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Science on Stage 2024

Is Scratch the answer to a playful and investigative approach to modelling competences in science?

How do we write a code in Scratch that shows the movement of molecules in the gas phase? Or a model of a black hole? Or the kinetic energy in a pendulum swing?

This teaching material starts with an introduction and the background for programming simulations in Scratch, and why it makes sense for students themselves to write codes in their work with investigative and modelling competencies in science. With a playful, exploratory, and investigative approach, students have the opportunity to write codes in Scratch in one or more of the simulations based on instructions provided in teaching material.
The teaching material discusses the academic, practical, and didactic aspects of inquiry-based teaching. As well as more than 20 codes for Scratch and BBC Micro:bit. Capture your students' understanding of models and technology.

It is an advantage if you are already registered as a user on scratch.mit.edu and have some experience with programming in Scratch. Or that you are just wildly curious.

This teaching material consists of a short guide and an example of code in Scratch. The material is aimed at students in the upper grades (12-16 years old). The teaching material contains codes for animations of a rainbow, the natural cycle of water, a black hole, the movement of exoplanets around a star, Niels Bohr's atomic model, pendulum oscillation, small magnet model, regular polygons, the Earth's magnetic field, chain reactions, and many more.

Use BBC Micro:bit as a measuring instrument in physics education. The teaching material also includes codes for the BBC Micro:bit. The material contains instructions for using the Micro:bit as a thermometer, for measuring kinetic energy in a swinging pendulum and as a magnetic field meter measuring instrument.

Science-on-Stage 2024 participant Mr. Steen Petersen from the Danish team is a teacher at Fredericia Realskole in the subjects of mathematics, physics, chemistry, geography, and biology. He himself is wildly curious about programming as part of the modelling competences in science.

In Denmark “modelling competence” is one of four competences in the science education. By programming in Scratch, students make their own models in science. Pupils gain a better understanding of the academic material by making codes for small animations and simulate physical, mathematical and chemical phenomena on a computer.

In the following, the words programming, code, animation, digital model, simulations and computational thinking are used. Sometimes the meanings of the terms can flow together. I use the word programming to mean writing a program in Scratch. And I use Scratch as an example.

Animations and simulations are words for making a digital model of a physical phenomenon on a computer. It can, for example, be a simulation of the location of the electrons in Bohr's atomic model. The simulation shows on the computer screen how electrons are filled up from within the inner electron shell. Or a simulation of how small magnets move when a steel blade is magnetized.

Programming codes provides new opportunities to involve students actively "in their own learning". The reflection "what happens if?" and the slowness of having to do the programming and think through and adjust the program as well as the discussion about possible improvements in the code. It takes time and the slow process is important when the students work to make the program work and to explain to each other what the model shows.

The students are actively involved when they write small programs themselves. They learn both about a known physical phenomenon, and at the same time they learn how a program in Scratch works. The students work with the guidance sheets from this booklet. The guide helps students get started with basic coding in Scratch. There are then opportunities to discuss and further develop the models.

The students face challenges along the way when they try to predict what the program does, test the program, and they examine whether it matches their expectations, change and adapt variables, interpret results and finally write new programs.

It can take a long time to get a program to work perfectly. Precisely the slowness of this process is important for the students when they really need to understand and explain what is happening. It takes time to write the code, it takes time to debug the code, test and adjust. This process is important.

When we solve tasks in science subjects with programming, it can become even clearer that we are working with scientific models. Models are simplifications of reality, and students are not always aware that they are working with simplifications with limitations and assumptions. An understanding of natural science as indisputable facts can be limiting for students' learning of natural science methods and ways of thinking. (freely translated from Naturfag, number 1, 2022, page 67, Andreas Haraldsrud, University of Oslo)

Programming and simulations in science are closely related to one of the competence goals in the subject technology understanding.

Computational thinking deals with the analysis, modelling and structuring of data and data processes. This means that students must learn to decode phenomena and processes from everyday life, from professional contexts and in digital artefacts and describe these in the form of algorithms and digital models. (source: Technology understanding, emu.dk)

Regarding computational thinking, it is stated in the curriculum for technology understanding in skill and knowledge objectives that the student must acquire knowledge of techniques for constructing and evaluating digital models, and that the student can construct and evaluate digital models of the physical, chemical and technological environments.

This booklet consists of worksheets for 20 programs of digital models in Scratch and BBC Micro:bit. The sheets briefly describe the idea in the program, show a proposal for the scratch code and give suggestions in "discussion" on how the students themselves can improve, change and further develop the program. The discussion also sets up a discussion of what the digital model is good at and less good at explaining.

The sheets guide students to gain knowledge about constructing digital models, to assess and discuss digital models of the physical, chemical and technological world.

Teaching in coding simulations in science education can take place based on this plan.

1. Distribute copy sheets to the students and start by jointly predicting what the code does.

2. Write the code in Scratch or BBC Micro:bit and make a test.

3. Investigate whether the program can be improved by changing variables, adding some new blocks or removing a block.

4. Further develop the code or write a new code. At the bottom of all sheets there is a presentation for discussion and further investigation of the model.

Scratch (scratch.mit.edu) is a platform where students can program, draw shapes, make shapes move on the screen, make sounds, draw with a pen, make computer games and a lot more coding. Programming takes place by dragging in different blocks and putting them together in the programming field.

Scratch is free to use. The teacher can create a teacher account with their classes, where students can register as users. Never use your own name as a username.

I wrote most of the codes myself. A few codes for gas model, pendulum and temperature measurement I have been inspired by others. Below I have referred to sources. It is not in my interest to infringe on the rights of others.

Steen Petersen, April 2024

See on You Tube

Molecules in gas	https://scratch.mit.edu/projects/690148787
Niels Bohr's atomic model	https://scratch.mit.edu/projects/690475256
Pendulum swing	https://scratch.mit.edu/projects/690530194
Small magnet model	https://scratch.mit.edu/projects/693361885/
Draw a rainbow	https://scratch.mit.edu/projects/694989406/
Earth magnetic field	https://scratch.mit.edu/projects/695543196/
Regular polygons	https://scratch.mit.edu/projects/694973251/
Model of a black hole	https://scratch.mit.edu/projects/699037357/
Natural water cycle	https://scratch.mit.edu/projects/710779461
The Solar system	https://scratch.mit.edu/projects/717621085/
Exoplanet in orbit	https://scratch.mit.edu/projects/721395361/
Snow crystal	https://scratch.mit.edu/projects/614727439
Triangles	https://scratch.mit.edu/projects/132609162
Spirals 1	https://scratch.mit.edu/projects/194023685
Spirals 2	https://scratch.mit.edu/projects/194023685
Mandala	https://scratch.mit.edu/projects/133081830

BBC Micro:bit kinetic energy in pendulum swing

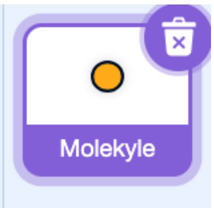
BBC Micro:bit build a compass

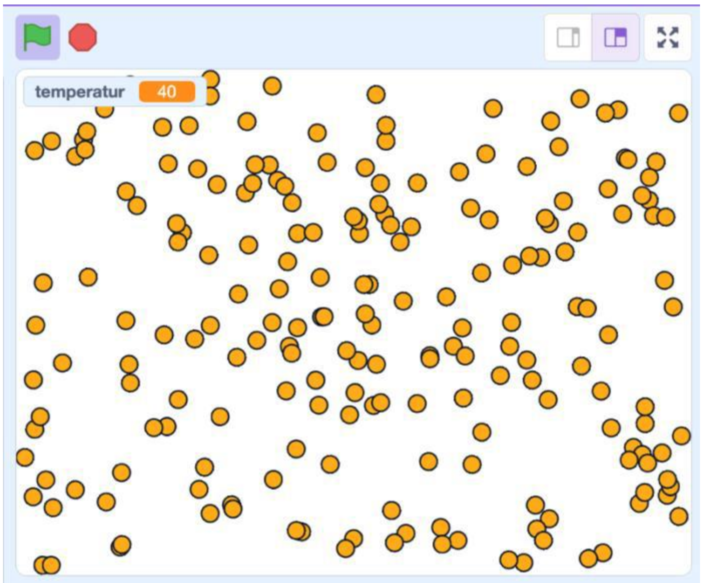
BBC Micro:bit temperature part 1 and part 2

BBC Micro:bit magnetic field meter

Molecules in gas

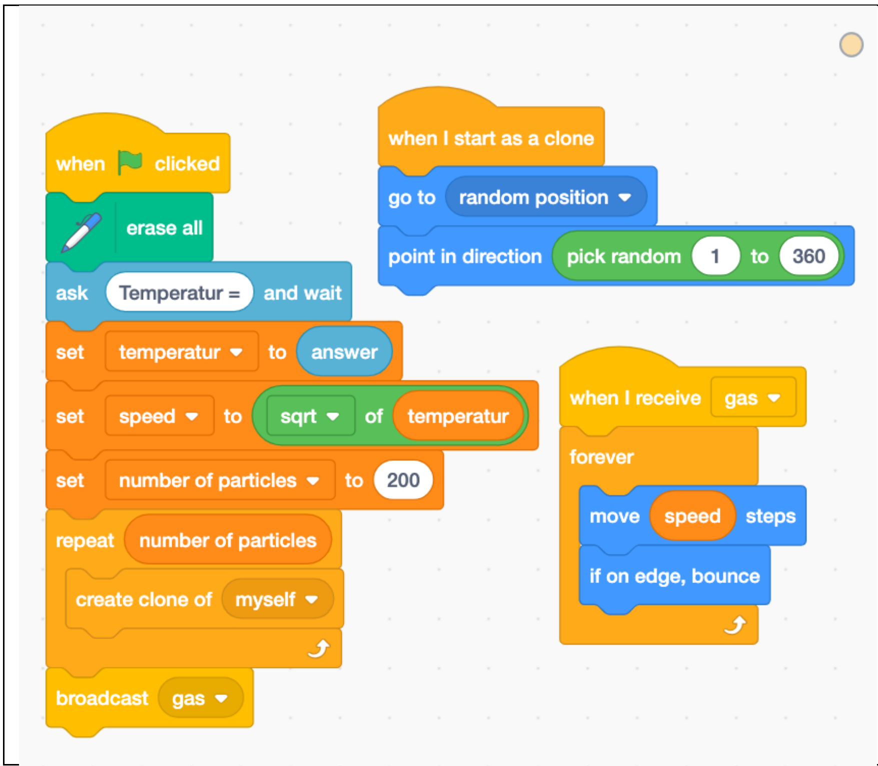
Draw a new sprite as a molecule.





Write the code.

Inset a variable and call the variable “temperature”.



The program asks for the temperature. Write a number between 0 and, for example, 100.

Then, 30 clones are created, moving randomly on the screen with a random direction between 0 and 360 degrees and a speed that is the square root of the temperature.

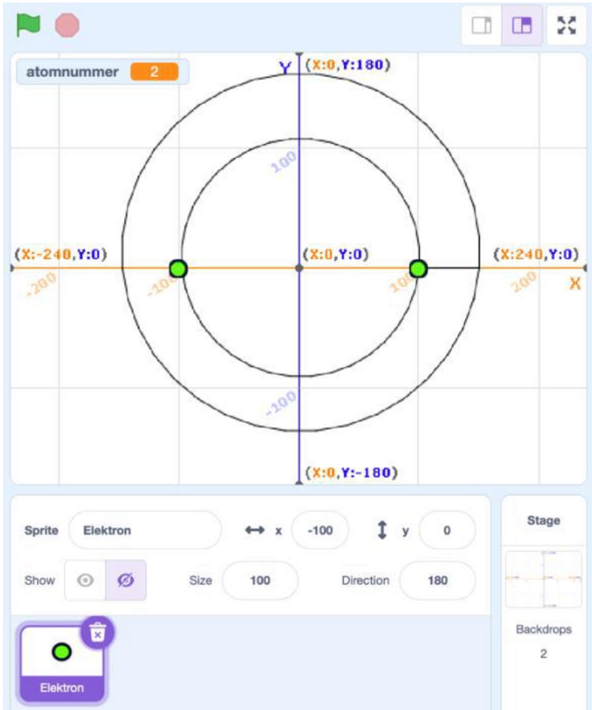
They bounce back if they hit the edge.

The program runs indefinitely.

Investigate:

How do we create a simulation that can display the other states of matter: solid and liquid?

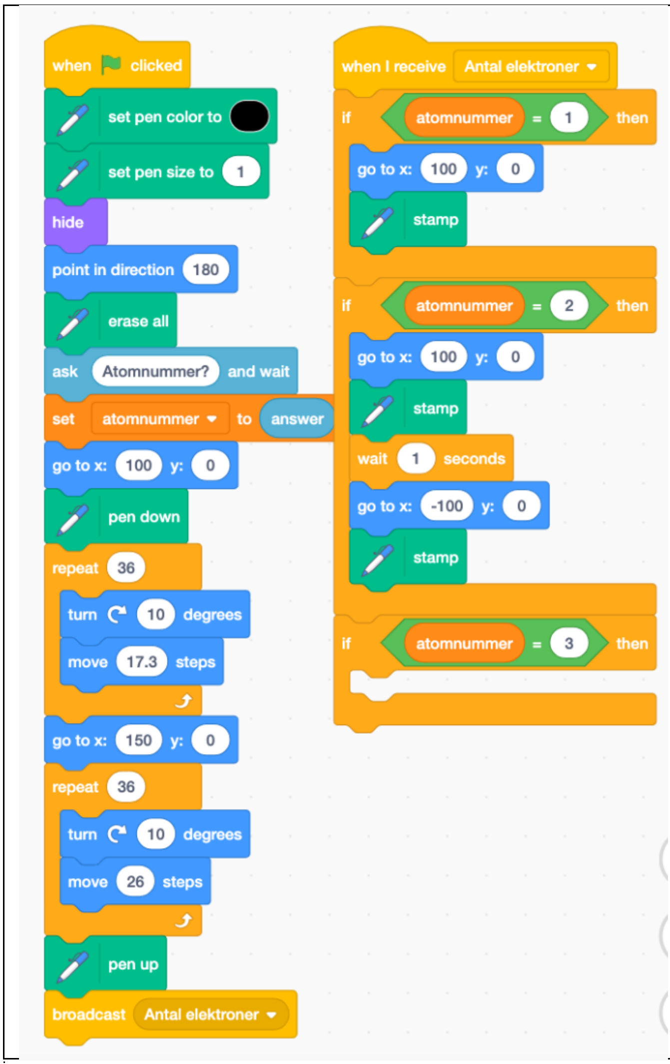
Niels Bohr's atomic model



In Niels Bohr's atomic model, an atom has electrons in shells around the atomic nucleus. Electrons fill the shells from the inside, and the innermost shell can hold two electrons. In shell number 2, there is room for eight electrons.

The program asks for the atomic number. Then, two circles are drawn. If the atomic number is 1, one electron is placed in shell 1. If the atomic number is 2, two electrons are placed. Continue the program yourself with more electrons in shell 2.

You'll need an extension in this program. You have to find **the Pen** used for drawing.



The electrons are shown as green circles in shell 1 and in shell 2.

You have to continue the code yourself so that the electrons are displayed when the atomic number equals 3.

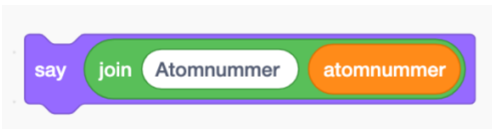
Set Direction=180 (down)

The background scene is a coordinate system that can assist you with the coordinates.

Coordinate for electron number 3 (150, 0)
Coordinate for electron number 4 (0, 150)

Investigate:

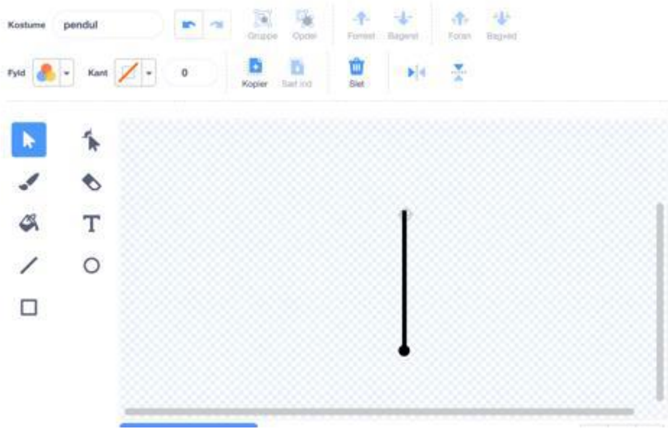
How do you make the program say the atomic number?

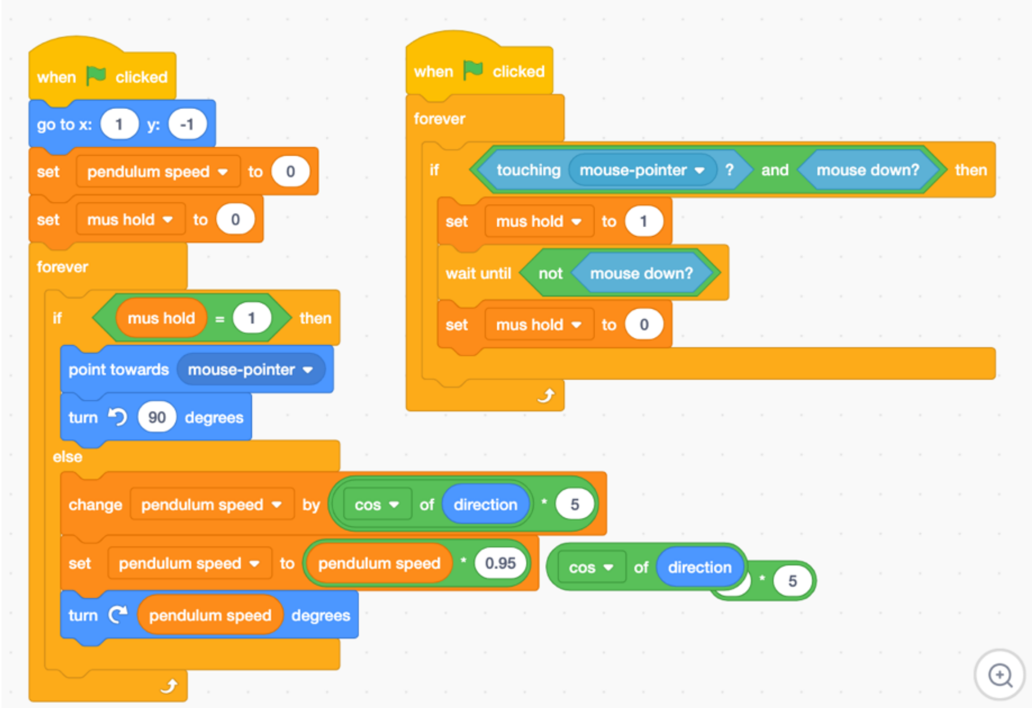


Pendulum swing

Draw the pendulum in a new sprite.

To initiate the swing, lift the pendulum on the screen out to one side using the mouse.

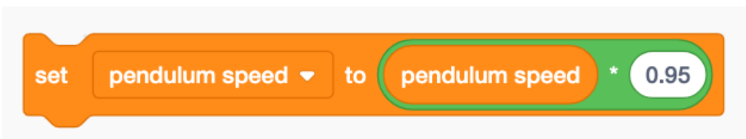




The pendulum demonstrates a damped oscillation, where it dampens rather quickly, causing the pendulum to swing less and less until it eventually comes to a stop.

Investigate:

What will happen if you change the factor 0.95 to another number?



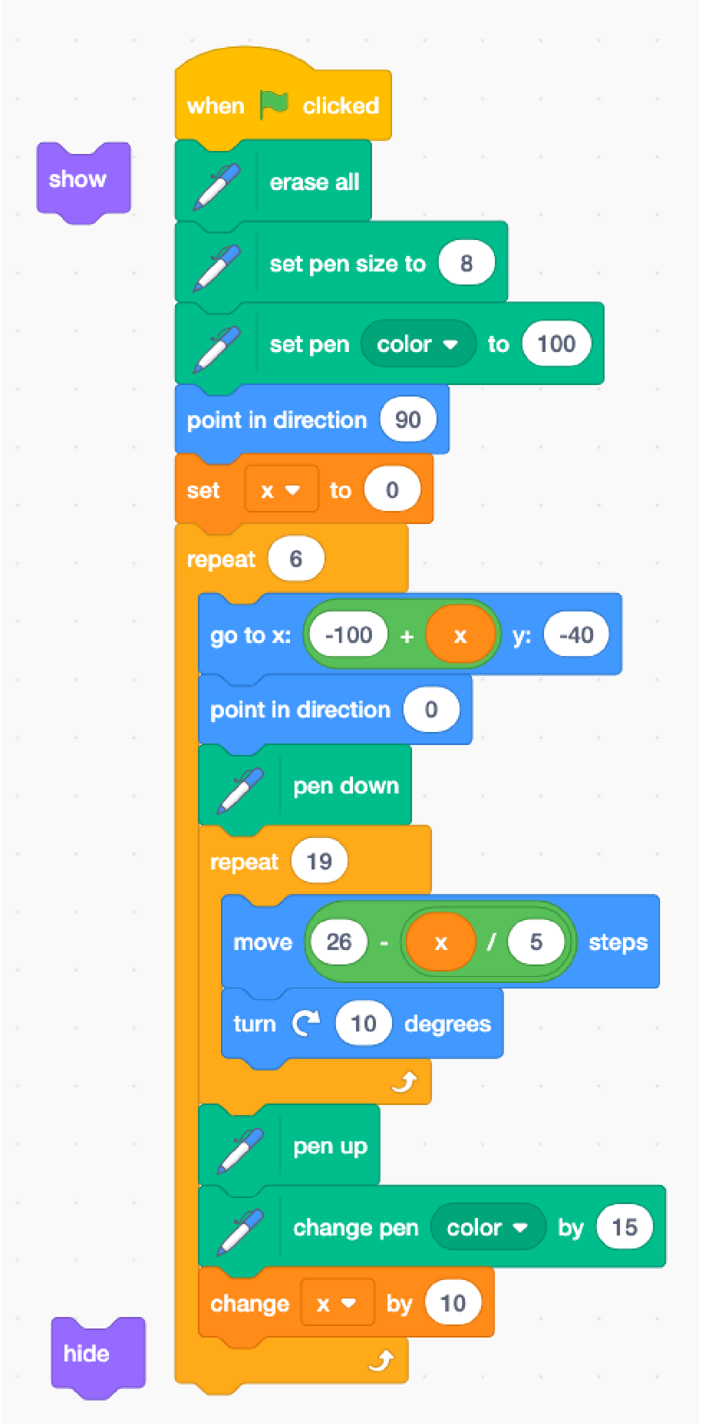
Explain the formular.

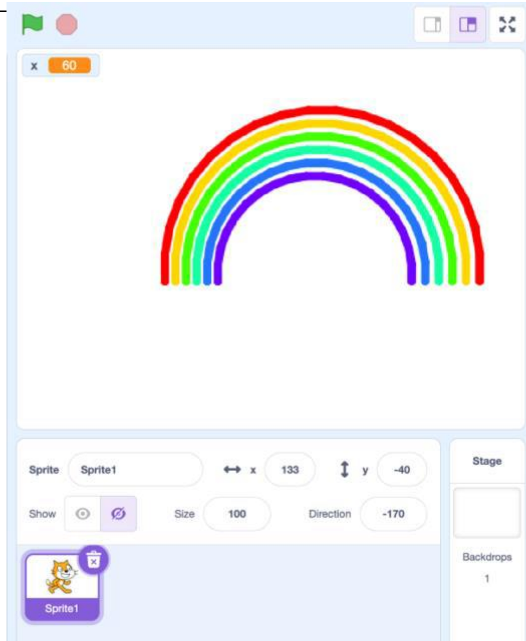
$$T = 2 * \pi * \sqrt{\frac{L}{g}}$$

Draw a rainbow

The colours in a rainbow are formed when white light from the sun is refracted in water droplets. The colours in the rainbow form because the different colours in the sunlight refract at slightly different angles.

Write a program that draws the colours of a rainbow.

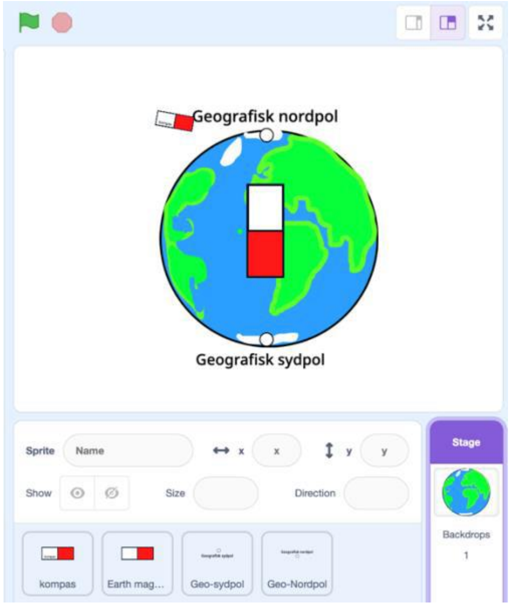




Investigate:

What will happen if you change some of the numbers and colours?

Earth magnetic field

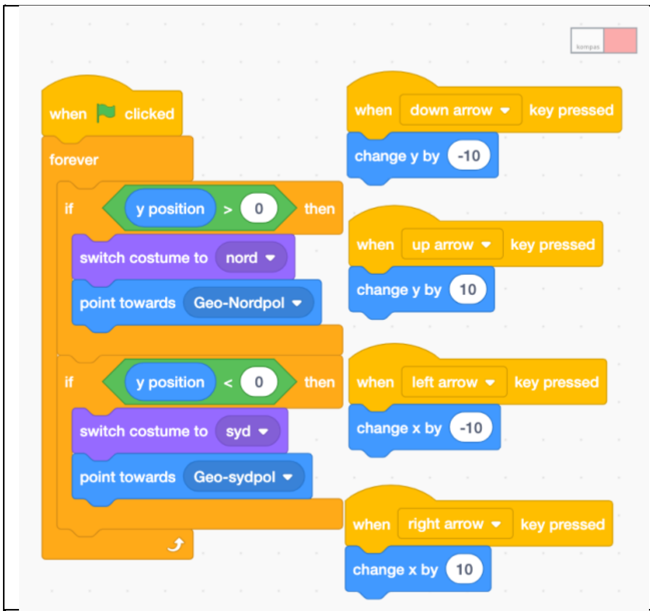
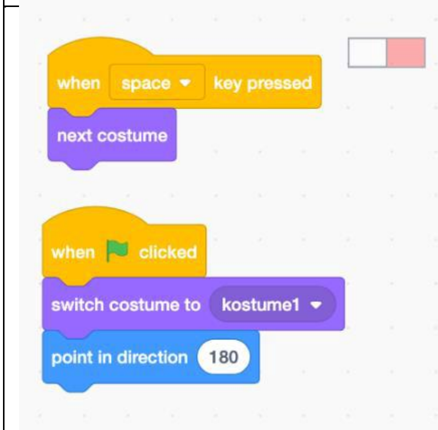


In this model of the Earth's magnetic field, we imagine that there is a large bar magnet inside the Earth.

The bar magnet inside the Earth points with the magnetic south pole up towards the Earth's geographic north pole.

The compass thus points with its north pole towards the Earth's geographic north pole.

The earth is drawn as a background. Two small circles are used as the geographic north pole and south pole.

	The compass is the small bar magnet outside the Earth and it always points towards the Earth's inner magnet. The compass is controlled with the arrow keys. If the compass is above the equator (and the y-value is greater than 0), then the compass must point towards the geographic north pole. If the compass is below the equator (and the y-value is less than 0), then the compass must point towards the geographic south pole.
	The big magnet is a model of the Earth's magnetic field. With the spacebar you can show and hide the magnet. Costume1 is a picture of the magnet. Costume2 is empty. It has two costumes where the first costume is a magnet and the second is empty. Point in direction 180 means that the magnet is drawn horizontally in the drawing code but must stand vertically.

Investigate:

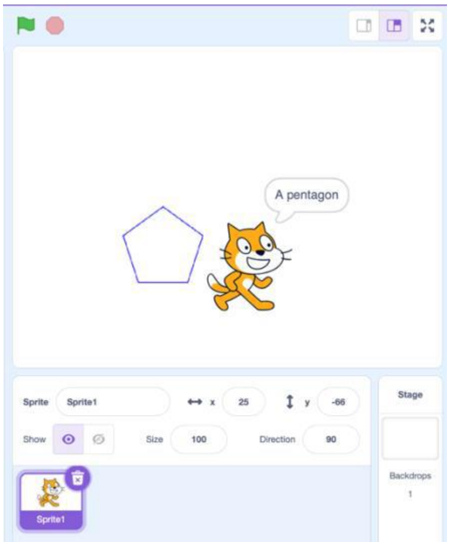
Why does the south pole of the bar magnet inside the Earth point towards the geographic north pole?
How does a compass work?
What is the model good or bad at explaining?

Regular polygons

A regular polygon is a shape with sides of equal length and angles of equal measure.

A regular pentagon has five sides of equal length and five angles of equal measure.

Here is a program that constructs a regular polygon with a number of sides you enter as the variable 'answer.'



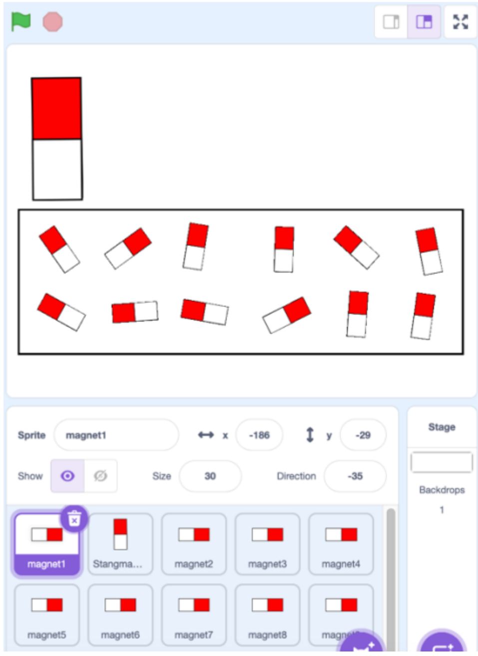
The side length is adjusted in the calculation: side length = 60 - answer to ensure a large polygon can fit on the screen.

Two green connectors join in the last block of the program to assemble the words 'Here is a [answer]-sided shape.'

Below, it shows how you can use 2 connectors to get the text on the screen.

Investigate:

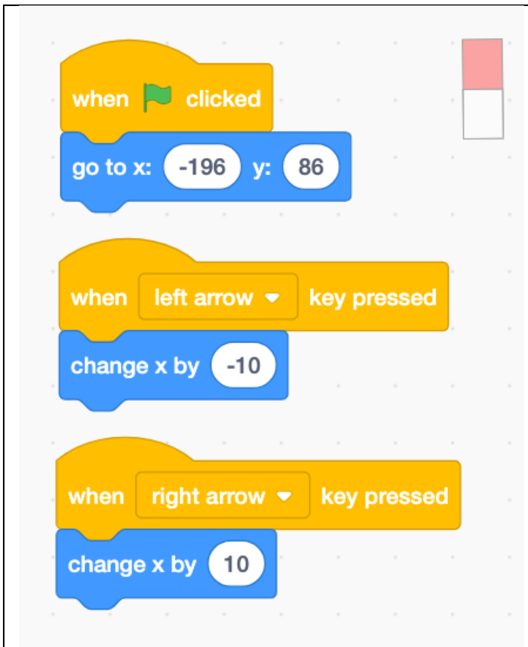
Small magnet model



Magnetization of an iron blade is explained using the small magnet model.

Many small magnets within the iron blade align themselves with a bar magnet slowly moved across the iron blade. This alignment of the small magnets magnetizes the iron blade.

Move the bar magnet using the right and left arrow keys.

<table>
<tr>
<td>
</td>
<td>Draw a bar magnet in a new Sprite.

Write the code.

Use arrow left and right to move the bar magnet.</td>
</tr>
<tr>
<td>
</td>
<td>Draw a small magnet in a new Sprite, write the program, and then make as many copies as you need.

Investigate:

Which parts is the model good at explaining?

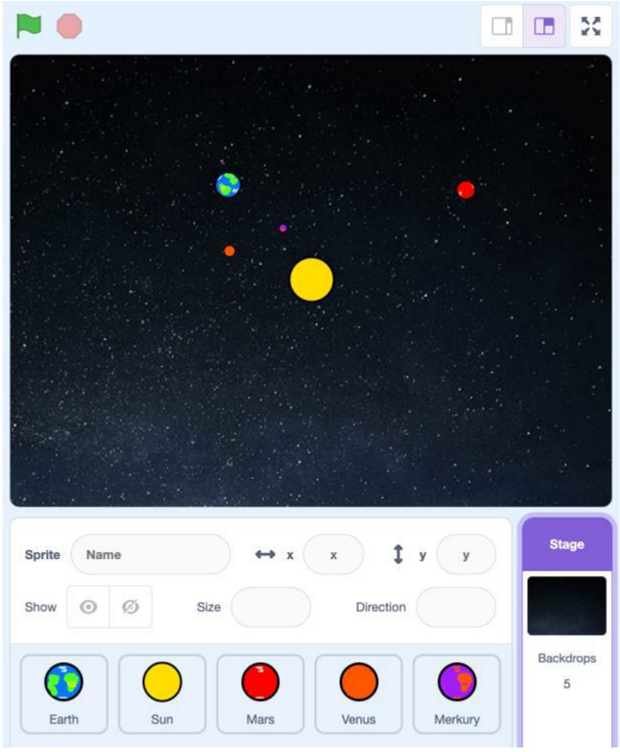
Which parts of magnetization can the model not explain?</td>
</tr>
</table>

The Solar system

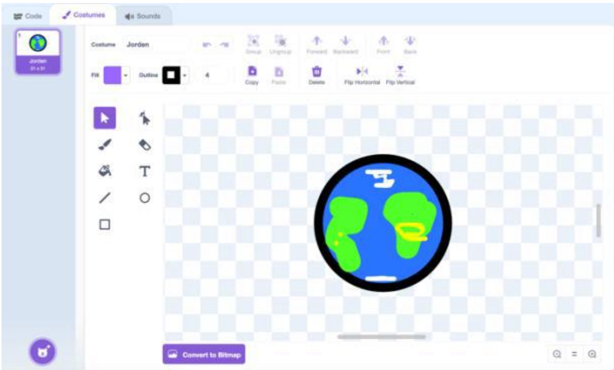
Write a code for a simulation of the solar system. The simulation shows the orbits of the four inner planets around the sun in the solar system.

Use stars as background.

Make five new sprites and draw the inner planets.



Orbit
Mercury 88 days
Venus 225 days
Earth 365 days
Mars 687 days



The code for the Earth orbit around the sun.

Use the same code for Mercury, Venus, and Mars by changing the variables of the start position and the orbit.

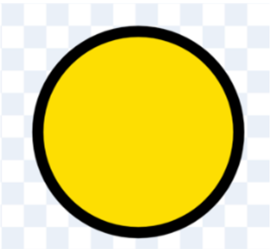
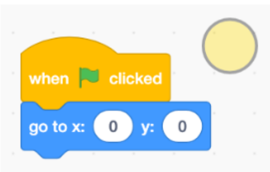
Investigate:

What is the model good/bad at showing?
Investigate distance and aspect ratio of the sun and the planets.

The solar system 2

Here are some helps with the codes for the planets Mercury, Venus, and Mars.

Make new sprites and draw your own planets in Costumes.

<table>
<tr><th>Sun</th><th>Mercury</th><th>Venus</th><th>Mars</th></tr>
<tr>
<td>
The sun is placed in the centre of the screen.

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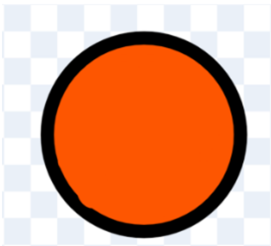
<td>

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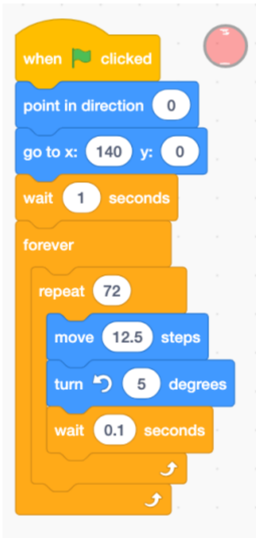
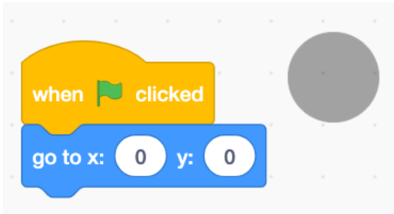

</td>
</tr>
</table>

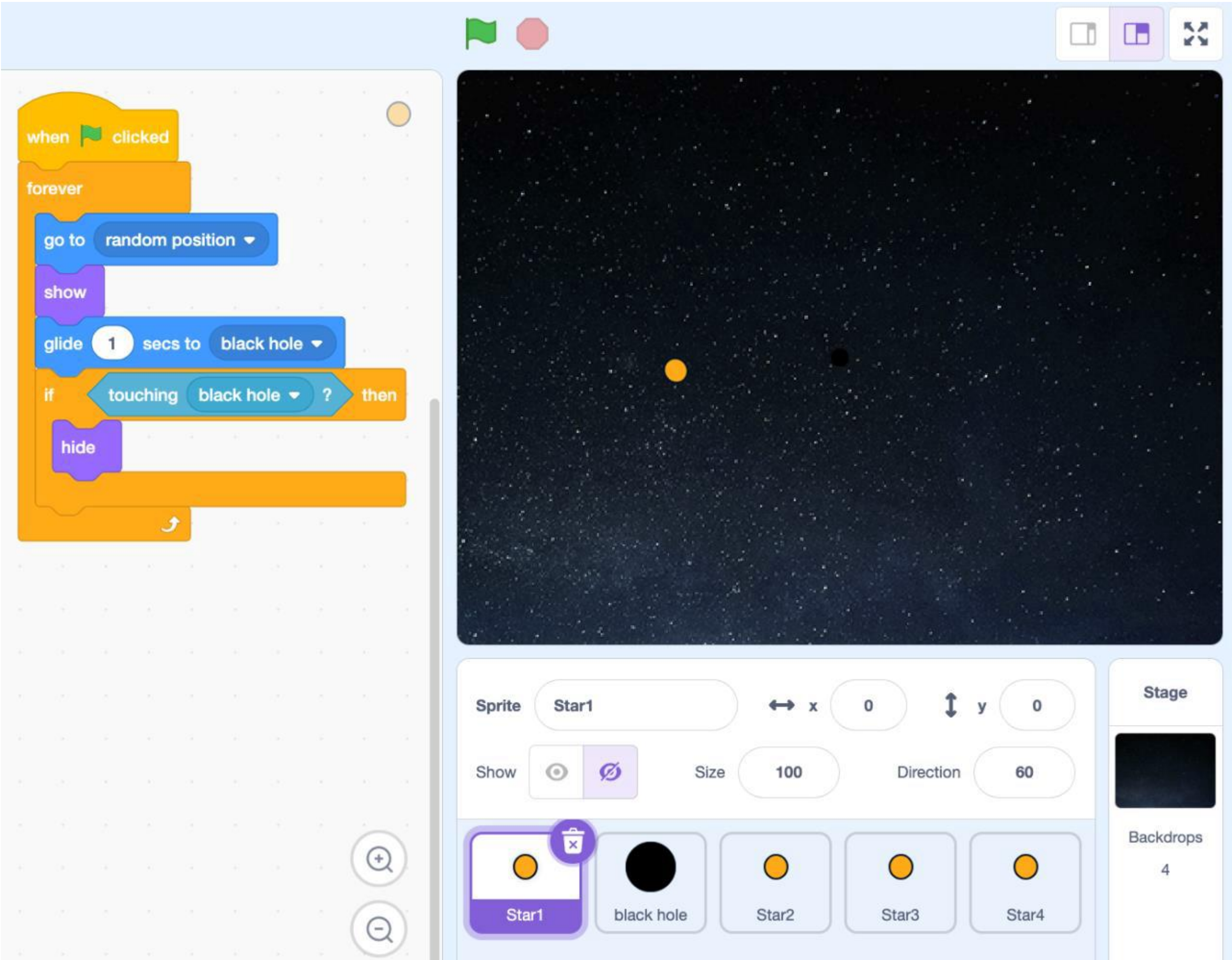
Orbit
Mercury 88 days
Venus 225 days
Earth 365 days
Mars 687 days

Model of a black hole

The universe consists of planets, stars, galaxies, and black holes. A black hole is one of the strangest things in the universe that many astronomers wonder about.
They are so heavy that it attracts all matter. Even light cannot escape from a black hole.



In the model, you build a black hole that swallows yellow stars.
Make four copies of star1 and let them start a little later.
The black hole in the code is at little black dot in the centre.



Investigate:

Astronomers have photographed black holes. Search the web and find out more about black holes. Gas and stars close to the edge of a black hole light up - and are "swallowed" by the black hole.

What does a black hole weigh?

Where do black holes come from and how are they formed?

What is an event horizon?

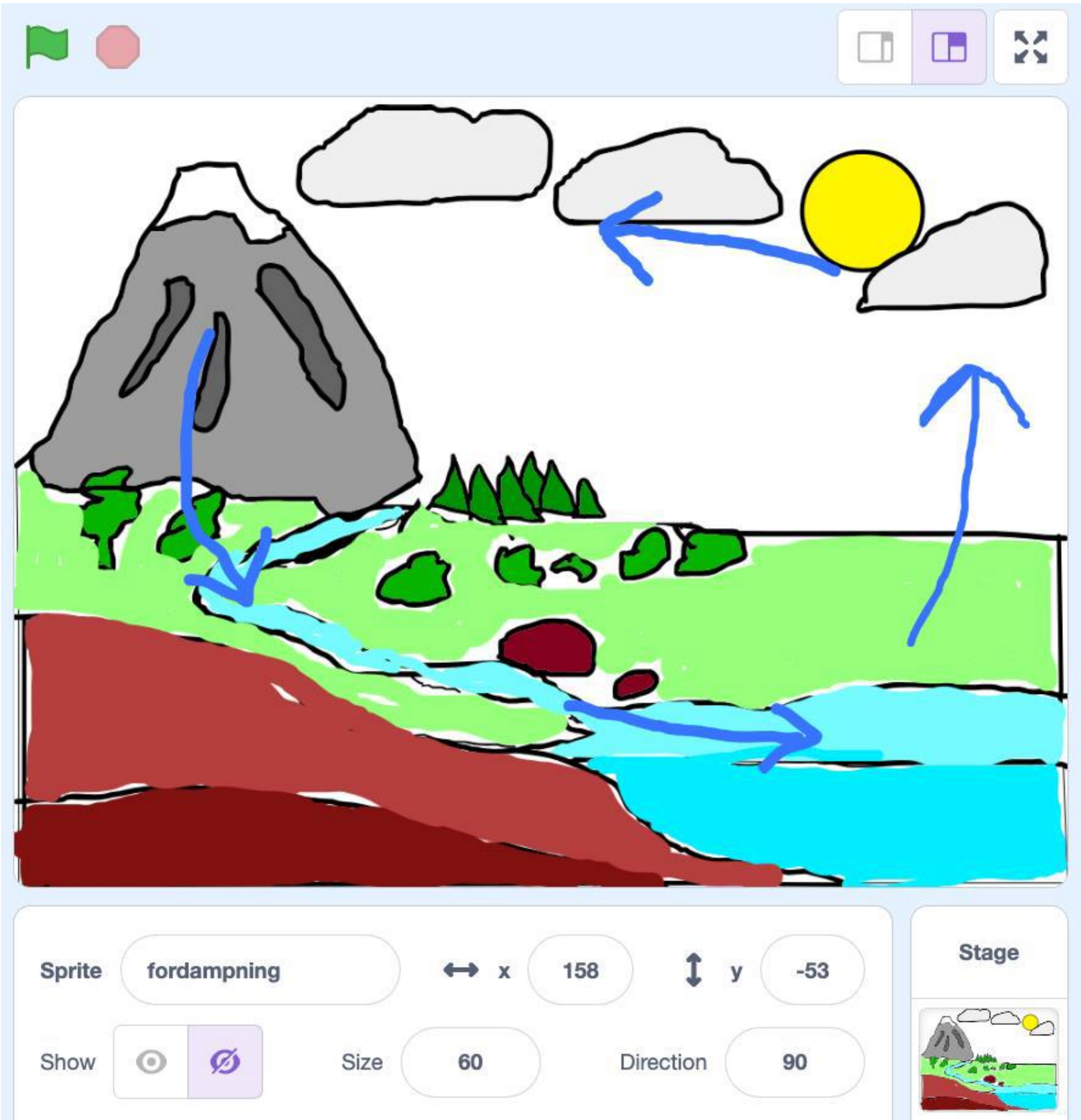
Natural water cycle

There are many drawings and illustrations of the water cycle in physics books, geography books and on the internet.

You can use the images as inspiration for the landscape and make your own symbols for rain, evaporation and circulation.

Now you must make a small cartoon showing the water cycle.
You can explain some of these terms in the cartoon: Evaporation, condensation, precipitation, seepage, groundwater, surface water, rain, snow and solar energy.

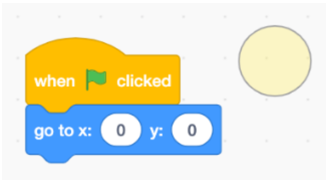
Draw the landscape as a background. Write small programs for evaporation and rain.
Attach arrows and write small texts for speech bubbles.

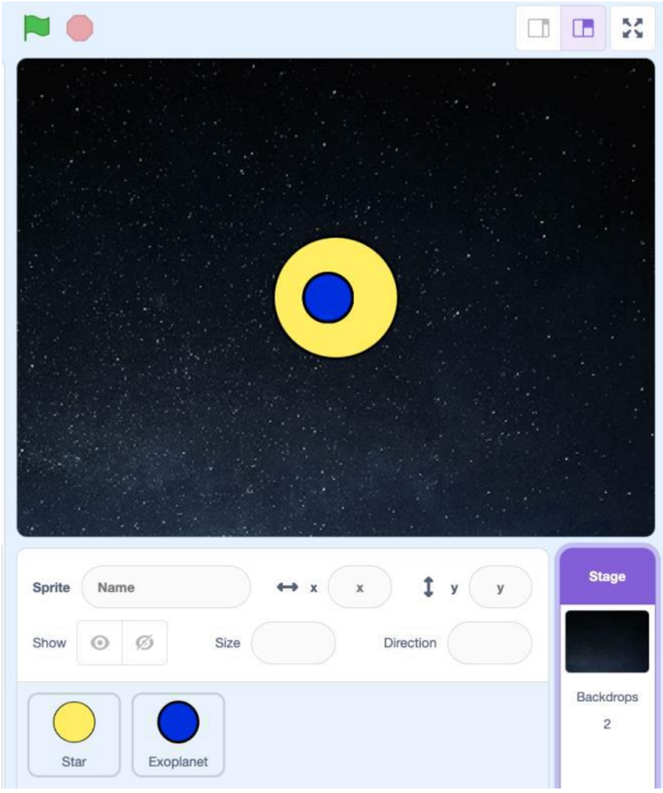


Exoplanet in orbit

An exoplanet in orbit around a star other than the Sun.

Draw a yellow star and an exoplanet as two circles. Determine or change the size of the exoplanet.

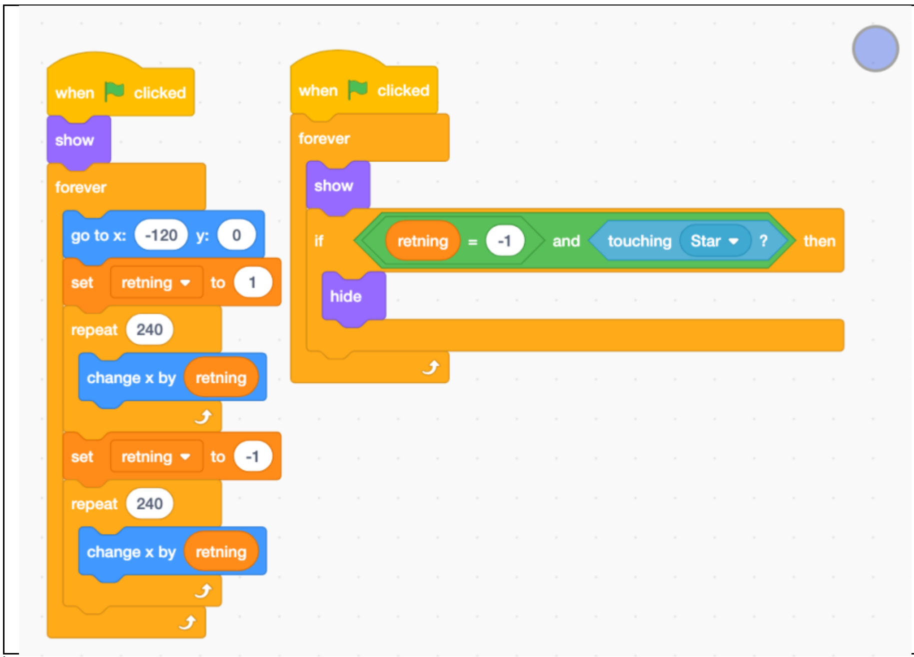




Write a program that causes the exoplanet to "go into orbit" around the star.

Astronomers have discovered many thousands of exoplanets since 1995. One of the methods for discovering an exoplanet is called the transit method.

The transit method is used to see a fluctuation or attenuation in the light from the star.



Program for the exoplanet.

Forever, the exoplanet goes to the right (when direction is 1) and to the left (when direction is -1).

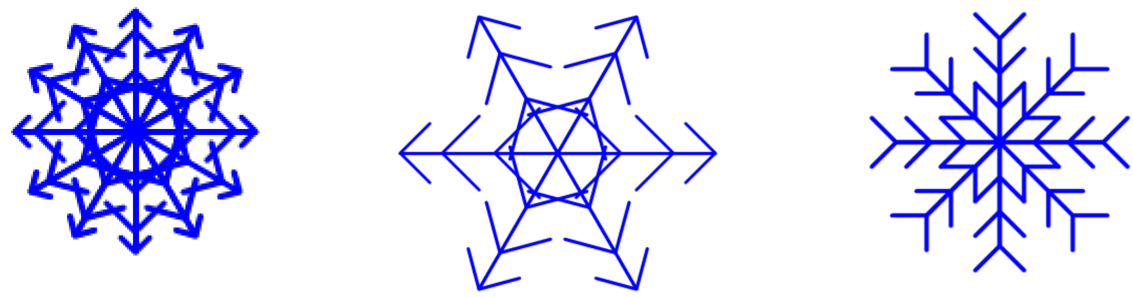
The second part of the program checks with **if-then** whether the exoplanet touches the star. When it touches the star it is hidden and it looks like it is moving (hidden) behind the star.

Investigate:

How does the transit method for exoplanets work?
How many exoplanets have been discovered?

Try this: Show the animation on a large screen and measure brightness with a lux meter on a mobile phone.

Snow crystal



It is said that no two snow crystals are alike in the whole world.

Repeat 12 times draw 12 times the same drawing.

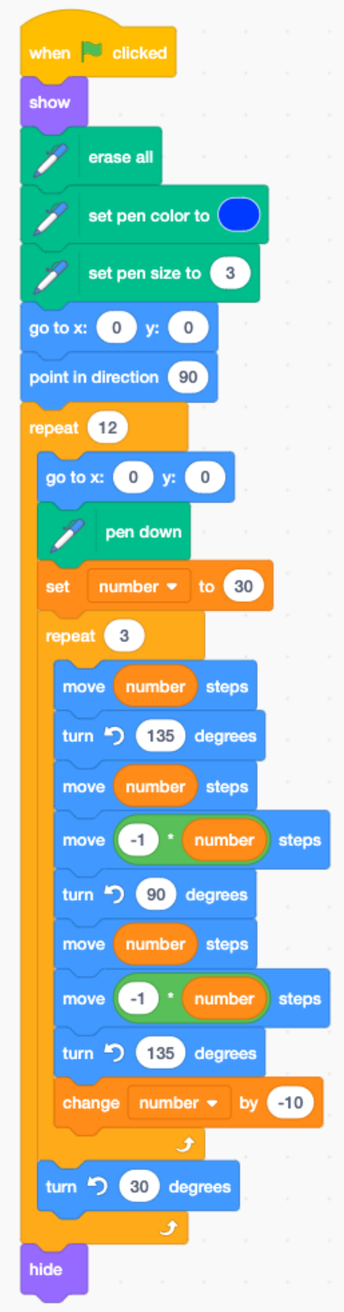
Repeat 3 times drawing the inverted arrows which become smaller and smaller.

The variable **number** controls the size of the arrows in the snow crystal.

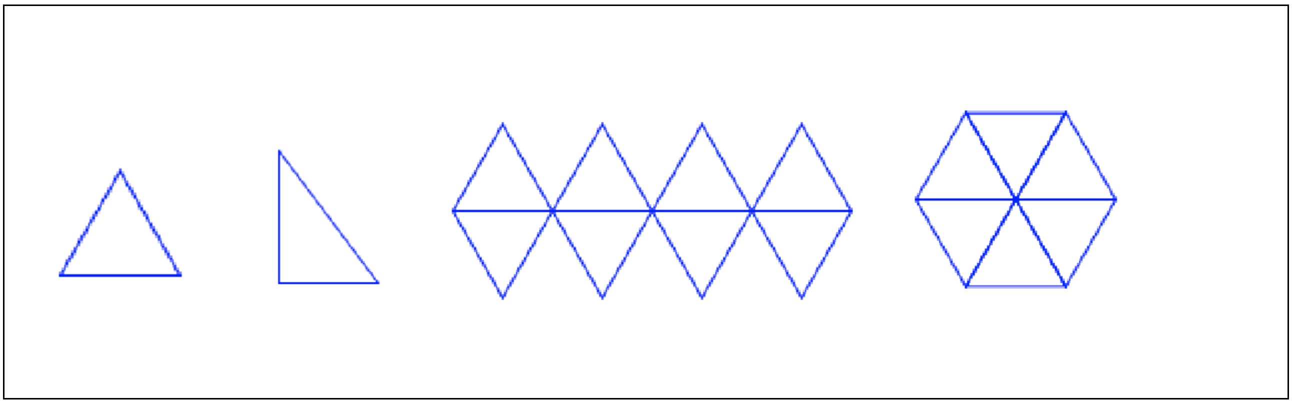
Challenges
Change on the variable numbers and on repeats and rotate degrees and draw brand new snow crystals.

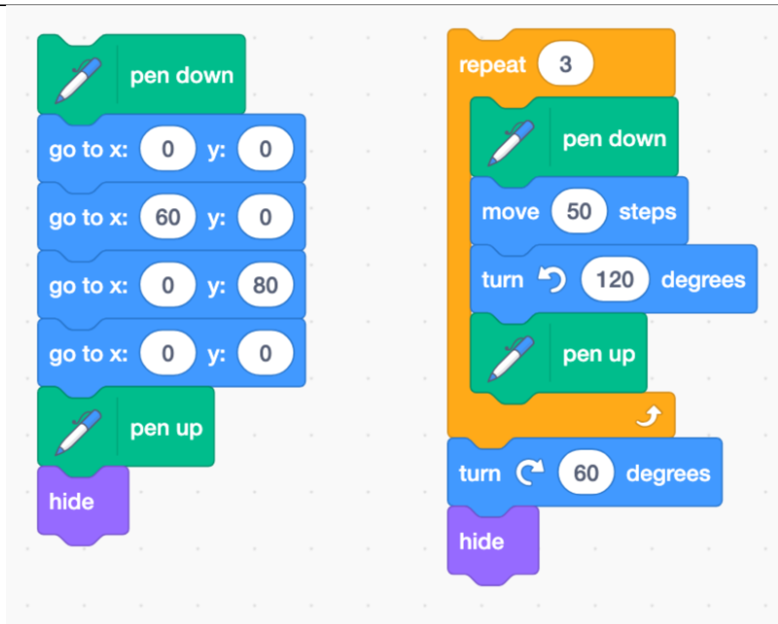
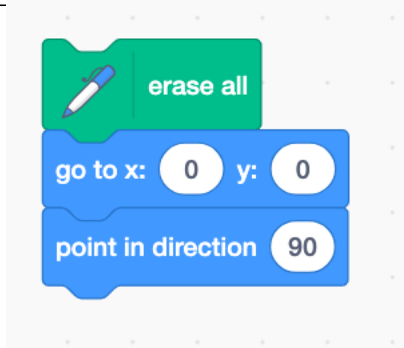
Change pen colour and pen size and draw brightly coloured snow crystals.

Write your own program that draws snow crystals.

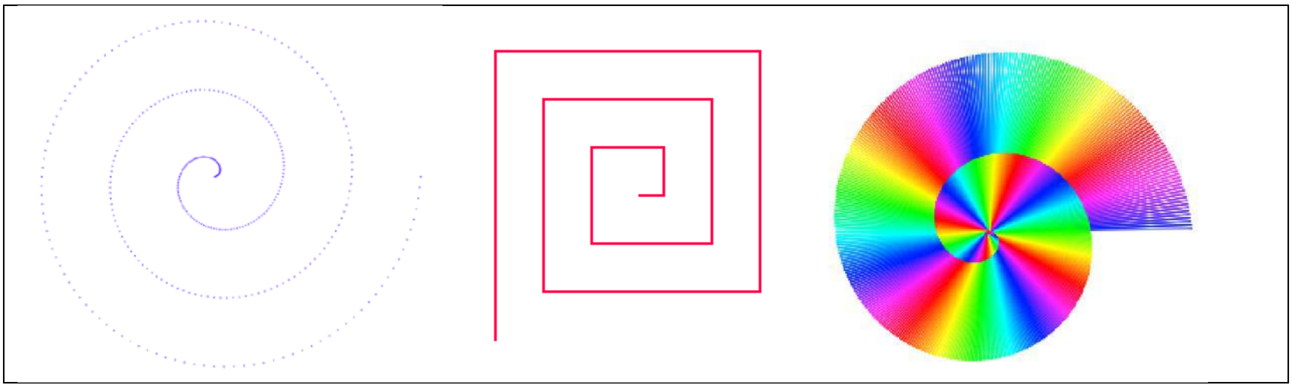


Triangles



Write the codes that draw triangles. Pen down and Pen up is used to draw the triangles. **Challenges** Draw your own triangles.	
This little code cleans up the screen.	

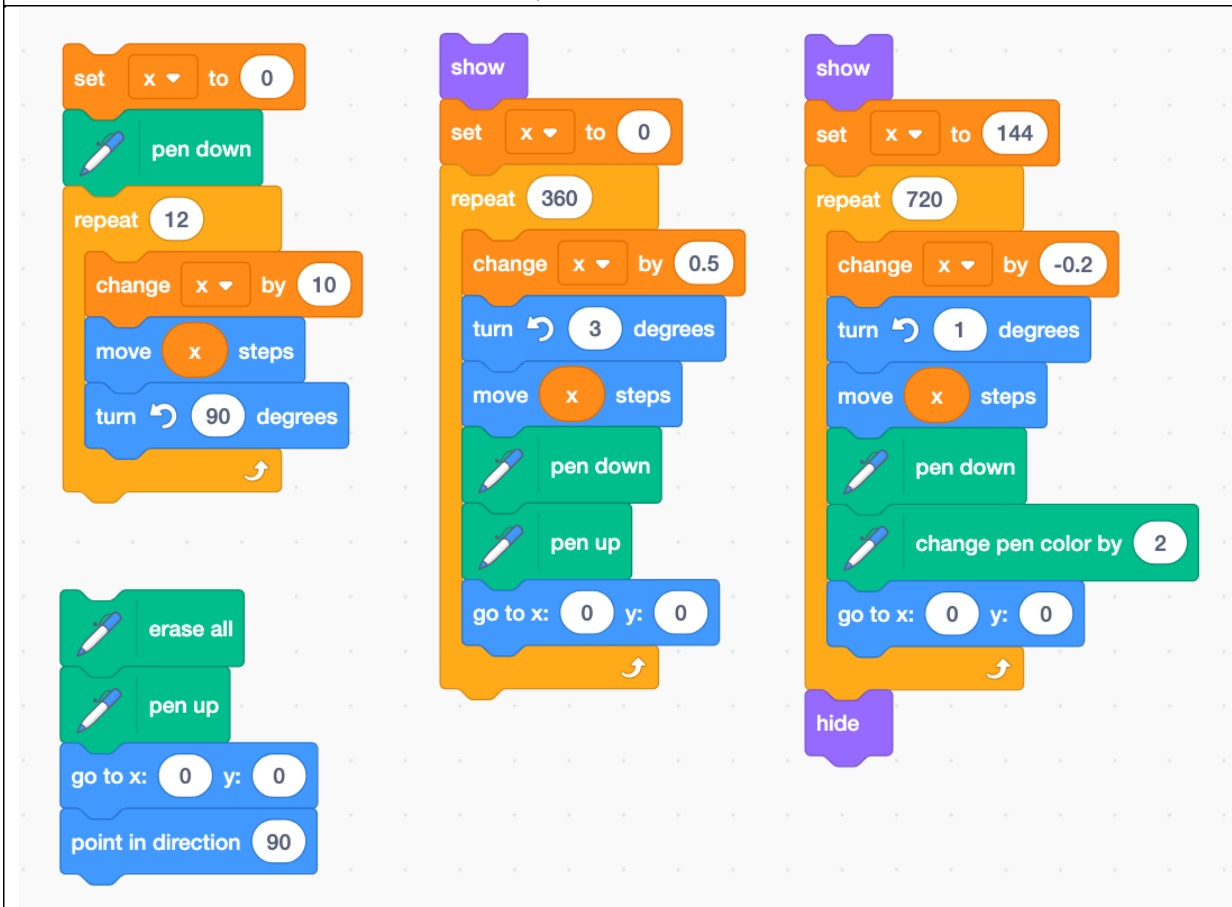
Spirals 1



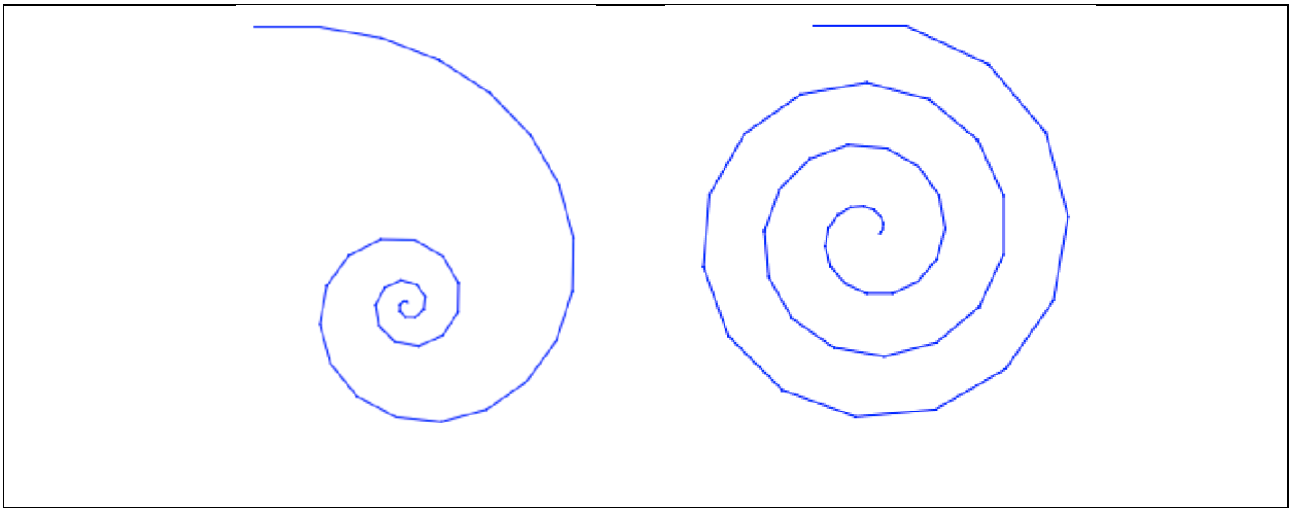
There are two types of spirals.
An Archimedean spiral is like a coiled water hose that has the same width in each individual path. A logarithmic spiral grows in width. Snail houses are an example of a logarithmic spiral.

Challenge
Can you predict which of the codes draws the spirals above? Try to change x by another number.

The little code in the left corner cleans up the screen.

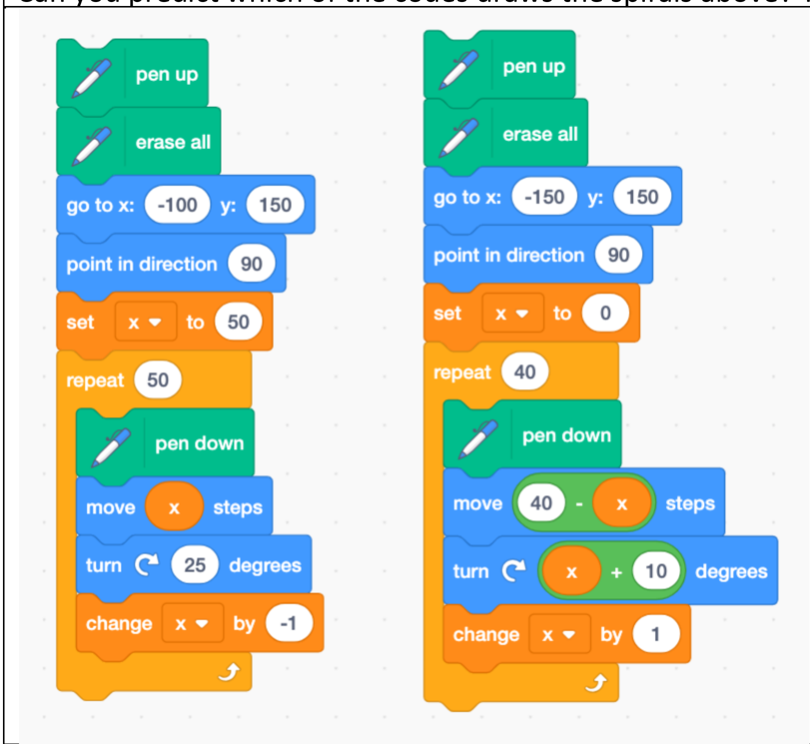


Spirals 2



There are two types of spirals.
An Archimedean spiral is like a coiled water hose that has the same width in each individual path. A logarithmic spiral grows in width. Snail houses are an example of a logarithmic spiral.

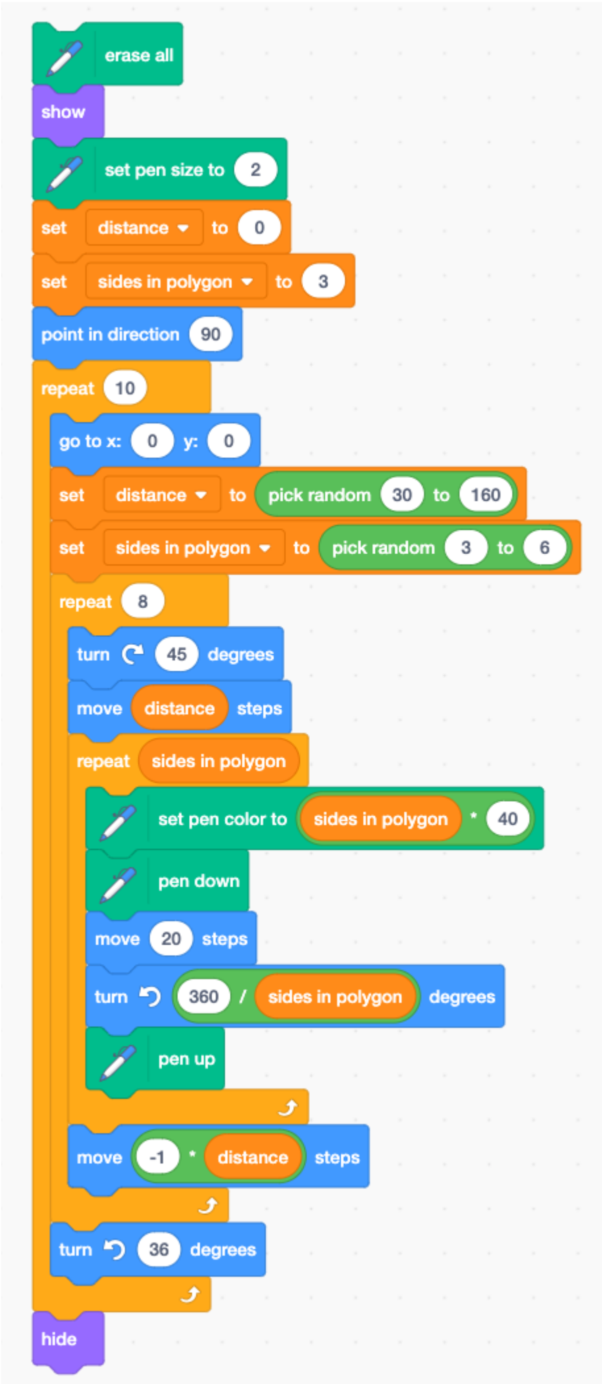
Challenge
Can you predict which of the codes draws the spirals above? Try your own code

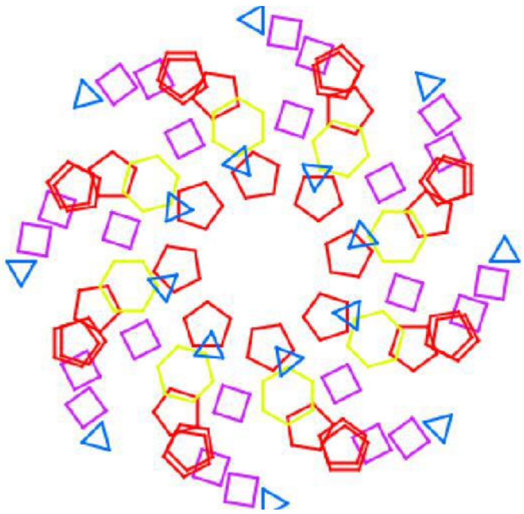


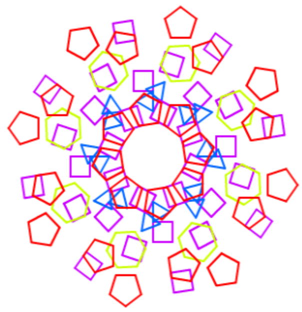
Mandala

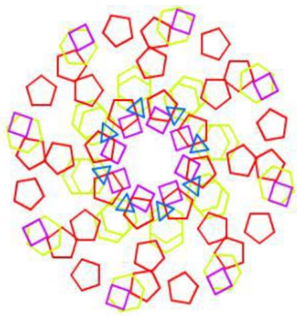
Draw beautiful patterns with random coloured polygons.

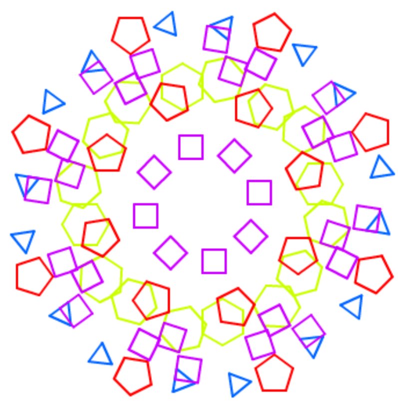
Create two variables “distance” and “sides in polygon”.









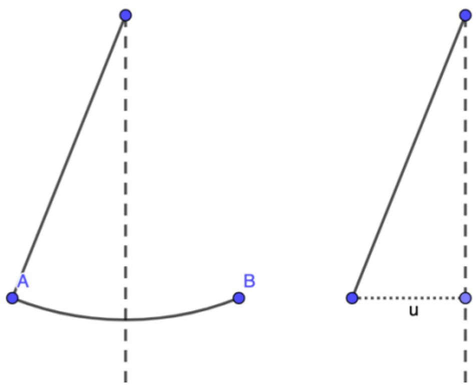


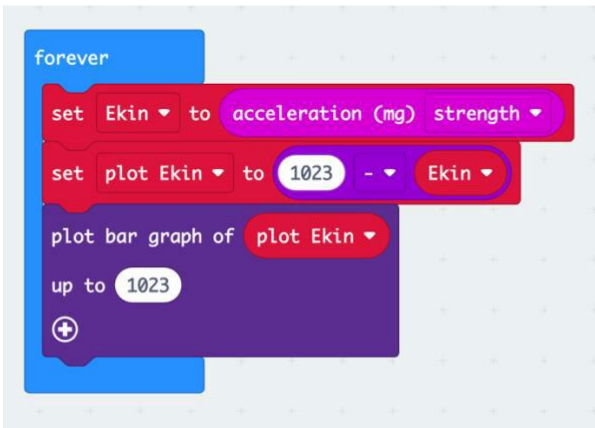
BBC Micro:bit kinetic energy in pendulum swing

Micro:bit can measure acceleration with a built-in accelerometer. We can use this in measuring kinetic energy in a swinging pendulum.
Acceleration is a number that tells how quickly the speed changes. When the acceleration is 0, there is no change in velocity. Then the speed is constant, i.e. the same and does not change.

Task 1:
Build a pendulum, write a program for BBC Micro:bit at **https://makecode.microbit.org** (see suggestions for the code below in the theory section) and investigate with Micro:bit when the pendulum moves fastest (greatest kinetic energy). The Micro:bit is attached to the pendulum and performs oscillations.

Theory:
The kinetic energy E_{kin} is highest when the pendulum swings past the start/stop position. Here, the plump has the highest speed when it swings. Kinetic energy is also called energy of movement and can be calculated with a formula that includes speed.
The potential energy E_{pot} is highest in the outer positions. In the outer positions, the plumb reverses its direction of movement – you can say that the plumb stands still for a very short moment. The potential energy can be calculated with the formula $E_{pot}=m \cdot g \cdot h$, where *m* is the mass of the plumb, $g=9.82\ m/s^2$ is the gravitational acceleration on Earth and *h* is the height.

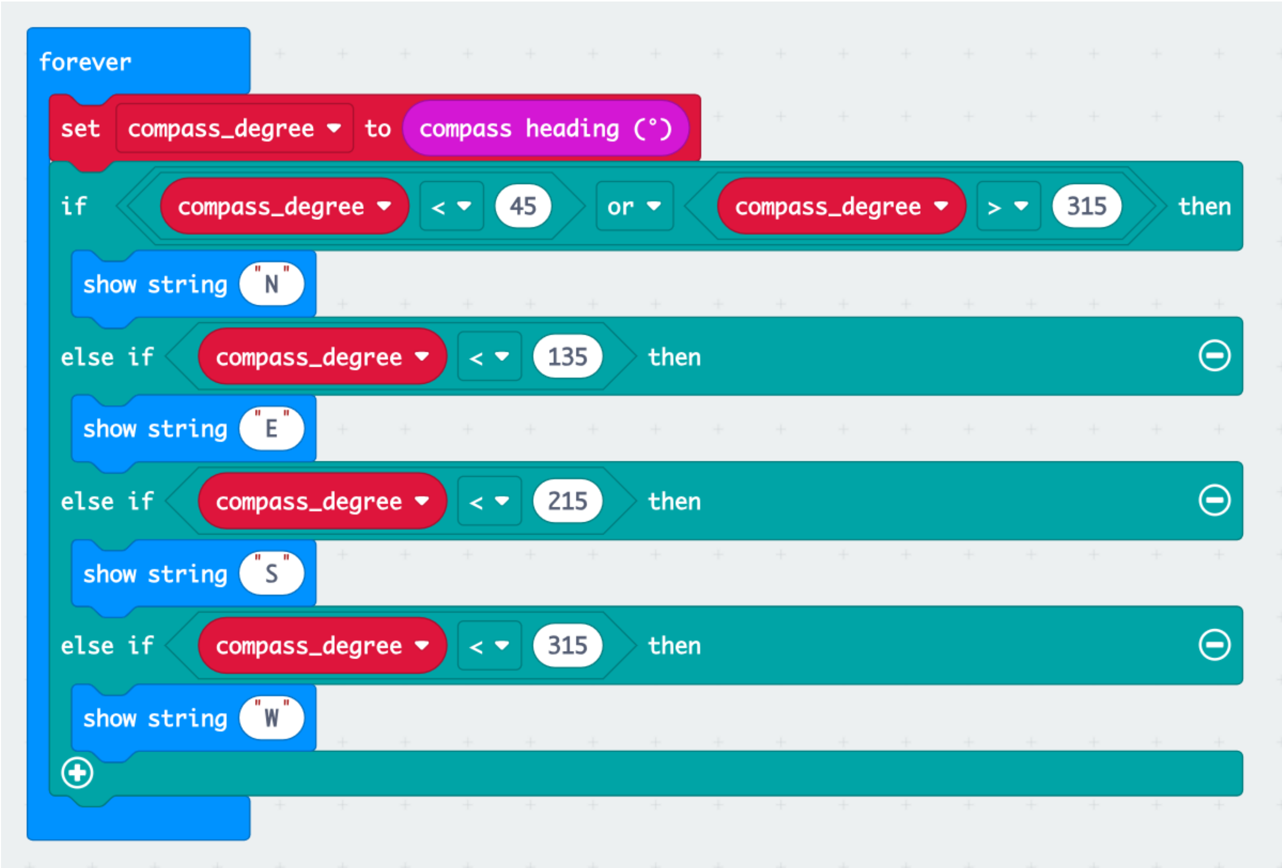




Task 2:
Make a written assignment on a maximum of 1 A4 sheet, in which you show and explain the following:
• Write name/group, class, subject and date in the header of your assignment
• Write at the top of your assignment: **Kinetic energy in a swinging pendulum**
• Show with pictures your setup of a swinging pendulum and measurement of kinetic energy.
• Explain how BBC Micro:bit can measure kinetic energy – use the theory and your knowledge of acceleration.
• Create an experimental description
• Write which materials are used in the experiment
• Hypothesis: what do you think happens in the experiment with the pendulum?

Build a compass with BBC Micro:bit

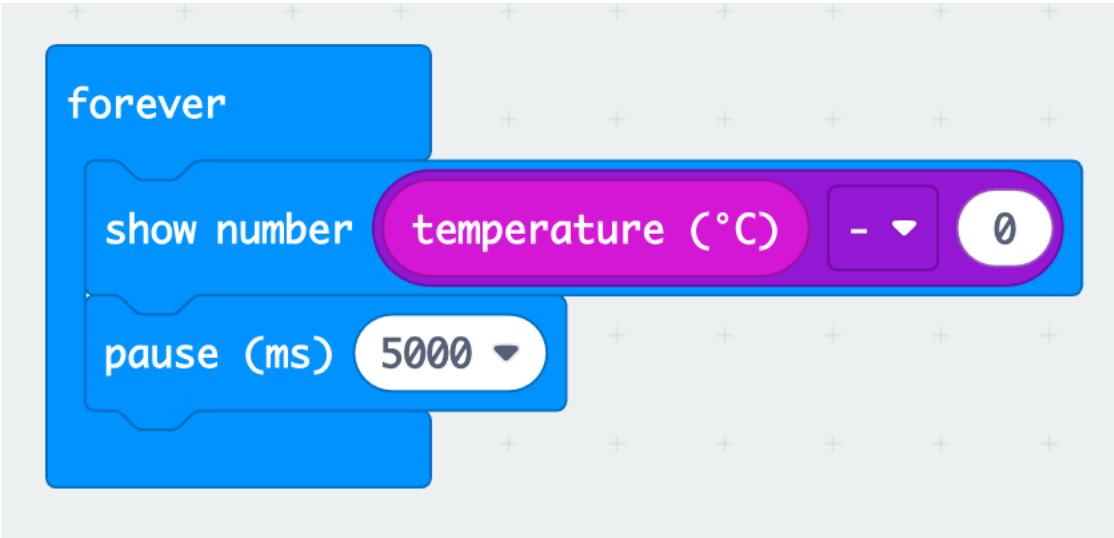
Build a compass with the BBC Micro:bit. The compass shows the direction north, south, east and west.



BBC Micro:bit temperature – part 1

A Micro:bit can measure temperature in degrees Celsius.
In Micro:bit, a temperature sensor is built into the CPU.
A CPU is the actual "brain" of a computer.

Enter the code and the temperature is displayed and then there is a pause before the temperature is displayed again.



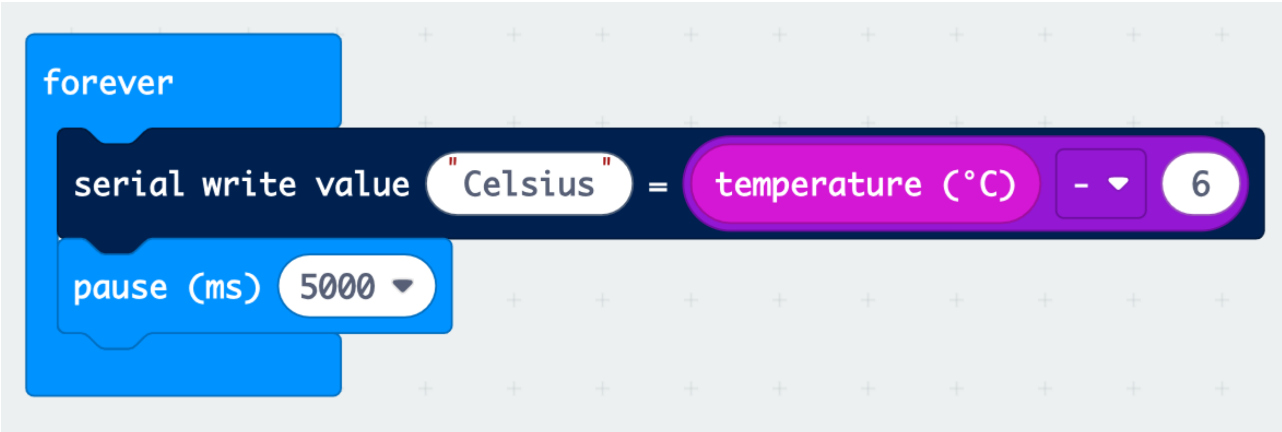
It appears that 0 is subtracted from the temperature. It sounds a bit mysterious. The code is prepared for you to calibrate the displayed number. If the number is 28 and the temperature is actually 22 degrees, then you must subtract 6. You can do that by inserting 6 in the last field and use this code instead.

If you would like to take many temperature measurements over time, you must store your measurements. It will be shown in part 2 how you can store measurements.
But it also requires that the Micro:bit is connected to a computer.
Micro:bit cannot store numbers itself.

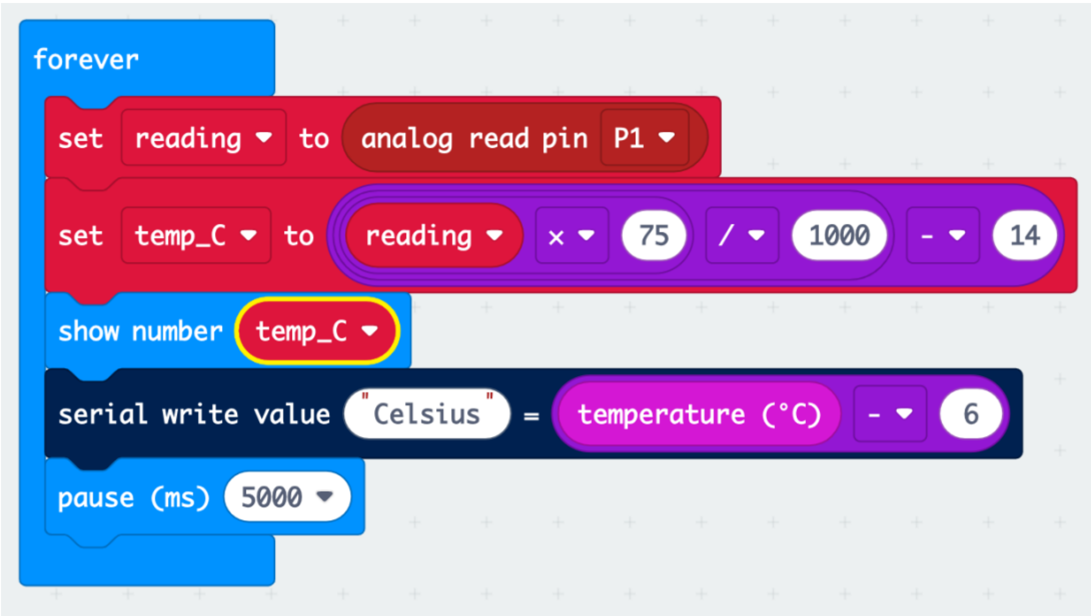
BBC Micro:bit temperature – part 2

In Micro:bit, a temperature sensor is built into the CPU.
A CPU is the actual "brain" of a computer.

I have calibrated the temperature and subtract 6 from the number. There is an error of 6 degrees. I subtract them from the temperature – 6.



Micro:bit and computer are connected so that data is displayed on the screen.
Data can be recorded and downloaded into a spreadsheet.

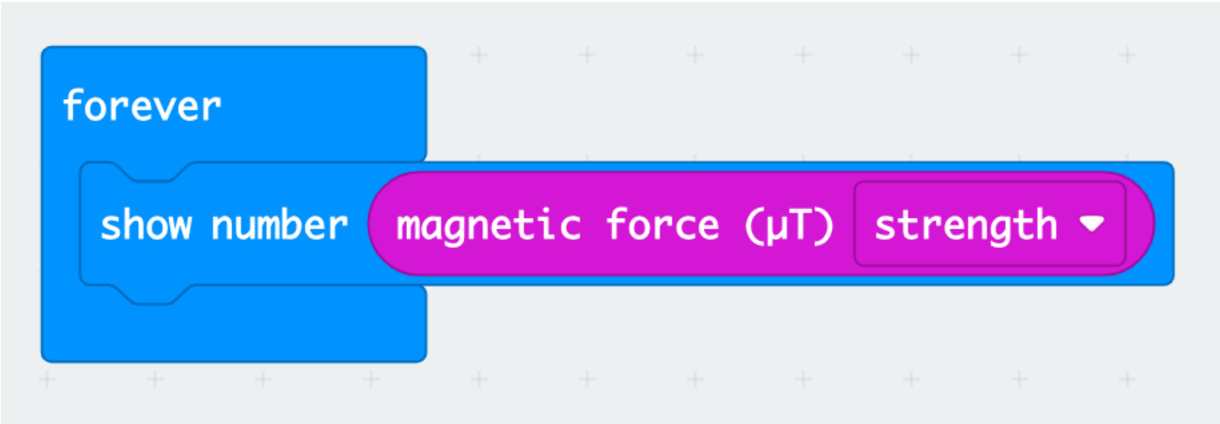


Micro:bit connected to computer which shows the temperature measurement on a graph. Data can be downloaded to excel. It has a small bug or irregularity, as the format is 4,089 seconds which is not translated into numbers in the spreadsheet.

Source to this activity: https://www.youtube.com/watch?v=tZy9Ev21B4c

BBC Micro:bit magnetic field meter

Enter this program into the "forever" loop.
The Micro:bit displays the magnetic strength, which it measures with a small built-in compass on the back of the Micro:bit.



Read the figure for the magnetic strength and insert the measurements into the chart.

No magnet	µT
A bar magnet near the right side (by the B button)	µT
A bar magnet near the left side (by the A button)	µT

Investigate

What do you find out with your measurements?

Where is the compass on a Micro:bit?

What does µT mean?