One Million Earths inside our Sun

Students will learn how to build a model of the Sun, which can fit nearly 1 million little Earth balls.

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| **AGE** | 4+ |
| **LEVEL** | Pre-school, Primary, Middle School, Secondary, University, Informal, Other |
| **TIME** | 30min |
| **GROUP** | Group |
| **SUPERVISED** | Yes |
| **COST PER STUDENT** | Medium Cost |
| **LOCATION** | Does not matter |

**CORE SKILLS**
Asking questions, Developing and using models, Analysing and interpreting data, Using mathematics and computational thinking, Communicating information

**TYPE(S) OF LEARNING ACTIVITY**
Guided-discovery learning, Student Teaching, Problem-solving, Reading/Watching Comprehension, Role-Playing/Drama/Performance, Debate, Modelling

**KEYWORDS**
Sun, Earth, Scales, Distances, Big numbers, Relative sizes, Close packing of equally sized spheres
SUMMARY

GOALS

- Students will learn how to build a model of the Sun, in which nearly 1 million little Earth balls can fit.
- The model will help students of all ages (from kindergarteners to adults) realise how much smaller our Earth is compared to the Sun and how far away the Sun is from Earth. This will give them a sense of the scale of our Solar System and how Earth compares to the Sun.
- Students will learn how to work with large numbers and how to make them manageable.

LEARNING OBJECTIVES

- Using the mathematical concept of close packing of equally sized spheres, (older) students can calculate the number of Earth-sized balls that will fit into the Sun: hypothetically (squeezed and without space between the balls) and in reality (close packed but with space between them). The students will be able to estimate that the numbers vary between 1.3 and 1 million.
- By analysing and interpreting the data, students can determine how to choose an appropriate scale for building a model of the Sun that will be filled with nearly 1 million Earth balls.
- The students will learn to take into account the materials needed for and costs of the model.
- By comparing the sizes of the Earth and Sun, students will learn about relative sizes: the diameter of the Sun is 109 times the diameter of Earth, and the distance from the Earth to Sun is about 100 times the diameter of the Sun.
- Younger students will be encouraged to improve their range of numbers while attempting to fit nearly 1 million Earth-sized balls inside the Sun sphere.
- By walking the distance from the Sun model to the Earth model, the students will experience the difference between distances in a model and distances in reality.
EVALUATION

- The teacher will discuss with the students how to calculate the number of Earth-sized balls that would fit into the Sun and ask them to name the number: 1 million.
- The students will explain how they choose the appropriate scale and calculated the costs for it: if the scale is wrong, the model will be too big or too small.
- Ask the students how often the diameter of the Earth fits into the diameter of the Sun and how often the Sun fits into the distance between the Earth and Sun.
- Ask the students what the difference is between walking in a model and walking in reality.

MATERIALS

To build the Sun:
- 2 clear plastic fillable balls (30 cm in diameter)
- 14 L of polystyrene beads (bean bag filler, around 3 mm in diameter)
- Acrylic colour (dark blue)
- Cup
- Bowl
- Box with a lid
- Hairdryer
- Laundry net
- Power drill
- Rubber gloves
- Sellotape
- Funnel

To build a shell to resemble the solar surface:
- Wallpaper paste
- Tissue paper (yellow)
- 1 clear plastic fillable ball (30 cm in diameter)
- Tinfoil

To do the activity:
- Sun model from above (wrapped in the yellow shell)
- Tape measure
- 14 L of polystyrene beads (bean bag chair, around 3 mm in diameter)
Earth is our home planet, which makes it very special for us. It circles around the Sun every 365 days. But Earth is not alone in this aspect: seven other planets and some dwarf planets rotate around the Sun as well. In comparison to the mass of our Sun, that of the planets in our Solar System is very small: if you take 1000 dice, you need 998 to build the Sun and only two to build the planets. From just these two dice, you need 2/3rds for the planet Jupiter and just the remaining 1/3rd for the other planets. Our Earth is so small! All planets are bound to the Sun by gravity. Gravity is THE force in space. Earth also has a moon, and it takes the Moon about a month to rotate around our Earth. When you look into the sky, the Moon and Sun seem to be of the same size. This is because although the Moon is 400 times smaller than the Sun, it is 400 times nearer Earth than the Sun is.

The Sun is our star. It shines its light in every direction in space. We on Earth are very lucky to be at the right distance from the Sun: near enough to have liquid water and warmth and far enough not to be burnt by its radiation. The Sun has been a reliable partner of Earth's for nearly 4.5 billion years now.

This activity is about the sizes of the Sun and Earth and their distance from one another. But it is not about simply comparing numbers: it is about building a model that will show that the Sun is about 1 million times bigger than the Earth. For this, we will actually fill a Sun sphere with lots of Earth balls!

Before we start, we must take a look at the numbers and do some calculations:
Diameter of the Sun: 1.39 million km
Diameter of the Earth: 12,742 km
Distance from the Sun to Earth: 149.6 million km

We see that
The diameter of the Earth is 109 times less than the diameter of the Sun.
The distance between the Sun and Earth is about 100 times the diameter of the Sun.

How many Earths would fit into the Sun?
This is a bit tricky. For a rough hypothetical estimation, divide the volume of the Sun by the volume of the Earth:

\[ V_{sphere} = \frac{4}{3} \pi r^3 \]

This is about \(109^3 = 1.3\) million

BUT:
If we want to fit real little balls into a big sphere, we must consider that we cannot squeeze the small balls. In reality, there will be space between the balls!
Let us take a look at our chemistry or math book. There, we can find a method to calculate the highest average density that is possible when small Earth balls are packed as close as possible to each other in a big sphere representing the Sun.

\[ P = \frac{\pi}{3\sqrt{2}} = 0.7405 = 74.05\% \]
This was determined by Carl Friedrich Gauss. The equation means that only 74.05% of the space in our big solar sphere is actually occupied by the smaller balls. The rest is empty. This, in turn, means that we can pack

\[ N = P \frac{V_{\text{sun}}}{V_{\text{earth}}} = P \times \frac{R^3}{r^3} = 0.7405 \times 109^3 = 964,202 \approx 1 \text{million} \]

small Earth balls into the Sun sphere.

**Scales, distances and materials**

Thus, there are several possibilities for model building. But with 1 million little blue Earth balls to consider, we will have to take a look at the possible costs. Even if one Earth ball only costs 0.01 cent, the sum will be (more than) 100€!

A good and cheap possibility is using seeds. Unfortunately, we cannot colour them with fluid Earth blue colour because they would germinate. So if the lack of blue colour is acceptable, use white or the smaller black mustard seeds. They are quite spherical (!) and cheap.

Figure 1: Small black mustard seeds. Credit: Natalie Fischer
Black mustard seeds have an average diameter of 1.5 mm, so the diameter of your sphere needs to be $109 \times 1.5\text{ mm} = 16.3\text{ cm}$. To fill a sphere of diameter 16 cm, you need 2.14 L of black mustard seeds. With a bulk density of 0.89 kg/L, the Sun model will weigh 1.8 kg. This is quite heavy for that small a sphere.

Costs:
- 1.8 kg black mustard seeds: 18€
- 16 cm acrylic sphere: 4€

Please note that acrylic spheres are not available in all sizes! You may have to make a compromise because the sphere available is a bit too big or too small for your chosen Earth ball models.

If you want to colour the small balls so they really resemble little Earth-like balls – and I think this is an important detail – you need to use other materials, e.g. polystyrene beads. They are used to fill bean bags or for the retrofit insulation of un-isolated exterior walls. They are around 2.7–3 mm in diameter, so your sphere needs to be around 30 cm in diameter. For a 30 cm sphere, you will need around 14 L of polystyrene beads. Both are available online.

Costs:
- 14 L of polystyrene beads: 2€ (27€/300 L)
- 30 cm acrylic sphere: 25€
- Acrylic colour (dark blue): 2 €

It is clear that the materials (and their costs) influence the scale of your model. Small wooden balls would of course be perfect, but the model will be too heavy (>32 kg) and too expensive (1000 wooden balls of diameter 5 mm cost 12€, and you need 1 million of them!)

A brief check on the distance between the Sun and Earth (100 times the solar diameter) also shows that we have chosen well: 30 meters is a useful distance, because it shows the huge distance between the two celestial bodies and at the same time it fits well in every schoolyard.
To actually calculate the scale of our model, divide the real diameter by the model diameter:

\[
\frac{\text{Diameter of Sun}}{\text{Diameter of Sun model}} = \frac{1.39 \text{ million km}}{30\text{cm}} = 4.63 \text{ billion}
\]

the scale is 1:4 630 000 000.

That means that 1 cm in our model is 46,000 km in reality. When the students travel through this solar system, one step (80 cm) is about 3.7 million km. That’s pretty fast!

**How ‘good’ is your model?**

This is a very important question. You can even discuss it with older students. Of course, you will be asked if there are really 1 million or – to be exact – 946,202 Earth balls inside the Sun sphere. The answer is NO. But we are pretty close to this number. ;-) 

Possible mistakes:

- Polystyrene balls (or seeds) do not all have the exact same size. Some of them are a bit smaller or bigger because of the production process.
- The acrylic sphere is not available in all sizes. For our model with Earth balls around 3 mm in diameter, the acrylic sphere should be 32.7 cm in diameter. Such a sphere was not available. But because the polystyrene balls were a bit smaller than 3 mm on average, this was acceptable.
- When you fill the sphere and shake it, the little balls settle themselves, and you can fit some more in. You must decide when to stop eventually and declare the model finished.

But the quality of the model does not only depend on the exact number of Earth balls you were able to fit inside the sphere!

**Why build this model?**

It all starts with the question ‘How much bigger is the Sun compared to Earth?’ Of course, you can collect these values from a textbook or from the Internet and compare them. But these are extremely big numbers, hard to grasp even for adults. So you decide to build a model. As stated above, in most cases, you use two balls, a very big one and a very small one. This alone is already very impressive! But we seek something even more impressive: we really want the students to fill the Sun with Earth balls themselves, and we want them and others to see (nearly) one million Earth balls inside the Sun sphere! We will not build a fake model by gluing Earth balls only in the inside of the sphere to give the impression that the Sun is full of Earth balls! We will really do it!

The painting of the model Sun and Earth balls is part of the model building process. We want the models to look as genuine as possible. Of course, you can use the material without colour, for example, if you feel the painting process takes too long or you do not want younger students to work with colour at all. But the yellow colour makes the sphere more intuitively recognisable by the students as the Sun than a colourless sphere. The same applies to the small Earth balls: a blue tiny ball will look more like Earth than a white one. Without knowing the details, you can guess that the big yellow ball represents the Sun and the tiny blue ones, the Earth.

So this model is built to inspire students! To make them really wonder! To actually make them think about and work with the sizes of the Earth and Sun. Even young students can fill the Sun without knowing about the exact number of balls going in. Before the students fill the sphere, let them put their hands into the box with the million balls and glide their fingers through the ball pool. That’s one way to experience the number 1 million!

Older students can also do the calculations behind the number first and then prove it by putting the calculated number of balls (here, 14 L) inside the sphere.
You see, it is not important to fill exactly 946202 Earth balls inside the Sun sphere.

FULL ACTIVITY DESCRIPTION

The activity consists of two separate parts: building the model and working with the model. The first part nearly takes a day’s preparation time: colouring and drying the balls (45 minutes), filling the balls into the sphere (1.5 hours), producing the solar surface (60 minutes plus overnight air-drying). The latter part (working with the model) takes around 30–45 minutes.

Of course, there are a few options on how to carry out the activity: you can prepare parts of the model (e.g., the blue balls or the solar surface) ahead of the activity. Or maybe you have already built the model, and you can start working with it directly.

How to carry out the activity also depends on the education level of the students: all age groups (pre-school and primary school with help from their teachers) can build the model with the listed materials and work with the model as well. The theoretical part as described in the background information is intended for teachers and students with the appropriate mathematical background (upper secondary level, depending on the country and curriculum).

Initial steps

1. Start with the question ‘How big the Sun is compared to Earth?’. Depending on the age of the students, you will get different answers, for example, ‘The Sun is a small circle in the sky! And the Earth is big!’ (kindergarten students) or ‘The Sun is so much bigger than the Earth!’ (primary school students).
2. Ask the students how they came up with their answers. The younger ones may have heard it from their parents, while primary school students may have read about it in a book, and others may just have guessed. Your will also notice that the word ‘big’ can have different meanings: are we talking about diameters, volumes or masses? This offers room for further discussion.
3. Also ask them if they have an idea of how far the Sun is from Earth. Ask the students again how they came up with their answers. (This step can also be referred to later). Here, too, the answers will cover a wide range, from ‘Far away!’ (kindergarten students) to ‘Millions of miles!’ (primary school students).
4. Take a look at real nature: provide the data (diameter, mass and volume of the Sun and Earth and the distance between the bodies), or let the students find this information themselves.
5. Compare the numbers and talk about how to interpret the data: how do your findings compare to your initial ideas?
6. You will see that big numbers are difficult to grasp. It helps a lot if you talk about relative sizes, for example, the diameter of the Sun is 109 times bigger than that of the Earth. The distance between the Sun and Earth is 100 times the diameter of the Sun. (Older students can do the calculations on their own.)
7. Tell the students that in natural science, scientists like to visualize facts: they build models, which help them to understand things better. Discuss with the students why this helps.
8. Decide to build a model for this purpose too. For this, you will only need the relative sizes so even young students can think about how to do it. What will you need?
9. Tell the students that they will build a very special model: it will combine information about the different sizes as well as the different volumes. This
will be done not only by using two different big spheres but by filling the complete Sun sphere with Earth balls!

10. With older students, you can now do the calculations introduced in 'Background information'. For the younger students, you can mention the fact that we will try to fit nearly 1 million Earth balls inside the Sun.

11. Present the empty acrylic sphere as the model for the Sun and the white polystyrene balls as models for the Earth. Ask the students what they think the next steps are and what they need (colour, bowl, etc.)

12. Build the model.

**How to build the Sun model**

**Step 1**
Put on your rubber gloves, put some colour into the bowl and water it down.

Step 2
Fill the bowl with a cup of polystyrene beads and mix. When the balls are blue, add the next cup of balls and so on until there is no fluid colour left in the bowl.

Step 3
Fill three cups of the wet blue balls into the laundry net and close it but leave a small hole for the hairdryer. Switch the hairdryer on. After a few minutes, the balls will begin to fly inside the net.

Step 4
When the balls are dry, take them out and store them in a box with a lid. Be aware that the little balls can fly away very easily; one deep breath or fast action and they scatter in all directions! Repeat the process until all balls are dry.
At this point, let the students put their hands in the box so that they can ‘feel’ the number 1 million.

Step 5
Figure 11: The hole through which the blue beads will enter the sphere. Credit: Natalie Fischer

Drill a hole (10 mm) into the top of one of the clear plastic half spheres.

Step 6
Figures 12, 13: First step of the filling process. Credit: Natalie Fischer

Place as many of the blue balls into the other half sphere and close the two half spheres with a click. The plastic ball should be safe now, but just in case, put some tape around the ball where the two half spheres contact.

Step 7
Fill in the tiny blue balls through the drilled hole with a funnel or a small spoon until the sphere is filled. Close the hole with a piece of Sellotape.

That’s it!

There are nearly 1 million Earth balls inside this acrylic sphere.
How to make the solar surface (if you want to)

For this latter part of the modelling, it is good if you could ‘hide’ the interior of the Sun at the beginning. You can then build a solar surface. Of course, you can do it before or after building the Sun. To do it first is advantageous because you could use one half of the acrylic sphere as a model for the surface before it becomes part of the Sun.

Step 1

Figure 16: Material you need for the solar surface. Credit: Natalie Fischer

Prepare the wallpaper paste, wrap one half sphere with tinfoil and smooth the surface.
Rip the tissue paper to hand-sized pieces.

Step 2
Cover the surface of the sphere with wallpaper paste, and stick the first layer of yellow tissue paper on it. Put on additional wallpaper paste until the paper is soaked with it. Repeat the process until you have at least three layers. Ensure that all the pieces overlap each other.

**Step 3**

Let it dry for at least a day.

**Step 4**
Peel the yellow ‘coat’ off the sphere (this part is a bit tricky because the paper shrinks a bit when it dries). If you want, you can paint it. For stability, you can leave the tinfoil inside the yellow coat.

If you want the whole Sun wrapped, repeat steps 1–4 and build a second half.

Ready!

Figures 19-20: The Sun model from both sides. Credit: Natalie Fischer
If you want to use the model for an exhibition, you could string an Earth bead to yellow wool and wind it around the Sun.

**Next steps**

The model is ready, and the students have done a great job. Now step back and let them take a keen look at their model.

1. Let the students describe what they have done and what they think they can learn from the model.
2. Ask the students about the distance of the Earth to the Sun. Older students should be able to calculate it. You can tell younger students that it is 100 times the diameter of the Sun, which is 30 meters in the case of this model. Take a single Earth ball and let the students walk the distance. Every step is nearly 4 million km (3.7 million km)!
3. Notice: When the Sun is seen from the blue Earth ball, it looks as it does actually, in the real sky! So our model is correct!
4. Talk about the scale of a model. What would happen if we decided to make the Sun twice as big?
   Then everything (the diameter of the Earth, distance between the Earth and Sun) would be twice as big, too.
5. Decide what you could do with the model now. Maybe you can use it in an exhibition?
6. With the older students you can discuss the quality of the model. You could ask them ‘When is a model a “good” model?’ and ‘Do you know models that are not good?’

Some ideas for working with the model (if the process of making of the model is NOT part of the activity)

- Show the students the (yellow wrapped!) Sun model and ask them how big they think our Earth is compared to the Sun. If you wish, you can show them some different Earth models to choose from. Then pick out the real one. It is so small!
• Ask the students how often the Earth will fit into the Sun? To answer this, you can unpack the Sun and let the students take a look. There are about 1 million Earth balls inside this Sun model!
• Younger students can be invited to put their hands into a box with 1 million Earth balls to ‘get a feel’ for this big number (note that you have to prepare this box).
• Then ask the students if they have an idea of how far the Earth is from the Sun in real space in comparison to the Sun’s diameter: it is 100 times the diameter of the Sun (here, 30 meters). Let them walk the distance with long strides or use a tape measure to determine the distance. Put the Earth down there. From this distance, the Sun model looks as big as the real Sun in the sky.
• Reflect upon the activity and compare your initial thoughts about the size and scale of the Earth-Sun system with those regarding the model. Does it match what you expected or are you surprised?
Figure 22: The Sun seen from the Earth’s perspective
Here you will find some additional material you can look at.

Figure 23: Comparison of the Sun and Earth. Credit: SOHO/NASA

Another nice model for Sun and Earth is a yellow exercise ball (100 cm in diameter) and a small marble.

CONCLUSION

By completing this activity, students will learn that 1 million little Earths could fit inside the Sun. This will give them a perspective of the scale of the Sun and Earth.
ATTACHMENTS

• Sun Ball

CITATION

Natalie Fischer, 2021, One Million Earths inside our Sun, astroEDU,