristics (texture of the surface, shape, sound, magnetism, hardness).
- Students understand that, by using their senses (this experiment employs sense of sight, touch, and hearing) as well as "tools", they are able to distinguish and categorize different materials.
- Students practice working together as a team.

Characteristics of selected materials might be as follows:

object	surface	appearance	sound	magnetic properties	hardness
ceramics	Top side: smooth bottom side: coarse	Top side: white, shiny Bottom side: beige, granular	Clicking	not magnetic	very hard and inflexible
plastic spoon	smooth	matt	rattling	not magnetic	minimally flexible
metal spoon	smooth	metallic, shiny	clanking	magnetic	very hard and inflexible
cork	dull	granular, beige	muffled	not magnetic	soft and flexible
Styrofoam	dull	granular, white	muffled	not magnetic	very soft

After working on the five tasks, the whole class comes together to compare the results. This works best with a summary on the blackboard. To broaden the topic, you might want to carry out a 'Quiz about materials' in which you ask questions such as "Which object is smooth and minimally flexible?" (e.g. plastic spoon) or "What material is hard and magnetic?" (e.g. metal spoon). First, ask about materials that were part of the selection during the tasks, then also refer to other everyday objects or materials such as wood, sponges, erasers, and so on. To conclude, ask the students what material properties can be helpful in different situations. Example: "If you had to build a plane out of different materials, which characteristics would you have to look for?

Materials

Selection of materials (one per group):

- 1 small ceramic tile
- 1 plastic spoon
- 1 metal spoon (Note: First test that the spoon is magnetic!)
- 1 cork
- an object made of Styrofoam

For the different stations, you will need the following tools:

Station 1: The surface of materials (glovebox)
- 1 cardboard box
- 1 pair of disposable gloves or two small plastic bags
- 1 roll of packaging tape
- 1 scissors

Station 2: The appearance of materials
- 1 magnifying glass

Station 3: The sound of materials
- 1 tube with a length of approximately 1 m to function as drop tower (can be found at a hardware store. It is crucial that the tube's diameter fits all objects)
- 1 wooden board as base

Station 4: Magnetic properties of materials
- 1 magnet

Station 5: The hardness of materials
- 1 nail

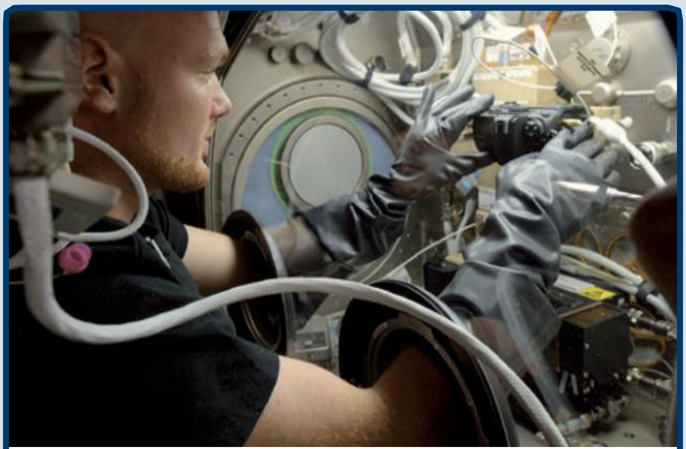
You are material detectives!

All objects that we use every day are made of very different materials. These materials show a variety of different characteristics: some are hard, some are soft and flexible, some are rough and others are smooth. Scientists develop said materials and strive to constantly improve them, depending on what they are made for. The International Space Station, too, is involved in researching new materials, because zero gravity often makes it easier to achieve results in experiments.

But now it's your turn: Just like real detectives, you will examine objects that are made from different materials. What characteristic does each one show? Find out now, your teacher has prepared everything for you!

Station 1: The surface of materials

Amongst other equipment, you will find a glovebox on the International Space Station. A glovebox is a 'box' used for the examination of materials or substances. It has two holes, through which you can reach inside the box. Not with your bare hands though, but with gloves that are attached to the box. That way you will be able to feel things that would be too risky to touch with your bare hands. But don't worry; your personal glovebox is not hiding anything dangerous from you. Feel the materials that are inside and try to find out as much as possible about their surface. What can you feel? Is the object smooth or rough? Write every-thing that you find out into your chart. Once you're done, take all the objects out of the glovebox and take them to the other stations to find out more about their characteristics.



This is the glovebox on the International Space Station, used to perform experiments involving materials or substances that should not be touched or inhaled. Image: NASA/ESA

Station 2: The appearance of materials

Now find out about the appearance of all your objects! Focus especially on colour and shape. Look closely and use the magnifying glass as well. Write everything you see into your chart!

Station 3: The sound of materials

Put down the wooden board as a base and place the drop tower on top. One person will have to hold the tube while someone else drops the different materials inside the drop tower. What can you hear? Do the materials make a clinking sound when they hit the ground? Or another sound that is very different? Try to describe the sounds and record everything in your chart.

Station 4: Magnetic properties of materials

Now a magnet takes centre stage! This is an easy way to find out whether an object has magnetic properties or not. Hold the magnet close to each object: does the object move towards the magnet? Test every object and write down your results in the chart!

Station 5: The hardness of materials

Are your objects hard or soft? Carefully scratch the nail along the surface of your objects. Does the nail leave a trace? Can you press it further into the object? Also, is your material flexible or not so easy to bend? Write everything down that you can find out!

Chart for your results:

object	surface	appearance	sound	magnetic properties	hardness
ceramics					
plastic spoon					
metal spoon					
cork					
Styrofoam					

6. Spacewalks

Astronaut at a spacewalk. Picture: NASA

When astronauts have to leave the space station for outboard work, it is often referred to as a "spacewalk". But such a spacewalk (officially known as Extra Vehicular Activity or *EVA* for short), which can last up to six hours, is anything but a "walk". Working in a bulky space suit, which, together with helmet and gloves, protects you from the vacuum and the extreme temperatures of space, is extremely strenuous despite the built-in climate control system. From the control centre, doctors monitor the astronauts' body temperature and other vital data, which are transmitted live to the ground with the help of so-called telemedicine. In addition, exiting the *ISS* into space is not without its dangers: In order to prevent astronauts from floating helplessly away from the station, they always have to hook onto a safety line. In case of an emergency, the "backpack", which is located at the back of the space suit, has small control jets with which an astronaut could find his or her way back to the *ISS*–but this has never been necessary.

Space walks are often used to install new equipment or replace defective components. Solar cells have to be repaired, power lines have to be connected or leaks in the cooling system have to be closed. New antennae or cameras are installed, docking mechanisms for future space transporters are mounted and much more. All of this requires precise planning and is therefore practiced down to the smallest detail during training in large diving tanks–where the buoyancy under water resembles a feeling of weightlessness. Nevertheless, a talent for improvisation is always required: for example, when a screw is tilted or another part is stuck.

Experiments and exercises

We will take spacewalks as an opportunity to discuss some of the characteristics of space– especially the extreme temperatures, vacuum and radiation. But first of all, an exercise on underwater training suitable for younger children.

Didactics

- The students develop a basic understanding of elementary parameters of space: temperatures, vacuum and radiation.
- They learn intuitively and playfully about phenomena such as static buoyancy, displacement and specific density.
- They practise analytical thinking.

Task 36: Underwater-Training

Astronauts practice outboard operations underwater.
Image: ESA

How it's done:

Why do astronauts practice a spacewalk underwater? After a short discussion, explain that the buoyancy of the water creates a "floating sensation" similar to weightlessness. During underwater training, the astronauts are balanced with lead weights in such a way that they do not drift to the surface but also do not sink to the bottom of the pool. With younger children, you can play this out using various objects in a tub filled with water. Example: An empty plastic bottle floats on the water, a bottle completely filled with sand sinks to the bottom. How much sand must the bottle contain to keep it floating below the surface? And if there is a little too much sand in the bottle: Why is it that you can return it to a balanced "state of suspension" with the help of a balloon that is attached to the bottle? Intuitively, the children develop an understanding of phenomena such as buoyancy, displacement and specific density.

Materials

- 1 tub, bucket or other large containers
- water
- different objects like empty plastic bottles (0.5 litres), sand, balloon etc.
- thread or adhesive tape

Task 37: Why are spacesuits white?

How it's done:

Ask the students why spacesuits are light-coloured. The answer: the light from the sun is reflected by a white surface, while a black spacesuit would absorb the warmth and heat up enormously. It's the same effect that you know from dark clothes or dark cars on sunny days. There is a simple experiment to make this clear. First, paint two bottles with opaque paint: one white, the other black. Fill both with water of the same temperature. Place both bottles on a windowsill (inside) in the sun for half an hour. Measure the temperature again, and lo and behold: the water in the dark bottle is warmer than the water in the white bottle.

Note: Of course, there should not be a radiator under the windowsill, as this experiment aims to demonstrate that the sun is a source of heat.

Materials

- 2 bottles
- black and white colour
- paint brushes
- water
- 1 thermometer
  (e.g. a liquid thermometer; make sure it fits through the bottle neck)

And here's a little variation: If you want to put older students (not younger children, who would be confused by this) to the test and make them really think, do the test again later–and use a trick: Unnoticed, pour much warmer water (from a thermos flask) into the light-coloured bottle! The results will now be very different, of course. Who will find out what is wrong here? In this way, students learn to analyse and question the initial conditions of an experiment. Such critical troubleshooting often occurs in science!

Task 38: Marshmallows in in a vacuum bell jar

Materials

- 1 vacuum bell jar or 1 large syringe
  (without needle)
- Marshmallows or “foam kiss”

How it's done:

In simple terms: In space is a vacuum. If you want to be very precise, you would have to differentiate between different regions in space and different qualities of vacuum. Close to the Earth, there are considerably more molecules per cubic meter than in the space between the planets or between solar systems or even galaxies. But these differences are something for much older students, so the simplified version is sufficient here.

To illustrate this, you can demonstrate various experiments in a vacuum bell jar, whereby marshmallows, for example, "inflate" when subjected to low pressure. It quickly becomes clear: to prevent this from happening to the astronauts, they wear space suits that provide airtight insulation from head to toe against the vacuum of space.

Note: If you do not have a vacuum bell at your disposal, you can also show the effect with a large syringe (without needle, of course). First pull off the plunger completely so that you can put a piece of a marshmallow into the syringe. Then put the plunger back into the syringe.
Push it very close to the marshmallow piece until there is hardly any air left in the syringe. You can now create a partial vacuum by pulling the plunger (close the smaller opening of the syringe with your finger). This leads to the marshmallow piece visibly expanding.

Task 39: Making the invisible visible

Astronauts are not allowed to leave the protection of the space station when a strong solar wind is on its way towards Earth. Normally, this stream of charged particles is rather harmless. On Earth, the magnetic field and the atmosphere protect us from it anyway. But after solar flares, the solar wind can increase to a "storm" and that makes this radiation dangerous for astronauts. Incidentally, damage to satellites and even blackouts in power plants are also possible.

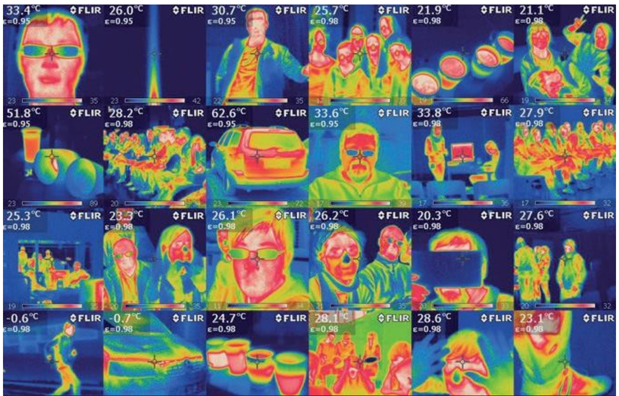
Materials

- 1 infrared camera (thermal imaging camera)
- 1 TV remote control
- 1 smartphone with camera

How it’s done

The following experiments show that there are general types of radiation that cannot be seen by human eyes:

If you own or can borrow an infrared camera (e.g. fire brigade, energy consultant or supply companies such as municipal utilities), you can use it to produce spectacular thermal images: In pseudo-colour, the cold tip of a nose reveals itself in an otherwise warm face. The imprint of a hand pressed on a table top can still be seen for a short while after. The invisible is made visible.



These recordings were made by students using an infrared camera. Image: DLR

Without complex accessories, the infrared radiation of a TV remote control can be made visible. Simply aim the remote control at the activated camera of a smartphone (test before, as newer smartphone cameras have an IR filter and the effect is then not visible). If you now press any program button, the otherwise invisible beams of the remote-control light up in the camera's display.

Hint: The experiments with infrared radiation actually have nothing to do with the solar wind and cosmic radiation; they only show that there is invisible radiation. If you want to deal with the topic in more detail, you can use a cloud chamber and follow how charged particles from outer space leave their traces in it. This looks like condensation trails from airplanes in the sky. Such a cloud chamber is a truly fascinating experiment, but it requires a great deal of effort. Instructions for schools on how to construct one can be found on the internet.

7. Returning to Earth

A few kilometres above the Earth, the main parachute opens and the *Soyuz* capsule glides to the ground.
Picture: NASA/Bill Ingalls

Usually, astronauts stay on the space station for about six months. The astronauts return as a group of three crew members, while another group of three crew members stay on the station for a few more months. The *Soyuz* spacecraft uncouples from the station and shortly afterwards ignites the engines opposite the direction of flight, which causes it to slow down and to descend. It then separates into several elements, of which only the landing capsule passes through the atmosphere to the ground, while the rest burns up in the atmosphere. The closer the capsule with the three astronauts gets to Earth, the more it is slowed down by the increasingly denser layers of air. The air heats up so much that it begins to glow. Contrary to what is often assumed, this is not so much due to the friction of the capsule, but mainly to the increased air pressure. The capsule compresses the air and when air is compressed, it heats up. Finally, the parachute opens and the capsule sails further down to Earth. Just before ground contact, a small retrorocket ignites to soften the impact.

After long stays in space, the unaccustomed force of gravity makes the astronauts' lives difficult. Despite all the training on board the station, their muscles and cardiovascular systems have to get used to gravity again. Even their sense of balance is impaired. However, after a few days, everything returns to normal.

A *Soyuz* capsule at touchdown.
Picture: NASA/Bill Ingalls

Spectacular shot of a capsule shortly after landing. In the background you can see a helicopter which is used to fly the crew members to the nearest airport. From there their journey continues to Moscow or–for NASA and ESA astronauts–to the USA or the European Astronaut Centre near Cologne. Picture: NASA/Bill Ingalles

It is now also time for us to return to Earth after our long journey into space–as always in the form of some playful interactive exercises.

Experiments and exercises

Task 40: It’s getting hot!

Friction generates heat. During re-entry into the Earth's atmosphere, this is not the crucial reason for the high temperatures that occur on the outside of the capsule, from which the crew is protected with a heat shield. Nevertheless, at the beginning you can do a little warm-up exercise. Have the children rub their hands together quickly and feel: It's getting warm!

Didactics

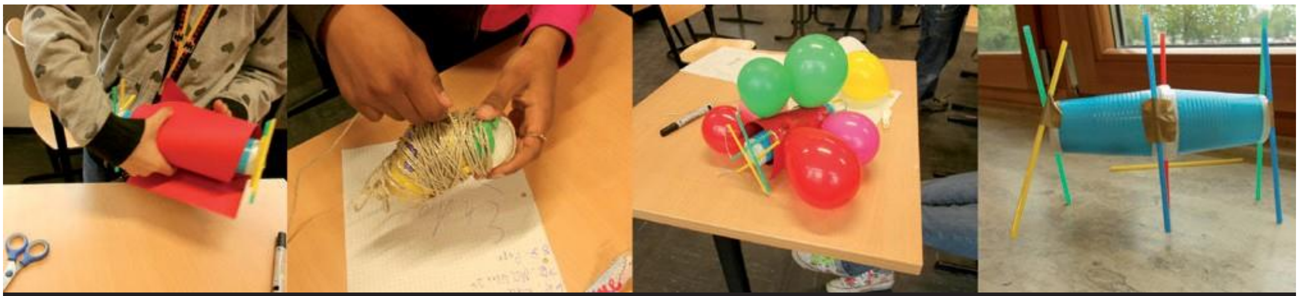
- The students learn about the challenges of bringing a crew back to Earth safely and unharmed.
- They learn how friction and pressure influence the temperature.
- They train their logical thinking skills and implement tasks with technical skill.

Materials

- 1 air / bicycle pump

The more important reason for the development of heat during re-entry can also be demonstrated quickly: Use an air pump and while pumping, feel the valve. It gets warm there, too! Conclusion: When air is compressed, its temperature increases.

Task 41: Egg astronaut – ready for landing!



Building the egg lander. Picture: DLR

Materials

Each Team gets

- 2 paper cups
- approx. 10 straws
- 5 balloons
- cardboard
- big piece of plastic foil (a cut open bin bag)
- approx. 5 m cord
- handicraft materials (scissors, adhesive tape, ruler, pen)
- 1 raw egg
- 1 small plastic bag (e.g. breakfast bag)

Note: If you don't want to waste food, you can use a Christmas bauble instead. Whether egg or ball: Keep some of the test objects in reserve, just to be safe. You should also pack the fragile cargo in small pastry bags before you distribute them, in case something does break during the task.

The aim of the experiment is clear: the landing has to be as soft as possible, because in this experiment the astronaut is symbolised by a raw egg. This is a real challenge, not only for younger children. Similar to the real *Soyuz* capsule, a parachute helps to slow down the load. However, instead of the retro rocket, which additionally reduces ground contact during a *Soyuz* landing contact during a *Soyuz* landing at the last second, we have taken inspiration from another area of space travel for this experiment: Just as airbags are occasionally used for landings of unmanned spacecraft on Mars, we use balloons here. Furthermore, cups, straws and other materials are needed–and the final stage of the flight can begin: We are returning to Earth. Egg astronaut: fasten your seatbelt and prepare for landing!

How it's done:

Distribute the materials to the small groups and let the children deliberate: How can ensure a soft landing using only these materials, where the raw egg remains intact as a "passenger"? After some time of reflection, help the children and point them towards a solution, which is as follows:

1. Place the packed egg in a cup.
2. Seal the opening of the cup with cardboard using adhesive tape (you can use a second cup, too).
3. Attach slightly inflated balloons to the sides and bottom of the cup. In addition, straws can be added as "landing legs".
4. Now all that's missing is the parachute: To do this, cut out a circle with a diameter of 40 cm from a bin bag. Cut a hole in the centre of the circle (5-10 cm diameter) to stabilize the descent. Attach four equally long cords to the outer edge of the parachute and also attach them to the capsule with adhesive tape.

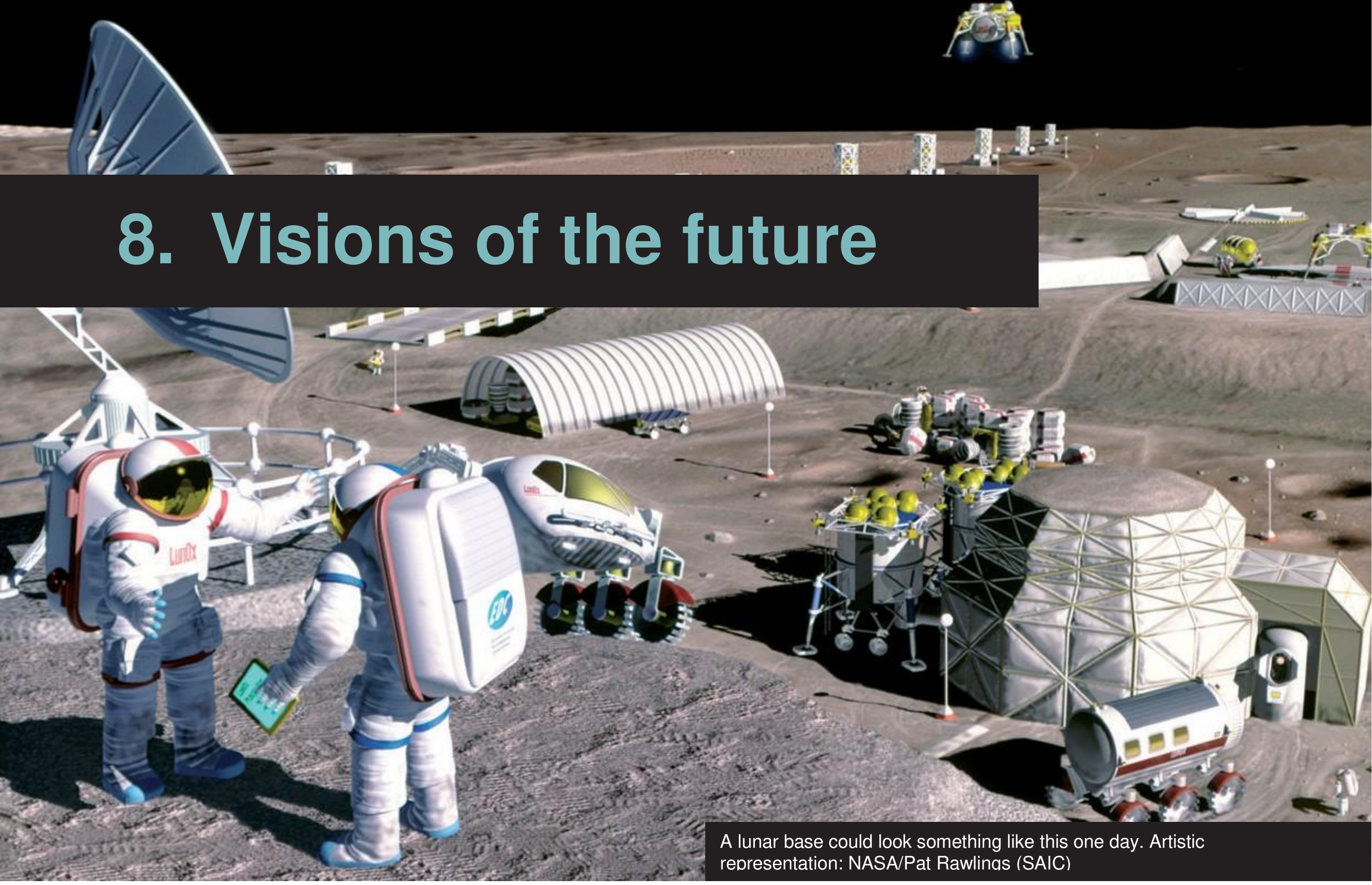
Afterwards ascend a staircase where the landings will take place.

Task 42: All of a sudden everything is very difficult

What does it feel like when you are suddenly exposed to gravity again after six months in space? Can the students themselves think of how this could be recreated? A simple method that at least gives you a feeling for it is piggyback walking with another child on your back. This allows the students to simulate the unusual force of gravity. And they notice: they are not able to stand up this way. Astronauts that have just landed also need help when exiting the capsule.

Unfamiliar gravity: A crew is welcomed by numerous helpers who carry them out of the capsule.
Picture: NASA/Bill Ingalls

8. Visions of the future



A lunar base could look something like this one day. Artistic representation: NASA/Pat Rawlings (SAIC)

The International Space Station is to be used for several more years. What's going to happen after that? The major space nations are currently developing plans for this. Possible targets beyond the Earth's orbit are the Moon, Mars or even an asteroid. Here we summarize for you as a teacher some considerations that underlie these scenarios–whenever they may be implemented.

The European Space Agency ESA has suggested that a research station could be built on the Moon, calling this idea "Moon Village". The far side of the moon would provide ideal conditions for radio astronomy, because of the missing radio spectrum pollution. In addition, there would be a lot of other research work, the extraction of raw materials and perhaps even space tourism.

On Mars, the focus of attention would be the search for life. We know from unmanned missions that there must have been liquid water there at some time. Some of the water evaporated into space, some seeped into the ground, where it probably still exists today as permafrost under the surface.

Since water is considered the basic prerequisite for life, the exciting question is: Did or do simple forms of life exist there? Automatic rovers–vehicles that are remotely controlled from Earth–have been studying the Martian soil for years. But perhaps only by sending humans to explore there will we be able to solve the mystery. In addition to such research missions, which would take about two years and would already be ambitious enough, there are much more far-reaching initiatives up to a Mars colony–some enthusiastically commented, others dismissed as completely unrealistic. Supporters such as the American entrepreneur Elon Musk argue that in the medium term, we must be able to move to another planet in the event of a global disaster (which is also the view of the well-known physicist Stephen Hawking). Critics consider this to be literally unworldly and urge us to use the necessary means more to solve our earthly problems. Without being able to decide this controversy here, a statement by Buzz Aldrin, the "second man on the moon", at least gives reason to think: According to him, the difference between dinosaurs and humans is that we are able to avoid possible dangers …

Asteroids are interesting for several reasons, one of them being highly controversial. They pose a serious threat to Earth: There are thousands of these rocky celestial bodies that occasionally cross the orbit of Earth and come very close to our planet. Smaller specimens, by the way, hit the Earth every day, but they usually burn up in the atmosphere. But if one day a larger asteroid approach us on a crash course, we should have "defence strategies" ready by then. There are various concepts for this: for example, by diverting the asteroid off course or even destroying it with unmanned probes. To do this, however, we need to know the composition of such celestial bodies very precisely. This could be the task of a manned mission to an asteroid.

It is not yet clear which of these scenarios will be realized and when. We end this book with playful ways of dealing with the vision of a Moon station– as a view into the distant future. Astronauts are also involved in such plans, and your students are now the ideal experts! In a creative game, the children give consider this and build a Moon base. It can, for example, be made of Lego bricks or, following the suggestions below, be built from everyday objects. But first, to get them in the mood, there is another exercise that provides some basic knowledge about the Moon and Mars–perhaps combined with a fascinating view of the night sky.

Experiments and exercises

Task 43:
Moon and Mars on the sports field and in the night sky

When it comes to the Moon or even planets like Mars, you should give the students some basic information about these celestial bodies in advance. This can be combined with a little hands-on exercise and possibly with the experience of a night-time observation tour. On the right-hand side, the most important "basic information" is highlighted.

Didactics

- The students acquire basic knowledge about the Moon and Mars.
- They develop their own ideas and thus live out their creativity and imagination.
- They train their ability for logical thinking and develop their artistic and manual skills.

Children have little use for information on sizes and distances. But with a simple trick, the dimensions can be well illustrated: To compare sizes, first place three small paper balls next to each other, with a diameter of about 1.2 cm (Earth), 0.6 cm (Mars) and 0.3 cm (Moon). Explain that in this model we have "shrunk" the huge Earth, the Mars and the Moon and pretend that these celestial bodies are as tiny as these paper balls. How far apart are these three celestial bodies on this reduced scale? Let's demonstrate on a football field! Because if you want to bring these spheres– although they are already quite small–into the true scale distance, a lot of space is needed: The small Moon sphere is only about half a metre (40 cm) away from the Earth, but Mars is a good 60 metres away! In order to be able to see the paper spheres and their positions at all, they should of course be held up by children. Everyone is amazed: This is how far away Mars is from us!

Moon:

The Moon orbits the Earth at a distance of about 400,000 kilometres (number strongly rounded). Astronauts only need about four days to travel this distance in a rocket. With a diameter of about 3,500 kilometres, the Moon is much smaller than our planet (more than 12,000 kilometres). It also has less mass (about 80 Moons would correspond to the mass of the Earth) and therefore less gravitational force: it is only one-sixth the Earth’s value. Also, it is important to know that the Moon has no atmosphere.

Mars:

With a diameter of about 6,800 kilometres, Mars is about half the size of Earth. It is a "desert planet" and has only an extremely thin atmosphere in which humans cannot breathe. Like Earth and the other planets, Mars orbits the Sun. Because it is further away from it than Earth, its orbit is much longer. It therefore takes about twice as long to orbit the Sun. So, we always overtake Mars on the "inner orbit". This means that Earth and Mars are sometimes on the same side of the Sun (the shortest distance between the two planets is then about 60 million kilometres), but sometimes they are on opposite sides of the Sun. Therefore, it is not possible to fly to Mars or from there back to Earth at any time, but one must wait for a favourable constellation of both planets for outward and return flights. Overall, a mission to Mars would be take at least two years.

This exercise can be linked to the fascinating experience of a nocturnal observation of the starry sky with the participation of some parents as carers. Perhaps the adults could bring binoculars or even a telescope or could you ask a local observatory or astronomy club for support. They will also tell you when the Moon and Mars (and other celestial bodies) can be seen in your area.

There are also several apps that make it easier to find your way around the night sky–including one by DLR_next, the youth portal of the German Aerospace Centre. And keep in mind that you will see significantly more stars away from city lights: Apart from flashlights that illuminate the path, there should be as few light sources as possible nearby.

Task 44: Building a village on the Moon

How it’s done:

Using the example of the International Space Station, we have already got to know many "ingredients" that are also needed for a Moon base: The individual "houses" are, similar to the case of the *ISS*, individual modules, which in the model could consist of white painted drinks cans and possibly stand on stilts (straws). It is best to place them, like all other elements, on a solid wooden board or chipboard, which, depending on the amount of work involved, can be plastered to create a Moon landscape.

Materials

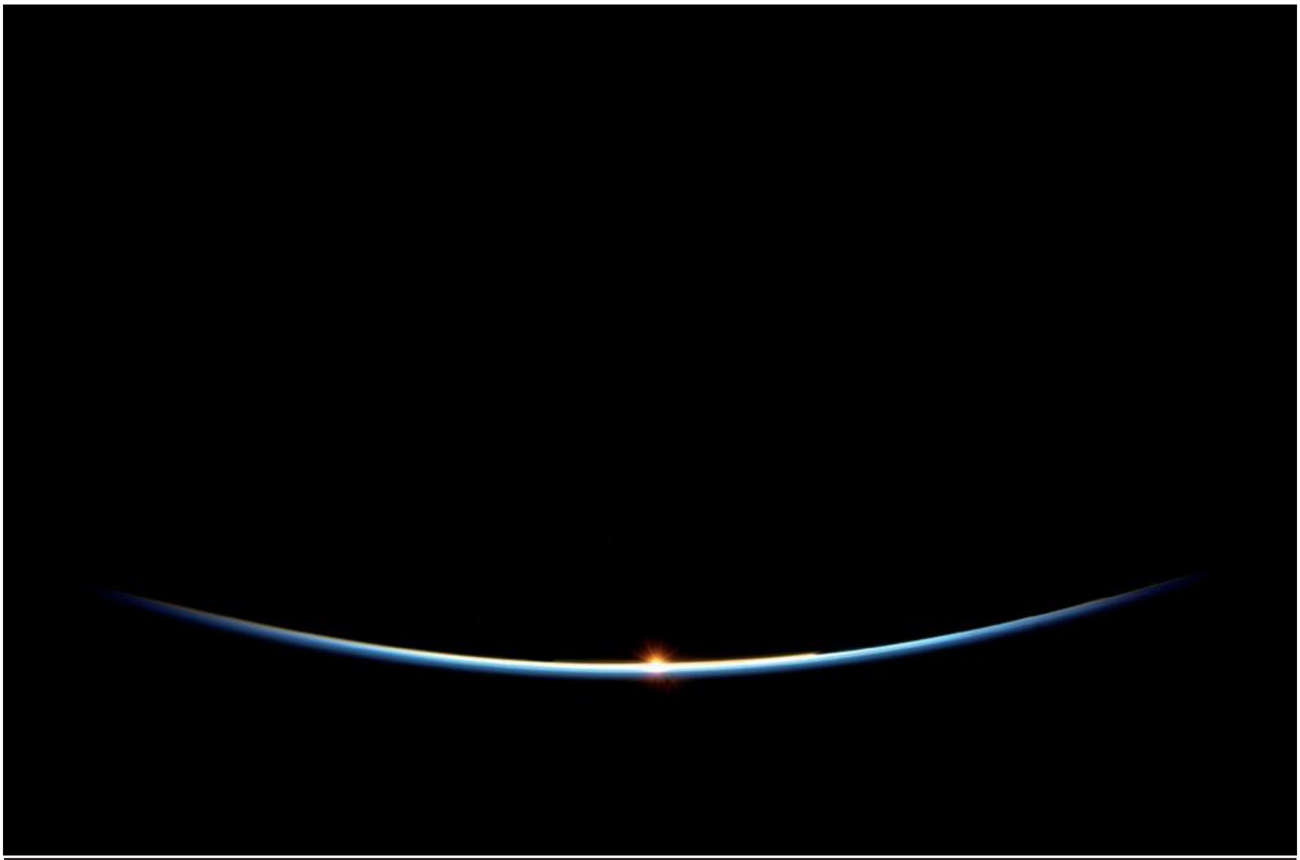
- drinks cans
- other packaging materials from supermarkets etc.
- craft utensils:
- scissors
- glue
- adhesive tape
- paint etc.
- further "ingredients" of your choice:
- cables
- aluminium foil etc.
- 1 wooden plate as base, possibly modelled with plaster to a lunar landscape

Here are some more suggestions: Solar energy is abundant on the Moon, so you need solar panels that you can make out of cardboard and aluminium foil. Of course, storage is needed for the nights in order to use the electricity even in the dark. These can be small boxes that are connected to the solar panels by cables.

Greenhouses for fresh food and modules with a view of the stars are also necessary, of course! The glass panes can be made in the model, for example, from transparent food packaging from the supermarket or from cling film. Of course, a lunar station needs a launch base and a landing place for spaceships nearby, with appropriate means of transport for astronauts and goods.

These few suggestions are enough for now, as the children can let their imagination run wild. And who knows? Perhaps your young "astronauts" will one day experience how the vision of a distant future becomes reality.

We have thus arrived on our journey into space in the future and hope that you and your pupils have had many interesting experiences, impressions and also a lot of knowledge–and that you have had fun doing all this! Because, as we all know, this makes learning easier. So, we conclude with a famous quote from the writer and pilot Antoine de Saint-Exupéry: "If you want to build a ship, don't drum up men together to collect wood, assign tasks and divide the work, but rather teach the men the longing for the wide, endless sea." By the way, the saying is not only valid for men and not only for ships, but also for spaceships …



Sunset in orbit–seen from the International Space Station. Image: NASA

The following partner institutions have contributed to this booklet:

Deutsches Zentrum für Luft- und Raumfahrt (DLR)

DLR is the Federal Republic of Germany's research centre for aerospace. In addition to its research and development work in aeronautics, space, energy, transport, security and digitisation, DLR is responsible for the planning and implementation of German space activities on behalf of the Federal Government. DLR also has two project management agencies for research funding.

In close coordination with the European Space Agency ESA, DLR is involved in the International Space Station *ISS* and the mission of the German ESA astronaut Alexander Gerst in several ways–from scientific experiments to project support on the German side.

The present issue was produced on the initiative of DLR, which is also particularly committed to promoting young scientists. Many of the teaching experiments proposed here are based on similar experiments in DLR's student laboratories. In addition to these so-called DLR_School_Labs, which introduce some 40,000 children and young people to the 'fascination of research' every year, DLR also carries out numerous other measures for schools. These include competitions for ideas, information events–including workshops for teachers, a web portal for young people called DLR_next–see www.DLR.de/next–and teaching materials from the DLR_School_Info series, in which this issue also appears.

Deutsche Physikalische Gesellschaft (DPG)

The German Physical Society (DPG) is there for everyone: whether students, researchers, pupils, teachers, Nobel Prize winners, people working in industry or simply those interested in physics. The DPG sees itself as a link, mouthpiece and communication platform for people who enjoy physics. Together they all unite to form the largest physics society in the world, which as a non-profit organisation does not pursue any economic interests. The DPG is particularly involved in the school sector and in teacher training–and is also dedicated to political consulting. The DPG cooperates particularly closely with the Wilhelm and Else Heraeus Foundation.

Further information is available at www.dpg-physik.de.

Stiftung Jugend forscht e. V.

Jugend forscht is Germany's best-known competition for young researchers. The aim of the joint initiative of the Federal Government, "stern", industry, science and schools is to get young people interested in mathematics, information technology, science and technology (MINT) in the long term, to promote talent and to support them in their professional orientation beyond the competition. Young people up to the age of 21 can participate. Younger students who want to participate must attend at least grade 4 in the year of application. The participants in the competition look for an interesting question for themselves, which they work on using scientific, technical or mathematical methods. The winners can look forward to high-quality cash and material prizes as well as internships, study visits and participation in international competitions. The Jugend forscht network works in close cooperation with schools, business, science, politics and the media. The patron of Jugend forscht is the Federal President. The Federal Minister of Education and Research is the curatorial chairwoman of the Jugend forscht e. V. foundation. Around 250 partners from industry and science organise the competitions, donate prizes and promote other activities.

Further information is available at www.jugend-forscht.de.

Klett MINT

Klett MINT is one of the leading agencies for educational communication in Germany and, as a member of the Klett Group, part of the largest German educational company. An enthusiastic team of educators, marketing and media experts develops didactically sound and tried-and-tested formats for teaching on behalf of companies, foundations, associations and authorities. In addition to the production of materials, the range of services includes consulting and marketing in the form of events and campaigns.

Through close cooperation with engineers, scientists or pioneers of digital education, Klett MINT projects contribute to modern, fascinating lessons and ensure that important topics of the future can be successfully communicated to pupils. In the process, unique connections are created between school lessons and "real life".

Klett MINT has been supporting DLR in the production of teaching materials for quite some time. In addition, Klett MINT supervises the format mikromakromint of the Baden-Württemberg Stiftung. This programme supports groups of schoolchildren in free research at school and extracurricular venues and enables schoolchildren to carry out water projects on Lake Constance on board the research vessel Aldebaran every year. As a long-standing partner of the Genius initiative and as founder of the formats #excitingEDU for digital education, Klett MINT stands for innovations in the area of application-oriented teaching.

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

DLR Deutsches Zentrum
für Luft- und Raumfahrt