WHAT IS PHYSICS

ARPHYMEDES

Aristotle (384-322 BCE)

Fig. 1

People still study his ideas today to learn about the principles of nature.

Aristotle was an important philosopher from Ancient Greece. He talked about nature of things that we now call physics. Instead of talking about specific theories or facts, he focused on general ideas about how things in the nature, both living and non-living ones, work. He wanted to figure out why things change or move and what causes them to do that. He was especially interested in how things, including living creatures and/or the universe itself, move and work together. Aristotle's ideas are at the beginning of a long line of books that he wrote about physics, the universe, and living things. People still study his ideas today to learn about the principles of nature.

Galileo Galilei (1564-1642)

The Sun is at the center of our solar system.

Galileo was an Italian scientist who studied stars, but also how things move in general. He was called the “father” of many important things in science. He studied how fast things move, how gravity works, and how objects fall. He also worked on everyday things like pendulums and balances. Galileo believed that the Sun was at the center of our solar system, which got him in trouble. He had to stay under house arrest until his death. But even though he could not leave his house, he still wrote an important book called “The New Sciences” before he died.

Fig. 2

Albert Einstein (1879-1955)

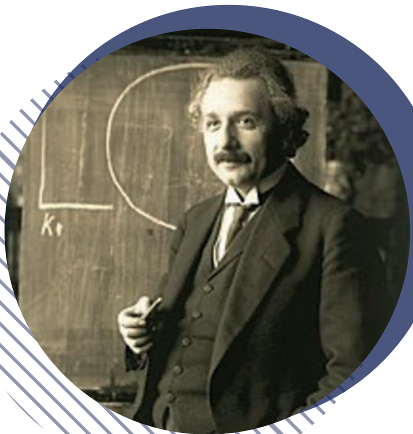


Fig. 3

The world's most famous equation: $E = mc^2$

Albert Einstein was a German-born physicist, widely acknowledged as one of the greatest and the most influential physicists of all times. Einstein is famous for coming up with the theory of relativity, which is all about how time, space, and gravity are connected. He also made important contributions to another theory called quantum mechanics, which helps us to understand how the smallest particles behave. Einstein’s mass–energy equivalence formula $E=mc^2$, which arises from relativity theory, belongs to "the world's most famous equation". Because of his important discoveries, he won the Nobel Prize in Physics in 1921 for figuring out the law of the photoelectric effect, which helped to understand wave-particle duality of light and develop the theory of quantum mechanics even further.

On this page you can find some proposals for projects that you can make at school or at home. There are even more on the accompanying webpage.

Project proposals:

1. Use one of the historical units of measurement to measure the width of the class.

2. Make your own time measuring device to measure the time to boil an egg.

3. Measure a length of wavy path. How can we do it?

4. Spot the International Space Station on the sky at night.

5. Create a robotic arm to pick different things.

Technical application

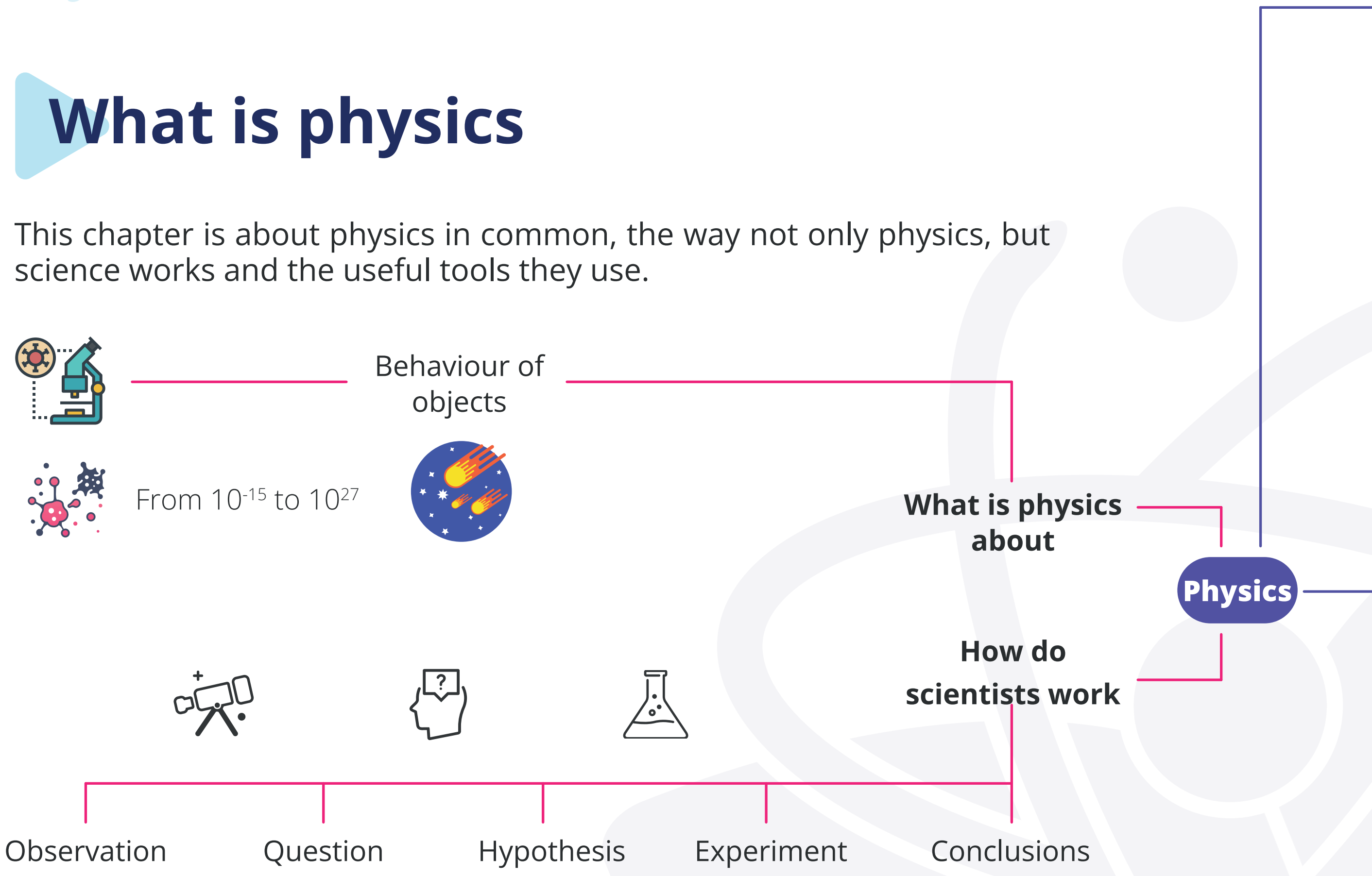
1. How does the International Space Station orbit around the Earth?

2. What devices are using technology developed in the space programs?

3. What experiments are actually done on ISS?

What is physics

This chapter is about physics in common, the way not only physics, but science works and the useful tools they use.



Physics studies how objects from the very tiny to the very big, and from the beginning of the Universe to its end behave. It searches for patterns or rules of behaviour of these objects.

Watch the following animation, it shows the size of objects using the power of ten.

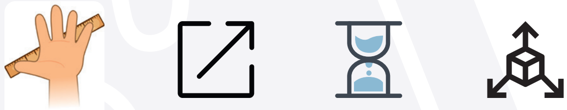
Why do we need physics

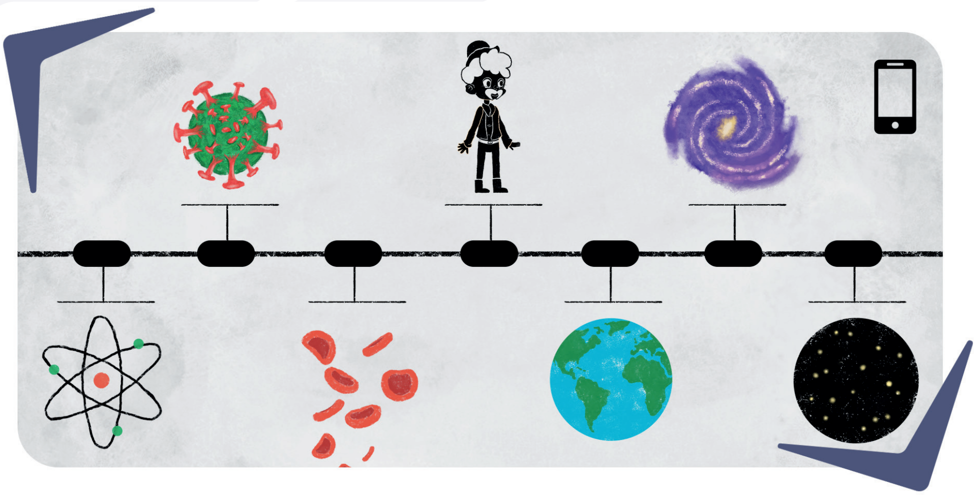
- Flying machines (aeroplanes, rockets, drones)
- Floating ships
- Seeing stars far away in the space
- Imaging internal parts of the body (CT, IRM)
- Lighting our houses and cities
- Heating our buildings
- Creating new materials and structures (rocket shields, invisible cloak)

... and for many other areas

Tools and language for physics

- Physical quantities
  - SI Units
    - second [s]
    - metre[m]
    - kilogram [kg]
    - ampere [A]
    - kelvin [K]
    - mole [mol]
    - candela [cd]
- Stage
  - Time
  - Space
- Estimation
- Scaling





Can you find some objects with the following dimensions? Try at least 5 of them. Write them down.

Your comments, question, observations.

The beauty of science is that part of it provides answers to problems and the other part discovers the next problem that requires a solution. From ancient times many rules and laws have been changed, upgraded, and

Some Famous Discoveries In Physics - Timeline

PRE-SCIENTIFIC

- 384–322 BCE - Aristotle: Aristotelian physics – any theory must be based on observed facts
- 250 BCE - Archimedes: Archimedes' principle

16th century

- 1514 - Nicolaus Copernicus: Heliocentrism – The Earth rotates around the Sun and not the other way round
- 1609, 1619 - Kepler: Kepler's laws of planetary motion

17th century

- 1632 - Galileo Galilei: The Galilean principle - the laws of motion are the same in all inertial frames.
- 1660 - Blaise Pascal: Pascal's law

21th century

- 2021 – Syukuro Manabe, Klaus Hasselmann - physical modelling of Earth's climate, quantifying variability and reliably predicting global warming
- 2020 – Reinhard Genzel, Andrea Ghez – discovery of a supermassive compact object (black hole) at the centre of our galaxy
- 2019 – Michel Mayor, Didier Queloz - discovery of an exoplanet orbiting a solar-type star
- 2018 – Arthur Ashkin - inventions in the field of laser physics, in particular for the optical tweezers and their application to biological systems
- 2017 – Rainer Weiss, Kip Thorne, Barry Barish - observation of gravitational waves

10^{-15}m Proton	10^{-2} m	10^{14} m
10^{-14} m	10^{-1} m	10^{15} m
10^{-13}m	10^{-0} m	10^{17} m
10^{-12} m	10^{-1} m Whale	10^{18} m
10^{-11} m	10^{2} m	10^{19} m
10^{-10} m Water Molecule	10^{3} m	10^{20} m
10^{-9} m	10^{7} m Diameter of Earth	10^{21} m

10^{-8} m Virus	10^{8} m	10^{22} m
10^{-7} m	10^{9} m Diameter of Sun	10^{23} m
10^{-6} m	10^{10} m	10^{24} m
10^{-5} m	10^{11} m	10^{25} m
10^{-4} m	10^{12} m	10^{26} m
10^{-3} m Needle Tip	10^{13} m	10^{27} m Observable Universe

supplemented, but the search for understanding the world goes on and scientists try to find answers on current research issues. Scientists must follow the principles, procedures, and ethical issues of scientific research.

1687 - Isaac Newton: Newton's laws of motion, and Newton's law of universal gravitation

18th century

1785 - Charles-Augustin de Coulomb: law describing the behaviour of electric charges

1782 - Antoine Lavoisier: Conservation of mass

19th century

1896 - Henri Becquerel: Radioactivity

1895 - Wilhelm Röntgen: X-rays

1887 - Heinrich Rudolf Hertz: Electromagnetic waves

20th century

1980 - Richard Feynman proposes quantum computing

1925-27 - Niels Bohr & Max Planck: Quantum mechanics – behaviour of particles (size of atom and smaller) and light

1915 - Albert Einstein: General relativity

1913 - Niels Bohr: Bohr model of the atom

1911 - Ernest Rutherford: Discovery of the atomic nucleus (Rutherford model)

1905 - Albert Einstein: Special relativity, proposes the photon to explain the photoelectric effect – found out how energy of light releases electrons in a metal and creates a current

Physics teaches us to look for odd and interesting things and to think about them. Through physics we learn how to process information, analyse information, and pass judgement on information.

Physics explains things like, e.g.:
- why planets move
- why ships float,
- why sugar dissolves better in warm tea,
- why do we see rainbows when it rains and many, many others.

Without science there would be no: TVs, computers, cell phones, light bulbs, aeroplanes, rockets, automobiles, electricity, and others.

Do you know that physics also has its popular stars? They share their excitement of discovering at various popularization events, through television, YouTube, and various podcasts.

Fig. 4

Neil deGrasse Tyson (born 1958) is an American astrophysicist, planetary scientist, author and science communicator.

"Physics is not a satchel of facts to be regurgitated, it is an understanding of the operation of nature. You do not have to learn every example, you can learn the foundational things and then apply the knowledge to what you see. That is the beauty of it and that is why physics' books are not the fattest on the shelf."

Brian Randolph Greene (1963) is an American theoretical physicist, mathematician, and string theorist. He is the chairman of the World Science Festival since co-founding it in 2008. It is a famous world event. Find out some topics that you think are interesting. "We all begin our life as little scientists - from the time we can walk and talk, we want to know what things are and how they work."

Fig. 5

Physics explains things like, e.g.:

Your comments, question, observations.

Without science there would be no:

Your comments, question, observations.

But there are many others who share their enthusiasm of discovering the rules and patterns that govern our life. You will find them in each country all over the world. There are science festivals, museums, and science centers where you can play and enjoy the world of science.

Find such people and places in your country and invite someone to come to your school, or ask teacher to go and visit the place you are interested in. Following are some examples where you can find such places and inspirations for Slovak pupils and teachers.

Search on YouTube

Konference Elixír do škol (elixirdoskol.cz) Milujeme vědu

Search on YouTube

Science experience center Aurelium made by KVANT forschool in Bratislava, Slovakia

Search on YouTube

Fyzika | Jednoduchéfyzikálnepokusy | PaedDr. Klára VELMOVSKÁ, PhD. | UniverzitaKomenského

Search on YouTube

JozefBeňuška - Pohodováfyzika | Fyzikálnepokusy | festival Pohodaprednáška

Search on YouTube

Zaujímavéfyzikálnepokusy | FrantišekKundracik | JednoducháFyzika | DeňotvorenýchdveríMatfyz

How do scientists work?

The way scientists work dates to the 17th century, to Galileo Galilei and Francis Bacon, who were the main actors of science revolution. However, it is still Galileo who has earned the position of the founder of the modern scientific method. The reason is that Galileo applied all the main steps of scientific research in his work: observation, research question, a testable hypothesis, testing the hypothesis by experimenting, analyzing the results, and expressing it in the language of mathematics.
More detailed: Scientists come across some problem or observe something odd and so they formulate the question. They gather information, read scientific papers, and then form the hypothesis. The hypothesis must be testable. (My flowers were stolen by fairies is not a scientific hypothesis).

Look on the Internet and find some testable hypothesis. They do not necessarily have to be in the field of physics.

Your comments, question, observations.

For testing the hypothesis experiments are used to gather data. You must repeat the experiment many times and each time you put down the data you see.
Data are analyzed to confirm or reject the hypothesis.
If the hypothesis turns out to be false, procedure is usually repeated to make sure that there were no errors in conducting the experiment or recording and processing the data.
If the hypothesis turns out to be true, it is always good to repeat the procedure to be sure whether the results are error free.
After reaching conclusion about the hypothesis, the results are communicated with scientific community so that they can redo the experiment and test the hypothesis themselves.
If the scientific community agreed upon the results, new advance in the science is reached.

Following is often repeated experiment; you can find the results on the Internet and compare with your own.

Observe the behaviour of water and other liquids by your choice, how many drops of water made by eyedropper will fit on the surface of various coins before the liquid spills over the edge of the coin. From your observation and data, what does the amount of liquid on the coins depend on? (The science connected to this activity is a bit advanced but with the help of a teacher you can come to some conclusions.)
Materials needed: eyedropper, water and other liquids, different coins.

Procedure:

1. Start with the smallest coin. Squeeze the drop on the surface and observe its behavior.
2. Predict how many drops will fit on the surface.
3. Record the number of drops.
4. How was your prediction?
5. Repeat the procedure with other coins and liquids.
6. Record your results in the table below.

Number of drops

Liquid	20 cent	50 cent	1 euro
Water			
Oil			
Detergent			
Alcohol			

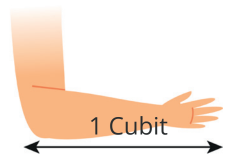
But remember. There can still be flaws in whatever step we did and so scientists publish their conclusion, so that other scientists can redo the experiment, gather data, and agree, or disagree with them. Only after common agreement conclusion is made, which is called objective truth. It means it is true, whether we believe it or not.

The scientists live in all countries, to be able to discuss together, they need to use common scientific language.

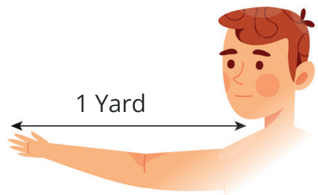
What tools and language do we use in physics?
Physical Quantities

The language of physics uses **physical quantities (words)** and looks for **relationship among them. Relationships are expressed by equations, graphs, tables (syntax of the language), that is why we often say that the language of physics is mathematics**. Physics is about telling the stories based on the mathematical description. **In physics we also have objects (characters), interactions (relationships), time sequence (plot), causes and principles (message) and the stage where the show goes on**.

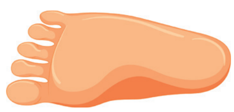
Objets are described by physical quantities. Physical quantities are characteristics or properties of an object that can be measured or calculated from other measurements. Already people who live in ancient times needed to measure and compare sizes of different things. Parts of the body were used as measuring tool in several civilizations.



A cubit is the length from the elbow to the fingertips. It was used in ancient Egypt.



Yard is the distance between the end of the outstretched arm and one's chin.



Foot is the measure of one's foot.

Hand-span is the maximum distance between the tips of the thumb and little finger.

Questions from astronomy, physics, chemistry, geology, and biology often give very large or very small number that is difficult to imagine and to write out in full. For example, the distance from the Sun to Earth is 149 600 000 000 m. Writing that many zeros is inconvenient and it is easier to make a mistake by calculation therefore we use for the number its scientific notation. It means writing numbers that are too large or small as a decimal: 149 600 000 000 m = $1{,}496 \times 10^{11}$ m.

But there were many problems with these measurements.

As civilization progressed and began to trade with one another, there became a need for a system of measurement that could be used by all countries. In the 17th century, some people started to develop the modern metric system, which is today called the International System of Units, or SI. The abbreviation SI is based on the system's French name, *Système Internationale d'Unités*, and is used in all languages.
The SI consists of seven base units, from which other units are derived.
The seven base units: of the SI are the metre, kilogram, second, kelvin, ampere, candela, and mole. We will need the first three for the start.
The metre (m) is the unit used to measure length and distance.
The kilogram (kg) is used to measure mass, which is a measure of the amount of matter in an object or substance. The second (s) is the SI unit of time.
The importance of using proper and standardised units can be described by using an example of the NASA "biggest embarrassments" in history. In the year 1998 NASA designed to monitor the Martian atmosphere by a 110 million Euro satellite. The navigation system was designed by Jet Propulsion Laboratory, which used metric system. While Lockheed Martin Astronautics in Denver designed and built the spacecraft in the English system. They provided the Jet Propulsion Laboratory with the crucial acceleration data calculated in English system, without the conversion to the standard SI metric. As a result, the spacecraft was reading incorrect data for the calculation of the safe distance to orbit the Mars. The result was that 125 million USD satellite ended up flying into the Martian atmosphere (Wikipedia contributors 2021).

Remember that the value of a property or a quantity is a combination of a numerical amount (1) and a unit (kilogram/kg) – 1kg. Using units makes us stop and think. Solving physical problem only with numbers do not reveal our mistake.

Scientific notation tells us how to move the decimal point, filling in placeholder zeros as we go.
The decimal point of a **large number** is moved **left** and the exponent is **positive**.

$$35000000 = 3,5 \cdot 10^{7}$$

The decimal point of a **small number** is moved **right** and the exponent is **negative**.

$$0,00035 = 3,5 \cdot 10^{-4}$$

Another way is to use prefixes. For example, instead of 1000 m, we use 1km. SI prefixes strictly represent power of 10.

Name	Symbol	Scaling factor	Example of using the name
tera	T	10^{12}	Terabytes of computer hardrive.
giga	G	10^{9}	Gigabytes of computer memory.
mega	M	10^{6}	Megawatts of electricity required by an entire city.
kilo	k	10^{3}	Mass is often measured in kilograms.
deci	d	10^{-1}	Fluids can be measured in deciliters.
centi	c	10^{-2}	Smaller distances are measured in centimeters.
mili	m	10^{-3}	Time in sports are often measured in miliseconds.
micro	μ	10^{-6}	The thickness or diameter of microscopic objects, such as microorganisms is measured in micrometers.
nano	n	10^{-9}	A water molecule is less than one nanometer.
pico	p	10^{-12}	Atomic radii is measured in picometers.

We have mentioned that physics is interested in things ranging from very small to very big, in the following table are some examples. Can you find examples and fill in the table ?

Length (m)	Phenomenon Measured	Mass (kg)	Phenomenon Measured	Time (s)	Phenomenon Measured
10^{-10}		10^{-5}		10^{-3}	
10^{-3}		10^{2}		1	
10^{11}		10^{25}		10^{7}	
10^{26}		10^{53}		10^{18}	

Another thing that is necessary to define is the stage. Everything happens in space and time. If we want to meet with someone we must say when and where. In science we mostly use the Cartesian coordinate system which was developed by the mathematician Descartes.

Generally, we can think of position as a point in space or a point on a plane or just a point on a line. Accordingly, it can also be described by the introduction of a coordinate system (three, two or only one coordinate).We live in three-dimensional space.

Descartes developed the coordinate plane which has two intersecting number lines that form axes. The horizontal axis is called the x-axis and the vertical axis is called the y-axis. The axes intersect at the point called the origin. A point on the plane can be described by its x and y coordinates written as an ordered pair: (x, y). The coordinates of the origin are (0, 0). Following animation will help you to imagine it.

Time

We are all familiar with time. Time is something that we use to measure how long things take and when events happen. It corresponds to the period that elapse between the two events. To measure time, we use clocks. We can think of it as a line that goes from the past to the future. Every event, like your birthday party or a school lesson, happens within a specific amount of time.

Time helps us keep track of our daily life. We cannot escape it because it is always there. Sometimes time feels like it is passing quickly, namely when we are having fun. Other times, it feels like it is going slowly, particularly when we are waiting for something.

Have you ever tried to explain to someone what the time is? Try to explain it to your classmate. What is your best explanation?

Your comments, question, observations.

It was very difficult, but do not be said. Probably nobody knows what time is, what we know is what time enables us. Thanks to time we can talk about change, we can recognize structures and patterns in our lives and the life of our universe. In our memory we remember events that occur in an apparently irreversible succession from the past to the present and into the future. Let us think about time like the quality that is measured using clocks. For measuring time, we try to find processes out there in nature that are cyclical, repetitive. Time rules our daily life, day has 24 hours, 60 minutes is an hour, 60 seconds is a minute. I have a task for you. Make your own clock.

1. Make research on the Internet, investigate books, ask some adults. It is up to you to find something repetitive, cyclical process that will be base for your clock.
2. Make some sketches of your clock and find material for its construction.
3. Make your clock.
4. Compare the time measured with your clock with the one you have. How precise are they? Can you improve the precision? How?
5. Present your clock to your teacher and classmates. Remember that according to your presentation everybody must be able to do the same clock, and do not forget to mention whether it was your idea, or where you found it. This is called citation.

Your comments, question, observations.

Science uses tools and devices to improve science work. We would like to mention two tools that help understanding even complex problems: estimation and scaling.

Estimation

Sometimes, when we must solve a problem, we are not able to grasp its whole range. In such cases we try to describe it using the estimations. They help us to design experiments and to get the best possible results.
We make estimations quite often, even without thinking about it. We estimate how long we need to get ready to school and according to it set up our alarm clock. The estimation technique is named after physicist Enrico Fermi ,as he was known for his ability to make good approximate calculations with little or no actual data. Fermi problems typically involve making justified guesses about quantities and their lower and upper limits.
There are even competitions between groups of students in solving Fermi problems, you can find the ones in the close vicinity of the place where you live. Some examples to make you interested in competitions.

Example

You would like to invite 5 friends for a party. How many boxes of juice should you buy? How many packets of chips?
Solution
Firstly, we estimate how much juice drinks one person – 0,3 to 0,5 l. We have 5 friends so the estimated amount for 0,5 l per person is 2,5 l. Because juice is sold in 1 l boxes, we buy 3 boxes.
If we suppose for one person half pack of chips, your estimated amount is the same 2,5 packs of chips and we buy 3 packets.

We can practise estimation also with lentil or jellybeans.
Make a grid of 9 equal squares, the size should be according to the size of square box you will use.
Put the grid into the box.
Take 2 teaspoons of lentils or jellybeans and place them in the centre of the box.
Shake the box so that they will spread evenly in the box.
Count the number in one square.
Ask your friend to do it with another square.
Add the numbers together and write down the sum.
Divide the sum by 2 to get average number in each square.
Multiply the average number by 9 to get the total number.
Verify your estimation by exactly counting the lentils, or jellybeans, or whatever similar you used.
How good was your estimation?
How can you make it better?

Example
Can you estimate the number of fish in this picture? You can use the idea from previous example.

Fig. 6

Scaling

Another useful skill is scaling. We have Arphy's figure and we would like to make it twice bigger. We must change the width and height of the picture. Watch what will happen if we stretch Arphy only vertically or horizontally.
See the animation, to learn how to scale Arphy.

We usually prepare omelette from hen's eggs. How about making it from an ostrich's egg? Ostrich's egg is 3 times larger than hens' (looking at the length). How many hen's eggs do we need for such a large omelette as from one ostrich egg? We make an omelette from the volume of an egg. When thinking about the volume of an egg it means the length to the power of three. It is an estimation as the egg is not symmetrical. The length measures have increased three times, the volume has increased 3x3 times = 27 times. Ostrich's egg weighs about 1.4 - 1.8 kg, its length is about 15 cm and can replace 25 to 30 hen eggs.

Fig. 7

Scaling ARphy