

TIPPING POINTS IN THE HISTORY OF SCIENCE



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TIPPING POINTS IN THE HISTORY OF SCIENCE

We will learn about many different inventions and discoveries that changed the way people see the world.

Tipping points in history is a topic that makes students think, reflect and find connections between different ideas. It doesn't ask the students to memorize any theory, but it requires reading and writing as well as online searching skills to do research on different discoveries. It also has several hands-on classes to break the routine of the class and engage those students who might find boring the searching lessons.

This project requires no previous knowledge and can be carried out at any time, but we would recommend to do it after the students have gone through some other projects, so they can make use and reflect on the knowledge they got in previous cycles.

Skills:

- Linking theoretical knowledge with real life
- Using timelines
- Doing online research
- Finding connections between different concepts
- Presentation skills
- Talking in public

Learning goals:

- Relations between discoveries in different fields
- Theory of evolution
- Genetic material and inheritance
- Electricity. Static and current

Lesson plan

Class 1: The evolution of history

For the first time in the project our students will listen to a master class where we will give an introduction to different ideas that changed the world as it was.

What do we need to know?

For this class we will hold a lecture that will be supported by a SlideShow. We prepared a script together with the slideshow to be the guide of the lecture, so here we leave the script itself. The slideshow can be found together with this document.

Slide 2

Naturally, humans have lots of prejudices. We have an idea about things based on what we know and the environment around us. We have the tendency to put ourselves in the centre of things and explain the world accordingly. Clearly we know much more about our direct environment, we know a lot about our house, our street, still quite some about our city, much less about our country, and beyond that even less.

Slides 3, 4 and 5

Maps, for example, are different for different countries because they position themselves in the centre and use themselves as reference point.

Slide 6 and 7

This same line of thought of putting ourselves in the centre of things, made people believe the earth is the centre of the universe. However, this turned out to be wrong. This was a mayor tipping point in science and changed a lot of things.

Slides 8 and 9

Subsequently people thought our sun was very unique, however with the development of technology, people found out that there are many stars with planets orbiting around them, so we are not that unique after all.

Slide 10

Because people are naturally curious, we want to expand our understanding of the environment around us more and more, so we develop technologies that make this possible, and slowly we can look much further than just our house, our street, and our city. Because of the curiosity, we lose our prejudices about our place in the universe and the world around us. Curiosity is the key to science. If you are not curious, you will not ask yourself questions, and you will not end up doing research and understanding more about the world around you.

Slide 11

Curiosity brings us to questions, these questions can be very big and difficult. Think of material, what are things made of, or the universe, or life and death. Initially, people try to solve these questions with mythical answers, answers that you just have to believe, without proof. For the universe for example, this was astrology, where people believed the future could be predicted by looking at the stars.

But what is the difference between science and the myths?

Science is empirical. You have to do experiments and see that your theory is valid. These experiments should be replicable anywhere and give the same result.

Let's see some examples of people who because of questioning the mythical theories through a scientific method, found answers that are still having a big effect on our lives:

Slide 12

Benjamin Franklin. He found out that lightning is not God being angry, but electricity. He tested this by putting up a kite; the lightning would strike the kite and the electricity goes down the string. In the beginning, like when some people said the Earth was not in the centre, his theory was difficult to accept for many people, as it would go against the idea of the higher up people who believed and said it was God being angry. It therefore took a long time for churches to put the lightning distractors on top of the church, as they said the theory was wrong.

Slide 13

Charles Darwin; Evolution. Basically the idea is that we started simple and everything developed and became more complicated, because of survival of the fittest, natural selection. His theory

was easy to understand, but it went against everything that people believed on at that time. According to him, species were not a fix unit, they changed over time to adapt to the environment. So, Darwin had to face harsh opposition to his ideas, and even ridiculization from other scientists and the public opinion.

Slide 14

His theory meant to say that everything on Earth is related to each other. So we can make a family tree and a timeline of which species started where.

But how do we know this? We cannot look back in time. So fossils play a big part in reconstructing the family tree.

Sometimes there are theories that need time to find proof. For example, “at some point fish moved out of the sea and became land creatures”. It took a long time until a fossil was found that actually supports the theory. So, if there is enough evidence to support a new theory, the theory as such stays as a base, but it can still be adjusted when new evidence, in this case, fossils are found.

Slide 15

Science and technology are a way to release ourselves from prejudice, and they both feed each other to keep on advancing. Because of knowledge you gain, you can make something and subsequently this technology will help you measuring, proof theories and gain more knowledge.

Slide 16

For example, gaining knowledge about physics and reflection led to the creation of lenses that allowed to create microscopes. This new technology, allowed to gain new knowledge about very small things that had yet not been studied.

Slides 17 to 24

On each of these slides there is a drawing. We will ask our students to try to guess what is each of them representing, and we will go back to it in the final part of the presentation

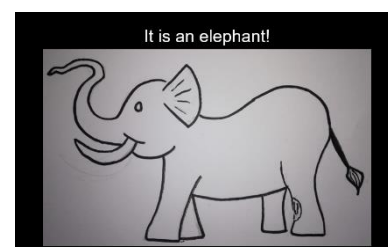
Slide 25

Everything in our universe is related. We know that the Universe is expanding. This means that before, things were much closer to each other. If we go back in time, things were so close to together that the huge pressure caused a huge explosion; the big bang. The big bang was the origin of both the smallest things we know and the biggest things we know, so they are all connected.

The interior of an atom, a human cell and the core of a star, everything is somehow connected. And so, all sciences are connected as well. We have tried to categorize reality and make closed boxes, each one labelled as one science, and each one focused on studying one specific aspect of reality. But the truth is that each and every science needs the rest; discoveries on one science can speed up discoveries in another one, provide new proofs for unproved theories or open new areas of research.

Slide 26

If we try to observe reality just through the glasses of one specific discipline we might not get the full picture, while if we put together the pieces from each of them and analyse the results as a whole, we might easily see, that there is *an elephant* in front of us.



Picture 1 Slide 26

What do we need to prepare?

- A laptop
- A projector to show the SlideShow
- A paper and pen for each student

Class session

For this session the students will just pay attention to the lecture given by the teacher, following the script of the SlideShow.

Class 2: Tipping points in Science 1

The students will do research about different inventions and discoveries and present their findings. Then we will mark them in a timeline covering from the discovery of fire to nowadays

What do we need to know?

In this class the students will do research about different important inventions and discoveries in science. We prepared eight for this session, but the amount could be changed according to the needs of the class. The discoveries that we chose for this session were focused on biology.

Existence of blood types

Different people have different blood types according to the presence of different proteins in their blood cells. There are 23 group systems that give hundreds of blood types if we take into account all the different elements present in the blood. The most important systems are the Rh factor and the presence of A or B antigens in the red cells. Those give the types A, B, AB and O, each of which can be positive or negative.

The ABO system was the first one discovered, in the early 1900s by the Austrian biologist Karl Landsteiner. His discovery allowed blood transfers to be safer, since choosing compatible blood types prevents rejection of the transfusion. Thanks to his findings, the first successful blood transfer was performed in New York in 1907.

Genetic inheritance

We all resemble our relatives. This is due to genetic inheritance. Our parents pass to us their genetic information that they got from their parents. This information contains all the data needed to create us, including the colour of our eyes or the shape of our noses. Gregor Mendel, a Czech monk was the first person to make an experiment and study the way one generation passes information to the next. His discoveries didn't get attention until 1900 when his job was rediscovered and now he is considered the father of modern genetics.

Between 1856 and 1863 he carried out experiments with pea plants that would lead to a set of rules about how information is transmitted from a generation to the next. For his experiment he crossed purebred yellow peas with purebred green peas. All the resulting peas were yellow. He crossed the offspring, and found that in the third generation green peas appeared again in a proportion of one green for each three yellow.

Circulation of blood

In 1628 William Harvey, an English physicist published a book where, for the first time, the circulation of blood around the body was explained. He was the first person stating that blood flows in only one way making two different cycles: once around the lungs and one around the body. He also stated that blood cannot move directly from one side of the heart to the other.

He knew that a discovery like this, that went against what people believed at the time, would be very difficult to accept, and he was right. It took over 20 years for his discovery to be fully accepted.

Double helix structure of DNA

Nowadays we are all familiar with the picture of a DNA string with a double helix shape. This discovery took a lot of steps. First the existence of a substance inside the core of cells was discovered, then its elements, sugars, phosphates and four compounds with nitrogen. Its shape was discovered in 1953 when Watson and Crick (English and American respectively). For this discovery, an essential tool was a picture taken by the chemist Rosalind Franklin. It was taken from Franklin's laboratory without her consent.

Cellular division

Using microscopes to investigate tissues was an emerging idea during the XIX century. Walther Flemming, a German professor was a real innovator in this area. He used a microscope to investigate the way cellules divide. Since the microscopes back then weren't as advanced as nowadays, the images were not clear, so he decided to add dye to his samples to get better images. Thanks to this, he was able to observe how one cell would create two cores, each with all the genetic information, and then divide. To share his knowledge, he wrote a book explaining the whole process of cellular division that was published in 1878.

Genetic code decipher

Once the composition of DNA and its shape were known the next step was to understand how it could be read. It contains the instructions to build anything in our body, but these instructions were in a language that had to be deciphered.

The genetic code was deciphered in 1961 by the biologists Nirenberg and Matthaei, who were American and German respectively. They discovered that every triplet of the four possible bases that form DNA, C, G, T or A, indicates one amino acid to synthesize. So, a string of DNA could be read as a sequence of bases, where every three of them would indicate an amino acid to create. All the amino acids together would form a protein.

Existence of microorganisms

Leuwenhoek was a Dutch textile businessman. He got some lenses to check the quality of the textiles, and he developed a deep interest in lenses after that. He built his own microscopes, and thanks to them, he was the first person to see a microbe, in its shape and the way it moves, in 1647. He investigated water, blood and other substances and sent his findings to the Royal Society, the English academy of Science. He was also the first person to observe a spermatozoid, proving that there were organisms in sperm. Even if he was not a scientist, but an amateur, he is considered the father of microbiology.

Synthesis of urea in a laboratory

Urea is an organic substance. It was believed that no organic substance could ever be recreated outside of a living body because it needed some kind of life power to be synthesized. Wohler, a German Chemist created urea in a laboratory in 1828, proving that organic material didn't need life power to be created.

What do we need to prepare?

- A laptop to do research for every two students. They could also use their own phones
- A big poster with a timeline covering from 1M years ago, when fire was discovered, until the current date
- Coloured markers

Class session

We will start the class showing the timeline. On it we can have some important events marked, like the discovery of fire, the invention of the wheel, the invention of writing, the beginning of Christianity and Islamism, or the discovery of America. Then we will introduce the objective of the class: doing some research about important discoveries in science. Each student will get one discovery and they will have to search for some basic information about it.

We put all the inventions in a box and each student picked one randomly. They can also be assigned according to the difficulty of the invention. We made students work in pairs to investigate two discoveries, so they would work together but everyone would have a discovery to present.

To avoid the students from presenting all the information they could find about their topic, we asked them to answer four questions: "When was this discovered?", "Where was it discovered?", "Who discovered it?" and "Why do you think this was an important discovery?". Once they have the information, they will present it to the rest of the class. They can also share any interesting or curious data they find, but they will have to adjust to a short time, around five minutes per student.

Once a student has presented their topic, they will add it to the timeline in the right place. They will have to choose what colour to use to write the discovery according to what discipline of science they think was most important for that particular invention. We used blue for Physics, green for Biology, purple for Chemistry and yellow for Geology. They could also use several colours if they consider that the discovery should be categorized in several disciplines at the same time.

Class 3: DNA

The students will learn how DNA stores its information and how it is passed from parent to child. Then they will use a chart to transcript DNA bases into the proteins that give colour to our hair and eyes.

What do we need to know?

DNA is short for deoxyribonucleic acid. It is basically the place where the whole building plan for our body is stored. It contains all the information of what we look like and how our body functions. For example, we could think of it as the building plan for a big airport. In this building plan all the information will be written down about what the airport will look like, but also about the places the airplanes leave from, and when they are allowed to leave, and when they are not allowed to leave. The DNA is like this but for our body. Almost all living organisms have DNA and it is located in the core of every single cell that forms our bodies.

We inherit DNA from our parents. The genetic information packs up in blocks, 23 blocks called chromosomes. We get a set of chromosomes from our fathers and another from our mother, so we have 23 pairs of chromosomes. Each chromosome has specific information. For example, the pair number 23 is the one that defines if we are physically a man or a woman.

When we have children we will only pass one chromosome of each pair and our couple will pass on one chromosome of each one of their pairs. Besides, our pair of chromosomes get randomly mixed every time they separate, which makes each sibling different, since they will take slightly different chromosomes from their parents.

The information in DNA is stored as a code made up of four chemical bases: adenine (A), guanine (G), cytosine (C), and thymine (T). Human DNA consists of about 3 billion bases, and more than 99 percent of those bases are the same in all people. The order, or sequence, of these bases determines the information available for building and maintaining an organism, similar to the way in which letters of the alphabet appear in a certain order to form words and sentences. DNA looks like a double helix that looks a little bit like a staircase. The outside part is made out of sugars and on the inside the different base pairs look like the stairs. The bases always pair in the same way. Cytosine will always appear together with Guanine and Adenine will always appear with Thymine. This helps our body detect mistakes when the DNA is read.

We need many different proteins in our body and all of them are made out of amino acids. The different proteins are responsible for everything in our body, from the colour of our eyes to what diseases we can suffer from. There are only 20 amino acids that we need, and combined in different ways they create thousands of different proteins. The 3.079.843.747 bases in our DNA indicate how to create these proteins. Every three bases are an order to create an amino acid. As different amino acids are created they are attached together creating a protein. Finally, there are some triplets of bases that means STOP. They are the mark to stop the protein.

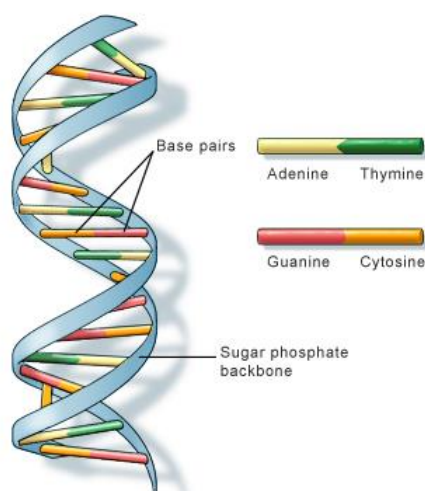
DNA is formed out of four different bases: Adenine (A), Thymine (T), Guanine (G) and Cytosine (C). These are presented in pairs. Adenine is always attached to Thymine and Guanine is attached to Cytosine. Using the chart below, it is easy to read a sequence of DNA. For example, let's say we have the following sequence:

A A A G C T T A A C G A A T T

We would start finding the respective pairs for these bases. We change every A for a T, T for A, C for G and G for C. So, we get the following:

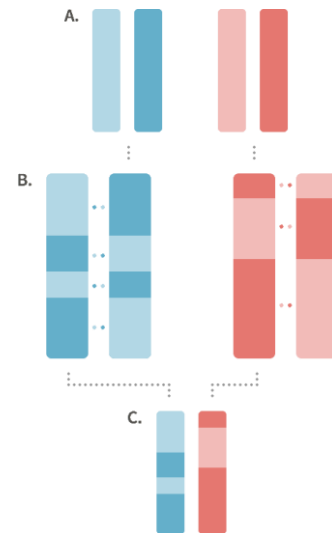
T T T C G A A T T G C T T A A

Now we find the amino acid created by each triplet until we find a STOP sequence.

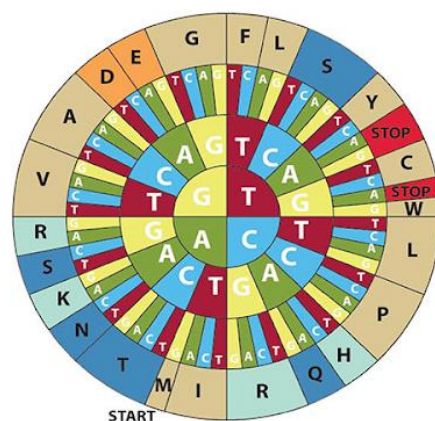


U.S. National Library of Medicine

Picture 4 Double helix structure of DNA



Picture 2 Mixture of pairs of chromosomes before being passed to the next generation



Amino acid code			
A - Alanine	G - Glycine	M - Methionine	S - Serine
C - Cysteine	H - Histidine	N - Asparagine	T - Threonine
D - Aspartic Acid	I - Isoleucine	P - Proline	V - Valine
E - Glutamic acid	K - Lysine	Q - Glutamine	W - Tryptophan
F - Phenylalanine	L - Leucine	R - Arginine	Y - Tyrosine

Picture 4 Transcription chart

T T T → Phenylalanine

C G A → Arginine

A T T → Isoleucine

G C T → Alanine

T A A → STOP

The resulting protein, is Phe-Arg-Iso-Ala.

The discovery and understanding of all this is not a job done by one person at one moment, but the combination of efforts of hundreds of scientists in different areas through the history of Science:

- Biologists, that knew how the cell is formed and how they divide.
- Studies about viruses, whose genetic information is simpler.
- Physicist thanks to who the X Ray techniques used for the discovery were available.
- Chemistry, that was needed to understand how the different bases join each others.

It also started investigations in many different fields and helped proving other theories that were already presented before:

- It gives strength to Mendel's genetic theory.
- It fits with the evolution theory from Darwin, that was stated years before.
- It helps understanding inheritable diseases.

What do we need to prepare?

- A copy of the transcription chart for every student

Class session

When we carried out this class we explained in the whiteboard, with drawings, analogies and discussion all the information about DNA. However, there could be ways to present the information in a more active way, as the one we are going to expose now.

We will tell the students what DNA is and how it packs into 23 pairs of blocks, chromosomes, each of which have different information. To understand how parents pass on genetic information we will give two balls of different coloured playdough to each student. This playdough will represent the DNA inside a cell. One colour will be coming from the mother, and the other, from the father.

The students can make chromosome pairs out of their playdough. It would be enough if each student makes just three or four pairs, it is not necessary for them to make all the 23 pairs of human beings. To make it easy to recognize different pairs, we can ask them to do a long one, a short one and a thick one, for example. Once they all have their chromosomes, we will ask them to work in couples. One will be the mother and the other will be the father. They need to decide what genetic information will be passed to their offspring. We want them to realize that each parent will have to pass only one chromosome of each pair, since otherwise the children will have double the amount of chromosomes. Another solution would be for each parent to provide half of the pairs. But then, how would each parent know what pair to provide? To understand why this option is wrong we can ask them to each make a decision on what to pass on without talking or even looking at what the other parent is selecting.

When all students understand how each parent provides one chromosome of each pair, some coming from their own mother and some coming from their own father, we will explain how, before division, the pairs are in contact with each other, so they get slightly mixed. The students can make three pairs of the same chromosome. If each pair gets a little bit mixed, all the six resulting chromosomes will be slightly different. For example, a blue one will have some red stains in the centre, while another one will have a big piece of red on the top side.

We will wrap up the conclusion quickly explaining again everything: how chromosomes get mixed and then one of each pair is passed to the next generation. With this, the way genetic material is inherited will be finished. The next part is to see how DNA is read and transcript. If the class is already too long, it could be split into two, and keep the following part for a second session.

We will explain in the whiteboard what DNA is made of and how the bases work. Then we will give out the transcription charts and we will explain how to use them. They will have to transcript thee following instructions:

Blue eyes protein = A A A G C T T A A C G A A T T → Phe-Arg-Iso-Ala

Brown eyes protein = C C A T T G G G G T T A A C T → Gly-Asp-Pro-Asp

Brown hair protein = A G A A T A C G A T T T A T C → Ser-Tyr-Ala-Lys

Blonde hair protein = G T T A T A C G A G T T A C T → Glu-Tyr-Ala-Glu

Finally, we will ask the students what branches of science they think are involved in everything we learnt today. This way we want them to reflect on how not only Biology is involved in this discovery, but Chemistry, Physics and Virology are as well.

Class 4: The discovery of penicillin

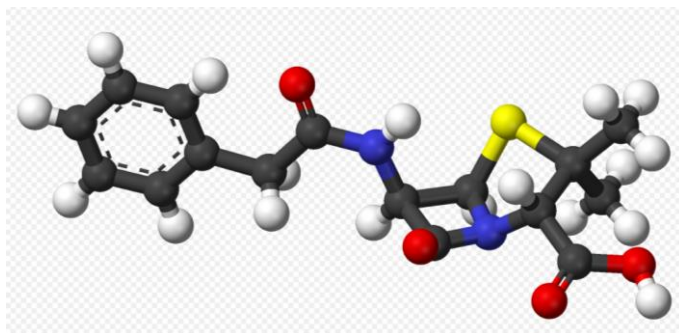
Students will learn how some discoveries happen by chance with the example of Penicillin. Then they will grow their own penicillin using bread.

What do we need to know?

Penicillin is an antibiotic that comes from mould. It is used to kill dangerous bacteria that infect us. Now it is not used as commonly as during the XX century (it was discovered in 1928) because we know other antibiotics that have less side effects, and because some bacteria, over the years, have developed resistance against it. However, it is still used very often. It prevents new cellular walls to be built in the bacteria cells. So, when a bacterium tries to duplicate and the wall is disintegrated, it cannot be formed again and the bacteria dies.

The story of its discovery is a very well-known example of serendipity. This is a discovery made by accident. Alexander Fleming was a Scottish scientist living at the beginning of the XIX century. One day, he forgot to close a dish with bacteria before leaving his laboratory. Some days after he came back and found out that the dish had now some green-blue mould that had entered through an open window, and it had killed the bacteria from the dish. After investigating the mould, he discovered that it was Penicillin. There are different kinds of Penicillin that kill different types of bacteria. This is one of them ($C_{16}H_{18}N_2O_4S$):

Penicillin can be grown in bread when it gets mouldy. Actually, mouldy bread has been used since old times to cure infections. The instructions to grow mould in bread are as follows:



Picture 5 A molecule of Penicillin

- Put bread in a bag
- Let it there until mould start to appear
- Take the bread and break it down in pieces
- Add a bit of water, put the pieces back in the bag and close it
- Don't move the bread until it is covered in green mould
- There will be white, blue, grey and green mould. The green one has penicillin

What do we need to prepare?

- Bread
- A plastic bag per student
- A sheet with instructions to grow Penicillin in bread
- A molecule of Penicillin built with a molecule building model

Class session

This will be a short class. We will explain the story of how Fleming discovered Penicillin by accident and how Penicillin is used to kill bacteria. Then we will present the Penicillin molecule for our students to see, and we will ask them to count the amount of each kind of atom that forms it. With this, we can get its chemical formula, $C_{16}H_{18}N_2O_4S$.

Then, we can pass to make our own Penicillin. We will tell our students how mouldy bread has been used before, even if they didn't know why it worked. So far the only step we can take in the production of Penicillin is to put bread in the bag. We will hand our students the sheets to grow the Penicillin and we will explain the steps that they can read in the sheet. Then the class will be dismissed and they can take the bread home to continue growing the Penicillin on their own.

Class 5: Tipping points in Science 2

The students will do research about different inventions and discoveries and present their findings. Then we will mark them in a timeline covering from the discovery of fire to nowadays.

What do we need to know?

In this class the students will do research about different important inventions and discoveries in science. We prepared eight for this session, but the amount could be changed according to the needs of the class.

Existence of the stratosphere in the atmosphere

The Stratosphere is one of the layers that form our atmosphere. Counting from the ground, it is the second layer, laying on top of the troposphere. In the troposphere temperature decreases as the height increases. It has a thickness between 7 and 17 kilometres depending on the place on Earth. Between the troposphere and the stratosphere there is a space, the tropopause, where temperature stays constant. In the stratosphere, temperature increases with height because the reaction between the ozone present on this layer and the ultraviolet rays from the Sun heats up the air.

This all was discovered in 1902 by the French meteorologist Leon Teisserenc de Bort. He was a pioneer in the usage of aerostatic balloons equipped with scientific instruments. Using this technique, he located the place where the temperature stopped decreasing, the tropopause. Simultaneously, another scientist, Richard Assmann also discovered the tropopause in 1902.

Discovery of Pluto

Pluto was the ninth planet of the Solar System, the one furthest away from the Sun. It was considered a planet until 2006, when it was categorized as a dwarf planet instead. It cannot be seen in the sky without a telescope. In the beginning of the XX century, an American businessman, Percival Lowell postulated the existence of a planet beyond Neptune and started searching for it. He spent 11 years using Mathematics and observation but he died in 1916 without results. In 1927 Percival's brother provided the funds to build a telescope that was used by Clyde Tombaugh to finally prove the existence of Pluto in 1930

Understanding of Dinosaur fossils

Dinosaur fossils were known since ancient times. People would find them when working their land, but they would not know what they were. Chinese thought that they were bones from dragons, and Europeans thought they were bones from giants and other biblical creatures. It was around 1820 when William Buckland, a reverend and Geologist, collected several fossilized bones of Megalosaurus and described a dinosaur for the first time in a scientific journal. He didn't use the word dinosaur, but he recognized it as a giant lizard. Some years later, Mary Ann and Gideon Mantell would identify another dinosaur, the Iguanodon, and they would recognize similarities between the fossils and the bones of iguanas.

Existence of planets in other solar systems

Until 1990 scientists suspected that there were planets in other stars. However, the technology available was not advanced enough to detect and find them. In 1992 the Polish astronomers Aleksander Wolszczan found proof for the first time of two objects orbiting a pulsar.

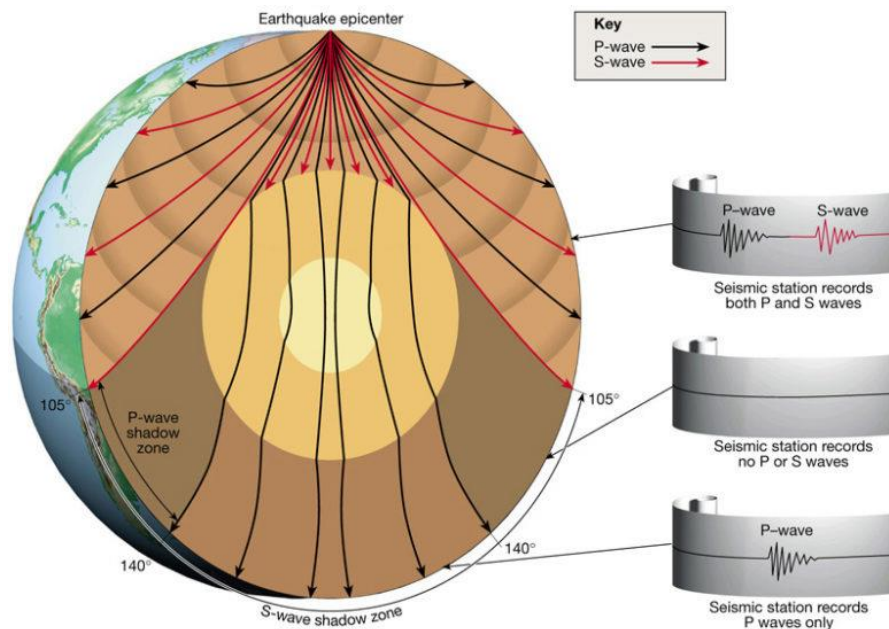
A pulsar is the result of a star that becomes too massive and explodes. They are called pulsars because they send regular pulses, radio frequencies. These pulses can be detected in laboratories, and if at some point the interval of the pulse is irregular, scientists can deduce that something is off. This is how Aleksander discovered that around a pulsar there were two objects orbiting.

Existence of the core of the Earth

Seismographs, machines to detect and measure earthquakes were invented in 1880. By then, the Earth was supposed to have a liquid core surrounded by a solid mantle, and the solid crust in the outside layer. Since traveling or getting samples from the inside of the planet is unfeasible all the information we could get from it came from the signals sent by earthquake waves. There are two kinds of waves, P and S, and both react differently to liquids and solids.

S waves cannot move through liquids, while P waves do, getting their direction changed because their speed is changed when passing from one medium to another. In 1936, Inge Lehmann, a Danish Mathematician and Geologist proved, by analyzing the measurements of different

seismographs around the world that the core of the Earth was divided into two regions, an external liquid one, and a solid inner core. She discovered that because, as shown in the graph, she observed that at some point S waves were not observed anymore and P-waves were displaced from where they were supposed to be. From that she could deduced that they had encountered a liquid region. Besides, P-waves on the opposite side of the earthquake changed direction again, so in their way through the liquid medium that had to encounter another solid area that changed their speed.



Picture 6 P-waves and S-waves traveling through the Earth

A very interesting detail about Inge's life is that she attended the first Danish school that taught boys and girls alike. She complained during her life about having to compete in the scientific field with men that were incompetent but who were given more credibility because they were men.

Lucy's skeleton

Lucy's skeleton is a set of fossilized bones that belonged to a female individual of a species that had a small skull, similar to monkeys, but that walked on two legs, like apes. It was discovered in Ethiopia in 1974 by the American paleoanthropologist Donald Johanson. Its discovery gave strength to Darwin's theory of evolution, since it is an intermediate step between the monkey family and apes. It also hits that the enlargement of our skull and, thus, our brain, came after our ability to walk on our back legs, liberating our arms to use them with other purposes.

Existence of Oxygen

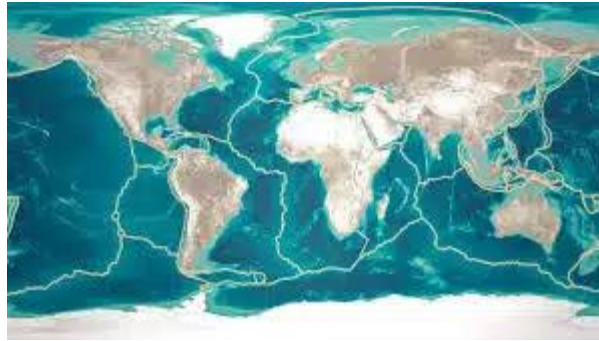
Oxygen is a very important element for us. We need it to breath and keep our body alive, and, since we are mostly formed out of water that contains oxygen, we ourselves are mostly made out of oxygen. It is also involved in combustion, so it is essential to have fire. However, its existence was not fully known or understood until 1772, when it was discovered at the same time by two scientists, the Swedish Carl Wilhelm Scheele and the English Joseph Priestley.

Years before, in 1624, the inventor Cornelius Drebbel was already able to create oxygen gas from potassium nitrate, and he used it to keep air breathable in a submarine. However, he did not know what exactly he was doing or why the gas he was creating would help them breath. He just knew that it worked.

Plate tectonics

The Earth crust is divided into different pieces that fit like a puzzle, the tectonic plates. They float on top of the mantle and crash against each other, creating earthquakes and producing mountains and volcanoes. Some also get separated from each other, producing leaks of magma. This theory was presented in the second half of the XX century, after 200 years of observations and theories.

- The most important of these observations were:
- The discovery of a mountain range in the Atlantic Ocean that extends forming a continuous network along all oceans
- The fact that South American and African coasts fit together almost perfectly
- Rocks with the same age and composition found in both continents
- Presence of fossils of the same land animals in places separated by oceans



Picture 7 World map divided into the tectonic plates

The person who made some of these observations and made a theory for the first time about the possibility of continents moving was the German geophysicist Alfred Wegner, in 1912.

What do we need to prepare?

- A laptop to do research for every two students. They could also use their own phones
- The big poster with a timeline that was already used in class 2
- Coloured markers

Class session

Each student will get one discovery and they will have to search for some basic information about it, as they did in class 2.

We put all the inventions in a box and each student picked one randomly. They can also be assigned according to the difficulty of the invention. We made students work in pairs to investigate two discoveries, so they would work together but everyone would have a discovery to present.

To avoid the students from presenting all the information they could find about their topic, we asked them to answer four questions: “When was this discovered?”, “Where was it discovered?”, “Who discovered it?” and “Why do you think this was an important discovery?”. Once they have the information, they will present it to the rest of the class. They can also share any interesting or curious data they find, but they will have to adjust to a short time, around five minutes per student.

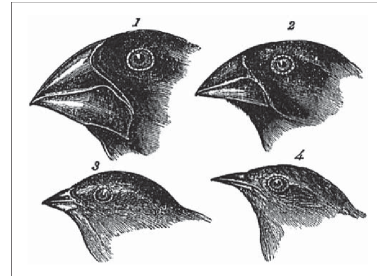
Once a student has presented their topic, they will add it to the timeline in the right place. They will have to choose what colour to use to write the discovery according to what discipline of science they think was most important for that particular invention. We used blue for Physics, green for Biology, purple for Chemistry and yellow for Geology. They could also use several colours if they consider that the discovery should be categorized in several disciplines at the same time.

Class 6: Evolution

Through a simulation game we will replicate the process of natural selection. This way our students will get to understand the basics of the evolution theory.

What do we need to know?

Charles Darwin was an English naturalist, geologist and biologist that lived in the XIX century. He joined an expedition in a ship, the HSM Beagle, that travelled around the world collecting data about different animal species and geology around the world. During this trip, in Galapagos islands, Darwin discovered that in every island the same kind of bird had developed slightly different beaks. Something similar happened to tortoises. Depending on their shells they could know from which island they were from. He also discovered fossils of extinct animals and realized that they look alike those living at the time in the same place.



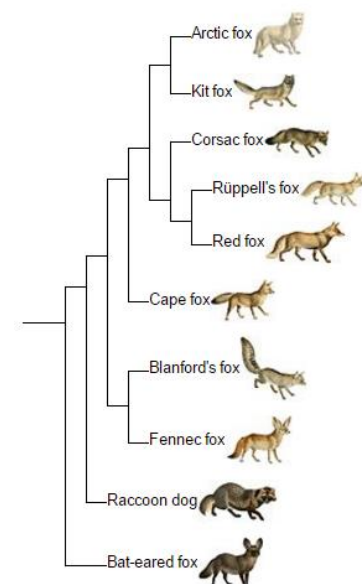
Picture 8 Some of the birds analysed by Darwin

When he arrived back in England after five years of traveling he came to a conclusion. It was possible that all the different birds that he saw in the different islands were originally the same bird that once lived in the main land, and it changed into several slightly different birds. Following that thought, it was possible that animals that lived at the time were related to the fossils he found. This brought him to the conclusion that species do not stay the same, but they change into new species and, therefore, all species are related to each other in a big family tree.

For a long time, he did not share his theory because he knew that it was so radically different to the beliefs of people at the time that the reactions towards his ideas would be very negative. He, himself, struggled accepting his own discovery since it questioned all his previous ideas about the world.

Another man, Wallace, came to the same conclusion as Darwin. Moreover, he understood how species change. He called it natural selection. Not all animals of the same species are exactly the same, sometimes they have different colours, sometimes they are bigger or smaller. Wallace realized that sometimes, certain characteristics can give an individual higher chances of survival. For example, for a rabbit in a polar area it is better to be white, so it can get camouflaged by the snow. Animals with these positive characteristics will be more likely to stay alive and, thus, more likely to have children and pass those characteristics to their offspring. Species will change adapting to their environment.

This same process can be applied to us. Humans come from the same branch as other apes like chimpanzees or gorillas. We all have predecessors in common that are now extinct. At some point four-legged monkeys developed the ability to walk on two feet, and since they were able to use their hands for other things, like grabbing food or tools, they managed to survive and reproduce more than those that couldn't use their hands. As time passed some of them developed bigger skulls and bigger



Picture 9 Genetic tree of the different types of fox

brains that gave them an advantage compared to those with smaller brain capacities. Over millions of years, the human kind as we are now emerged.

What do we need to prepare?

- An application that can generate random numbers between 1 and 10

Class session

We will begin the class telling Darwin's story.

For most of our students it was the first time that they were encountering the theory of evolution. It is a difficult topic to handle and understand if it is presented from the beginning as the theory that states that the human race comes from the same branch as other apes and monkeys. For this reason, we didn't talk about our origins, but only about the mechanism of natural selection and some easy, visual examples like the colours of rabbits.

We think that presenting the theory of evolution as a way of explaining our origins can produce rejection. People might be unwilling to understand the theory if it goes against one's beliefs. However, if we guide them to understand the simple basis of natural selection, then the step towards applying that same thing into our own existence is less complicated.

After explaining the basis of natural selection, we will make a simulation to see how it works over generations. The game will go as follows:

We start with a population of 20 moths. 15 are white and 5 are black, and they live in a forest where the trunks of the trees are white. The original colour of the moths was white, but a random change caused the offspring of a pair of moths to be black, so now there is a small population of black ones. Since the trees are white, the white moths have a higher survival rate. We estimate the rates as:

- White moth: 80% of survival
- Black moth: 30% of survival

This is the starting point. Now we will check for each moth if they survive or die. With a random number generator, we will generate a number between 1 and 10 for each individual moth. In the case of the white ones, if the number goes from 1 to 8, the moth survives and passes to the next generation. Otherwise, it dies. For the black moths, if the number goes from 1 to 3, it survives and moves to the next generation. Otherwise it dies

The first generation has gone through natural selection. Now we need to get their offspring. For that, we will begin by calculating the probability of each colour in the offspring by simply calculating the proportion of each colour in the population. For example, if 12 white moths and 3 black moths survived:

- Total amount of moths: $12 + 3 = 15$
- Proportion of white moths: $12/15 = 0.8 \rightarrow 80\%$
- Proportion of black moths: $3/15 = 0.2 \rightarrow 20\%$

With these rates we will produce 10 new moths. To decide the colour of each one we will generate a number. If it is 1 or 2, the moth will be black. If it is between 3 and 10, it will be white. Finally, we will have 10 new moths plus all the ones surviving from generation 1. The second generation is completed, and we can apply natural selection again using the survival rates that stay constant.

We can repeat this process again, and reach generation 3. Then, the forest burned. Now, the trunks of the trees are black due to the fire and the smoke. This means that the survival rate of black moths increases and white moths are easier to spot by predators. The new rates are:

- White moth: 20% of survival
- Black moth: 80% of survival

Changing the survival rates we continue for some generations. For the first new generations more white moths than black ones will die, but since the initial amount of white moths was higher, the offspring will also be higher for the white ones for some generations. However, as time progresses, white ones will die out and black ones will overtake. This is a clear example of survival of the fittest.

The game is pretty complicated to be done by the students alone. When we carried out this class, we focused the game on the whiteboard and gave a student the responsibility of been up in the stage crossing the dead moths and drawing the new ones in new generations, and another student was generating numbers while all the class would discuss the results and calculate together the new proportions after each generation.

Once the game is finished, the students understand how the process works and how it takes generations. We could briefly introduce the case of humans, asking them what features could have been key for our evolution. Possible answers are walking on two legs, having opposable thumbs or having a bigger skull.

Class 7: The Archimedes' principle

The students will be challenged to solve the problem that Archimedes faced when he was asked to check if a crown contained all the gold that had been provided to make it. The consequence of this challenge was the famous Archimedes' principle.

What do we need to know?

The Archimedes' principle states that an object, when it is immersed in a fluid, experiences a force that is equal to the weight of fluid that is displaced by the object. This is a fundamental law for fluid mechanics that was already stated in 250 BC. There is a famous legend about how he came to think about his principle.

Archimedes was a Greek scientist that lived in Siracusa, Sicily, that nowadays is Italy. He was a very famous mathematician and physicist, so when the ruler of Siracusa had a problem that required thinking, he called Archimedes.

The ruler had ordered to get a crown made out of pure gold, and he gave a block of gold to a crown maker. The crown was very beautiful and he was happy with it, but he was worried about one thing: how can he be sure that the maker had used all the gold and had not stolen any?

He weighed the crown, and it was as heavy as the block of gold that he gave to the goldsmith, but that was not proof enough. Maybe he had kept some gold and replaced it with enough silver to make the crown as heavy as the block.

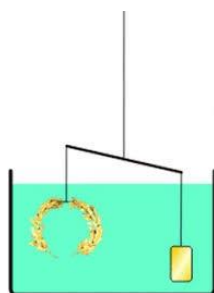
Even for Archimedes it was not an easy problem to solve. He could not melt the crown to compare the amount of gold with the block. So, he needed to find a way to discover how much volume of metal had been used in the crown.

He went to have a bath, and when he entered the full bathtub some water spilled out. Then he realized that the amount of displaced water had to be the same volume as he was occupying.

This gave him the idea to solve the problem, and he got so happy and excited that he forgot to put his clothes on, ran out of his house, completely wet and naked, shouting “Eureka” that in ancient Greek means “I found it!”

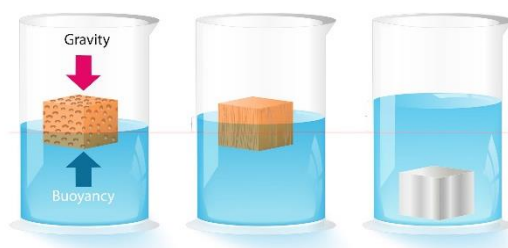
He placed the crown inside a bucket full of water to the top, and collected the displaced water in a second bucket. If this water would fill exactly the mould that was used to make

the golden block, then all the gold had been used. If the water was too much for the mould, then the volume of the crown was too big, and lighter material had been used in the crown. Archimedes’ proved that the crown had, indeed, silver mixed on it, which caused the goldsmith to face the rage of the ruler.



Picture 11 Proof for the crown having a bigger volume than the golden block

This experiment does not use exactly the formula of the Archimedes’ principle, but a much simpler approach. However, there is a way to apply directly the principle to solve the problem. Since they knew that the crown weighed as much as the golden block, if they were put in a scale they would stay balanced. If then the balance was put inside water and both objects would have the same volume, they would stay balanced. However, if the crown has a larger volume, it would displace more water and suffer a higher force pushing up than the block. Therefore, if the scale gets unbalanced, we can deduce that the object that stays higher has a bigger volume.



Picture 10 Archimedes' principle

What do we need to prepare?

- One irregular object per team
- Per team, a bucket big enough for the object to fit
- Water to fill the buckets
- Wider bowls to place the buckets inside and collect the displaced water

Class session

This class will be a challenge for the students. We will tell them the problem that Archimedes faced and, then, we will just tell them that Archimedes found the solution and he got so happy that forgot to put his clothes on and ran out of his house completely naked shouting “Eureka”, that means “I found it” in ancient Greek.

Once the students know the problem, we will divide them into groups and we will give each group an irregular object. Their aim is to find a way to measure their volume. They can use anything they find. After giving them enough time, we will evaluate how the students are doing and, if they get frustrated, we can provide some clues:

- Why was Archimedes wet and naked when he made the discovery?
- How can a bathtub be related with the discovery?
- What happens if you enter a bathtub that is completely full?

Once the time is finished, we will ask the teams what approaches they found, and discuss them. If any of them came out with Archimedes’ idea, we will let them briefly explain it. Otherwise, we will.

Class 8: Tipping points in Science 3

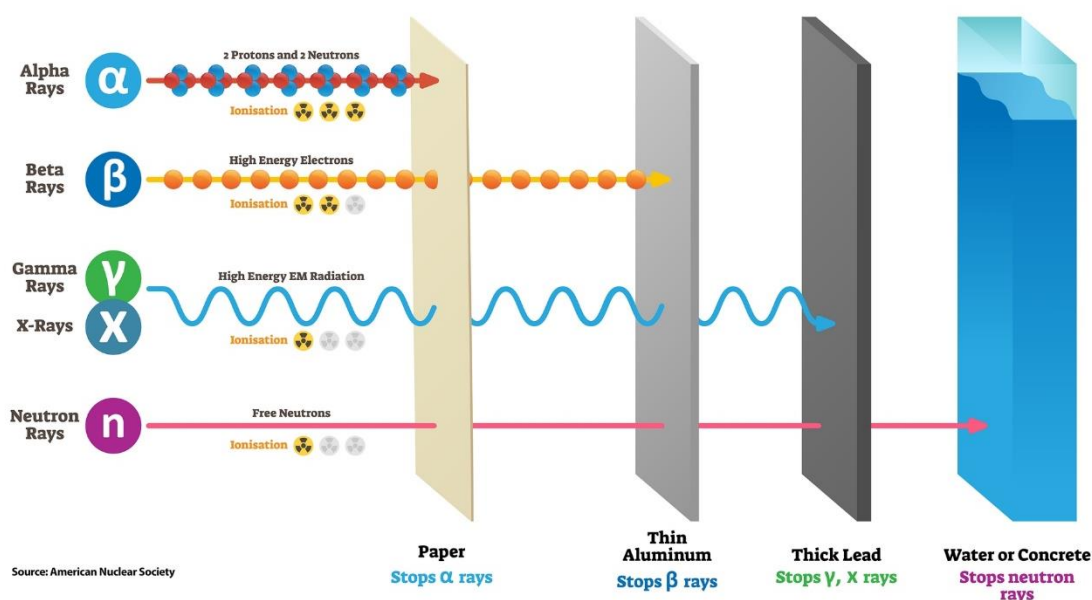
The students will do research about different inventions and discoveries and present their findings. Then we will mark them in a timeline covering from the discovery of fire to nowadays.

What do we need to know?

In this class the students will do research about different important inventions and discoveries in science. We prepared eight for this session, but the amount could be changed according to the needs of the class.

Radioactivity

The core of an atom is formed of protons and neutrons. The core of some elements is not stable, and to find stability they emit different radiations. This radiation can be sets of two protons and two neutrons, what we call alpha radiation. Beta radiation are electrons. They can emit electromagnetic waves, that can be gamma radiation or X-rays, and they can send free neutrons. This radiation is called radioactivity, and unstable elements that radiate, such as uranium or radium, are called radioactive elements.



Picture 12 Types of radiation

The first person detecting this radiation was the French Henri Becquerel, in 1896. He thought that phosphorescent elements like uranium could absorb sunlight and release it as X-rays, so he performed an experiment placing uranium in the Sun on top of some photographic paper that was covered from the sun with black paper. If there was an image in the photographic paper it had to be made by rays sent by the Uranium. The problem was that it was cloudy, so he saved all his things in a drawer waiting for a sunny day. Some days later he decided to develop the paper from his drawer and he saw a very clear picture, even if the Uranium hadn't been exposed to the Sun. This meant that the Uranium was radiating itself. Like this he discovered the existence of radioactivity, but he didn't understand it.

The responsible ones for the understanding of radioactivity were Mary and Pierre Curie. After hearing from Becquerel's discovery, Marie decided to take further steps. She realized that the radiation remained constant no matter the condition or form of the Uranium. She thought that

the radiation came from the atomic structure itself and coined the word radioactivity to describe it.

She kept on working with radioactive elements, but she didn't know about the dangers of radioactivity for humans. She died of a disease that is believed to be caused because of long exposure to radioactivity.

Theory of gravity

Gravity is a natural force. It causes all objects with mass to attract each other. This force is the reason why different bodies in the universe turn around each other; those with smaller mass turning around those with a bigger mass. It is also the reason why objects on Earth fall to the ground, being attracted by the core of the planet.

The formula that explains gravity, the universal gravity law, was established for the first time by Isaac Newton, one of the most important scientists of all times, in 1687. According to the legend, he started thinking about the reasons why things fall down perpendicularly to the ground when he was napping under an apple tree and an apple fell on his head. The force is calculated in terms of the mass of the two bodies involved and their distance.

$$F = -G \cdot \frac{m_1 \cdot m_2}{d^2}$$

This theory was revised later in the XX century by Albert Einstein. His theory of relativity solved the problems that Newton's ideas could not explain. For example, the movement of Mercury, which was approximately calculated by Newton's formula, but not exactly. Einstein's theory states that gravity is a deformation of the geometry of space-time caused by the mass of the bodies involved. For instance, Earth deforms space-time around us, making the space itself push us towards the ground.

Creation of Periodic table

The periodic table is a layout to present all the different atoms that exist. It is arranged by atomic number, this is, the atoms are ordered according to the amount of protons in their core, from 1, being Hydrogen the first element in the table, to -currently- 118, Oganesson. The table is organized in seven rows called periods.

In an atom, electrons are orbiting around the nucleus. They organize in shells, and each shell has space for a specific amount of electrons. Once a shell is full, a new, outer one is open. Each period, or row in the periodic table corresponds to a shell. The first row has two elements, Hydrogen and Helium, that only have one shell. Hydrogen has one electron, and Helium has two, that is the maximum capacity of the first layer. Second and third rows have eight elements because the second and third shell can accept eight electrons each. Finally, elements in the same column have similar chemical behaviours.

This table was created by the Russian chemist Dmitri Mendeleiev in 1869. He ordered the atoms by weight. Back then, the number of protons within an atom was unknown, but later it was discovered that his table had the atoms arranged according to their atomic number. Every time the chemical properties of elements started to repeat, he would change rows, so similar properties would lay under the same column. Again, the composition of electrons shells was not discovered yet, but Mendeleiev's observations fit perfectly with it. He even left space empty in his table for elements that had not been discovered yet, but that according to the table were missing. For this elements, he was able to predict correctly how they would behave based on its position in the table.

Existence of the electron

Electrons are subatomic particles with a negative charge. They are 1836 times smaller than a proton, and orbit around the nucleus of the atom. They play an essential role in phenomena such as electricity or magnetism. By 1881 the existence of electrons had been predicted, but it wasn't proved until 1897 by the English physicist JJ Thomson. His discovery proved the existence of a particle lighter than any other element and that was part of every atom. This meant that atoms were not indivisible units. This caused a change in the idea of the structure of matter itself.

Expansion of the Universe

According to the most accepted theories nowadays, the Universe originated in a huge explosion called Big Bang. Since then, the universe itself has been expanding. While the Big Bang is a theory because nowadays it cannot be proved empirically, the expansion of the universe is a proven fact. Actually, it is one of the key points to support the Big Bang; if the universe is expanding, in the past it had to be concentrated in one point from where it started growing.

The expansion of the universe was announced in 1924 by Edwing Hubble, an American astronomer. To reach this conclusion, he and another astronomer, Vesto Slipher, used the light of the stars. When that light reaches us it can be decomposed into its spectrum of colours with a prism. The spectrum gives information about the composition of the star, and also allows us to know if the star is getting closer or further to us. This is possible due to the Doppler effect. According to this, when an object goes away from us, its light turns red. The light of objects moving towards us turns blue. Slipher realized that the light coming from different galaxies moved to red, which meant that they were moving away from us. Besides, galaxies that are further away from us move away faster than those closer to us, what implied that the universe was expanding.

Existence of the Neutron

Neutrons are subatomic particles that exist in the nucleus of atoms and have no electric charge. They do not determine the kind of atom. This is done by the protons. For example, if an atom has eight protons it is oxygen, but an oxygen atom can have from four to twenty neutrons and it will still be oxygen.

The existence of positive and negative charged particles in the atom was known by the beginning of the XX century, but it was in 1932 when the English physicist James Chadwick discovered the neutron. He performed several experiments which results could not be explained by the current ideas of the time. The only way to make them fit was to assume the existence of particles that had no charge, this is, the neutron. However, years before his discovery, several scientists already predicted the existence of neutrons, but they couldn't prove it.

Chadwick's discovery changed the atomic model and speeded up the next discoveries in atomic physics.

Existence of the atom

The idea of atoms as the smaller unit of matter has been present in science since ancient Greece. Philosophers thought that matter could not be divided infinitely, so there must be a smallest unit that is used to build up anything in existence. It was a reasonable thought, but there was not prove to it.

In the first years of the XIX century, the English chemist John Dalton performed different experiments measuring the mass of the reactive elements and the products and checking that they were always the same. He concluded that all substances were made out of units of different elements, atoms. Atoms would be different for each element, and they combine in different ways to create different substances. He proposed that atoms were just small spheres. This

model would be proven wrong and changed by other more complicated models, but the basic idea of what an atom is and how they form other substances was right

Discovery of Uranus

All planets from Mercury to Saturn had been known from ancient times because they can be easily observed in the night sky. However, the discovery of Uranus, the next planet after Saturn, didn't happen until 1781. It was spotted for the first time by the English astronomer William Herschel in March of 1781, using his telescope, and he thought that it was a comet. Herschel and several other astronomers kept observing and analysing the orbit of Uranus and by 1783 they confirmed that it was a planet.

It was the first time that a planet in our solar system was discovered thanks to the use of telescopes. It was a revolution for astronomy, since it expanded the limits of the solar system for the first time in history. The next time a planet was discovered, Neptune, was in 1846, more than fifty years later.

What do we need to prepare?

- A laptop to do research for every two students. They could also use their own phones
- The big poster with a timeline that was already used in class 5
- Coloured markers

Class session

Each student will get one discovery and they will have to search for some basic information about it, as they did in classes 2 and 5.

We put all the inventions in a box and each student picked one randomly. They can also be assigned according to the difficulty of the invention. We made students work in pairs to investigate two discoveries, so they would work together but everyone would have a discovery to present.

To avoid the students from presenting all the information they could find about their topic, we asked them to answer four questions: "When was this discovered?", "Where was it discovered?", "Who discovered it?" and "Why do you think this was an important discovery?". Once they have the information, they will present it to the rest of the class. They can also share any interesting or curious data they find, but they will have to adjust to a short time, around five minutes per student.

Once a student has presented their topic, they will add it to the timeline in the right place. They will have to choose what colour to use to write the discovery according to what discipline of science they think was most important for that particular invention. We used blue for Physics, green for Biology, purple for Chemistry and yellow for Geology. They could also use several colours if they consider that the discovery should be categorized in several disciplines at the same time.

Class 9: Electricity

Through different experiences, and building several circuits, the students will learn about static and current electricity.

What do we need to know?

Electricity is a flow of electrons from a negatively charged area to a positively charged one. It is a natural force. So, it was always there, just needed someone to discover how to use it and control it. One of the first people working with it was Benjamin Franklin, the man who proved that lightnings are electricity. He flew a kite with a metallic wire on top during a storm. His kite was hit by a lightning and it was directed through the string to a Leyden bottle, a device used at the time to accumulate electricity.

There are two kinds of electricity:

Static

It piles up in a body. Through the friction between two bodies, electrons pass from one to the other, so one of them gets charged. It happens, for example, when we get a shock after touching something, or when we rub a balloon against our clothes. This electricity was known and used for a long time, and it is the one that produces lightning.

Current

It moves from one place to another. From negative to positive. This is the one that we use for our plugs.

Lighting are static electricity that is piled up in a cloud because it gets rubbed against the air in the atmosphere. When the electricity is too much to be held in the cloud, it will try to go out. So, the electricity is shot to the ground and we see a lightning. If we manage to control this flow, we get current electricity that we can use to power machines, like the light bulb that was patented by Thomas Edison.

To make any electric device work we need to make electrons from an energy source pass through it. To bring the electrons from the source to the device we need to provide a road. Conductive materials, like metals, provide a path for electrons to move from a negatively charged area to a positively charged one, creating a current.

What do we need to prepare?

- Balloons
- A metallic spoon for every two students
- A darkroom
- A small light bulb for every two students
- A battery for every two students
- Tape
- Different materials to make a circuit. Clips, pencils, metallic necklaces... anything can be tried

Class session

The class will start doing a small experiment to see static electricity. In pairs, the students will inflate a balloon and rub it against their hair. Then, in the darkness, they will bring a metallic spoon closer slowly, until a spark is heard and, hopefully, seen.

We managed to hear the spark every time we did it, but seeing it was not that easy, although we got to see it.

We will ask them, back in the class, if they have any idea of what happened. Using this experience, we will introduce what static electricity is and how it piles up in the balloon. We will

see the difference between static and current electricity and explain how current electricity is used to power devices like light bulbs.

Finally, the students will look for conductive materials to power up a light bulb. The students will work in pairs. We will place a light bulb for each team on the table, fixed with tape. A battery will also be taped to the table, and the students will have to find objects in the classroom to bring the electrons from the battery to the light bulb, and back to the battery, so it turns on.

If this activity is finished very fast or seems too easy, we can provide wire for the students to build circuits, and ask them to create parallel or series circuits.

Class 10: The connection between Sciences

Through the project we will have prepared a timeline with different discoveries. In this class the students will analyse how some of them prepared the grounds for others to come.

What do we need to know?

For this class there is no proper knowledge needed. It will focus on the relation between all the discoveries that were studied during the cycle. These relations do not need to be direct, like the need of inventing the telescope to discover Uranus. They can be subtler. For example, the understanding of fossils supported the theory of plate tectonics.

What do we need to prepare?

- The timeline that we have prepared along the cycle
- All the discoveries from the timeline written down chronologically in the whiteboard

Class session

For this class we will divide the students into teams, and each team will be assigned one of the tipping points that are written in the whiteboard. The task for the students will be to think and reflect about what other future discoveries depend on that one, and what past inventions had a role in their tipping points. They could even think about other important discoveries that have not been discussed but that are related to their tipping point.

As tipping points to reflect on we assigned the discovery of the atom, plate tectonics and the genetic code decipher.


Once the students have had enough time to make their connections, one person per team can go up to the whiteboard, mark the relations using arrows and explain the relations that they found.

Showcase

During the project every student will present at least three different discoveries after doing online research. Therefore, there will not be a final showcase

Exam

With this project we didn't intend our students to memorize any information. Our main objectives were two. First, for them to understand how different disciplines are interconnected,



and second, for them to see how many discoveries that confront the status quo can be difficult to accept by society. These two objectives can be checked through the students' interactions in class, so no exam will be needed.