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Teacher's Guide

3D printing activity

T. rex 'Trix of Naturalis'

Dear teacher,

Here's the educator's guide for the 3D printing activity.
This document contains information about:

- the structure of the activity
- background information on T. rex Trix of Naturalis
- the prints
- references to necessary resources and helpful tips

Plan your lesson according to your own best judgment. While the 3D printer is in operation, get started with another 3D printer. In total, the students will be working on this lesson effectively for about a day part.

If you have any questions about the content, contact Matthijs Graner (Naturalis) at matthijs.graner@naturalis.nl. For questions about printing, please contact your local technical support team via this link: www.ultimaker.com/en/company/what-support-means-to-us

Have fun printing and investigating!

Kind regards,

Matthijs Graner
Educational Developer at Naturalis

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Short description of the activity

During the activity, you will print different bones of Trix - one at a time. Students will wonder about what will come out of the printer. They will think about what it is, where it came from and where it belongs. They will think about the form and function and will be able to do calculations on steps and scale. Eventually, your students will put together Trix into a model (scale 1:15) for the classroom.

Target audience

Upper primary education (grade 4-7).

Objectives

- Students learn about the form and function of dinosaur bones and the skeleton as a whole, and make a connection between the bones of non-extinct animals and their own skeleton.
- Students describe broadly how T. rex lived (locomotion, step size, body size, etc.).
- Students learn what scientific research is and that science does not have all the answers.
- Students learn about the possibilities of 3D printing with regard to making bones and its use in practice.

Link with core objectives

The lesson is consistent with core objective 41* and can be extended with geometric assignments so the lesson will also be in line with core objectives 32** and 33***.

41* Students learn about the build of plants, animals, and people and about the form and function of their parts.
32** Students learn to solve simple mathematical problems.
33*** Students learn to measure and calculate with units and measurements, such as time, money, length, perimeter, area, volume, weight, speed, and temperature.

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Lesson plan

You can access the 3D scans (www.youmagine.com/designs/trix-in-parts) of the bones of Trix in a small format. You print the bones in the classroom. Choose either to print every part or only a part of the skeleton. The second option is closer to reality, as a complete T. rex skeleton has never been found.

Step 1 (length: ± 3 hours)

To spark curiosity, you start printing a part of Trix's skeleton at the beginning of the activity: the bottom of the pelvis (see photo), without giving any substantive information to the students. Students wonder what is being printed. They are curious, but only know that the print is the beginning of a fun activity, in which more will be printed.

Step 2 (length: ±15 minutes)

Discuss the first print in class. What do you notice? What does it look like? Where does it belong? What can you do with it? There are no answers yet. Ask students if it is part of a larger whole.

Step 3 (length: ± 8 hours)

Then print three parts: arms/shoulder blades, the back legs, and tail piece.

Step 4 (length: 1 hour)

Students learn more by examining the individual prints in groups and gather information on them. Everyone gets to see and examine all four components. They draw/craft how they think the animal looked according to their bones. The drawings will differ. You show them that there are many possibilities. How do we find out what the animal really looked like?

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Step 5 (length: 30 minutes)

Not all parts are being printed. Why not? In reality, one also doesn't find all of the bones. Students view movie clips of i.a. paleontologist Anne Schulp about how an excavation works. These videos can be found on the island 'Opgravia' in the Verwonderwereld (www.verwonderpaspoort.nl/dino) of the Verwonderpaspoort.

Step 6 (length: depending on the number of prints)

Which parts are the students still missing? When the questions on the form/function are answered correctly, an animal is pieced/devised, and videos of Anne are viewed and discussed in class, you may decide to print more or even all of the bones. Each time a part is printed, the students adapt their drawing accordingly.

Step 7 (length: 1 hour)

Put Trix together when everything is printed. The parts can be glued together. As a final task the students build the environment of Trix with many different materials (paper, branches, wood, etc.), in which eventually the printed skeleton can be 'exhibited'. If only some parts of Trix are printed to mimic reality, the excavation site can be built in which the bones can be exhibited scattered and half buried.

Alternatively, the activity can be completed in class with a discussion on Trix. How did it live? In what kind of environment? What did it eat? Would you like to see Trix in real life? Then visit Naturalis (with the class or on your own). Here, Trix can be seen until June 5, 2017. After this date, it will go on a trip through Europe and Asia and at the end of 2018 it will get its final resting place in the new museum.

Step 8 (Optional)

Do the students want to learn more about Naturalis and dinosaurs? Let them surf to the open world of the Verwonderpaspoort. This can also be done in class. Here they see all kinds of movies, carry out experiments and go in search of treasure. The episode of Klokhuis (www.hetklokhuis.nl/tv-uitzending/184/Dinosaurus) on dinosaurs is also fun to watch.

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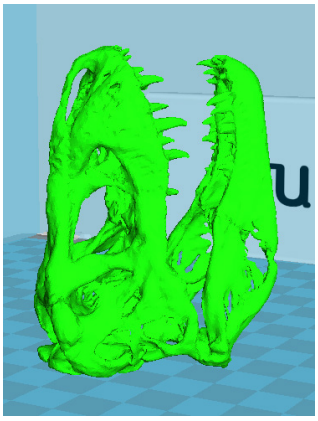
The prints

Here is the list of the seven objects that can be printed. The pictures are placed in the orientation in which you can print them.

The head of Trix

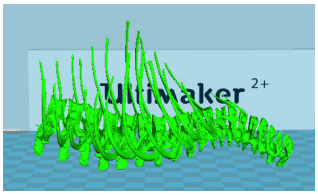
Print time: ± 4 hours



This is the head of Trix. In reality, the skull is one and a half meters long. In the lower jaw, you can see big holes. Scientists have discovered that it is highly likely it was bitten there by another T. rex. On the front of its snout (on the right) you can see a small hole below the nostril. Trix has probably had a nasty infection that never healed properly, but was there for a long time. The head helped us determine the age of the dino, and the feet showed us that it was a female. The thick eyebrows reveal that it is an old individual. For males, these are much smaller (like the rest of the body). The bite force of a T. rex is about 6000 kg. That would feel as if there were six cars on top of you!

Vertebrae and ribs

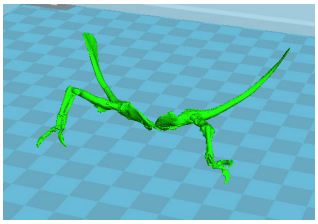
Print time: ± 7 hours



A lot of Trix's vertebrae and ribs were found. T. rex also had so-called belly ribs (not present in the print). These belly ribs protected the animal from e.g. the horns of the Triceratops.

Arms and shoulder blades

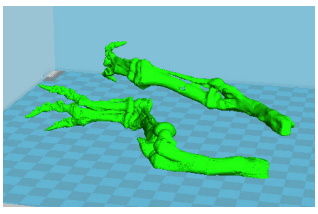
Print time: ± 1 hour



The arms of T. rex were very small, about the size of the arms of a 7-year-old child, but it could lift up to 300 kg with them! The muscles that were needed for this were attached to the long shoulder blades. There were two sharp claws the dinosaur probably used to rip apart its prey. Researchers believe it could also use its arms to hold its partner during reproduction.

Legs

Print time: ± 4,5 hours



The hind legs of T. rex were huge and roughly similar to the shape of a chicken leg. It couldn't run very fast with them, scientists believe about 20 km/h, so you could ride your bike and be faster than this dinosaur.

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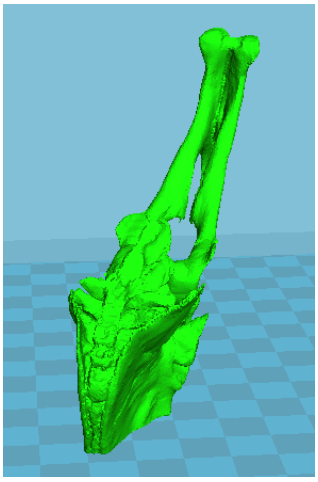
Hips

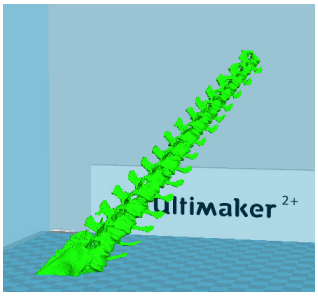
Print time: ± 6 hours



The hips of T. rex were huge. It consists, as with humans, of roughly two times three parts (left and right): the ilium, pubis, and ischium. The ilium is located at the top and clasps the vertebrae. The ilium is called that way because, with humans, it holds the intestines as a sort of bowl, in a T. rex this is not the case. The pubis is situated at the front in humans, but in a T. rex it sticks almost straight down like an anchor and is very large. The ischium protrudes to the back and is located underneath the tail. It possibly offered protection of the buttocks and may have served as a kind of protection for the eggs, so they would not smash to pieces on the ground. With humans, the ischium can be felt when you sit on someone's lap. It sits at the bottom of our buttocks.

Tail origin

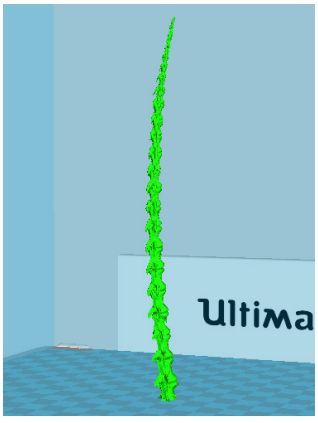
Print time: ± 7 hours



The tail of a T. rex is very long so it could maintain its balance easily, since its head is very heavy. In this part of its tail, Trix has a slightly crooked vertebra. Because of this, its tail may have been a little skewed. Perhaps this also caused its pain and difficulty walking.

Tail end

Print time: ± 2 hours



This is the end of Trix's tail. We're not sure how many tail vertebrae a T. rex had, since a complete tail has never been found. We looked at other skeletons of T. rex, where more of the tail was found. We think Trix had 42 tail vertebrae, but the bones at the end of the tail and some vertebrae in the middle of the tail were not found.

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The story of Trix

Passport

Name:	Trix
Type:	*Tyrannosaurus rex* (king of the tyrant lizards)
Gender:	probably female
Length:	up to 13 meters
Weight:	up to 5000 kilo
Time period:	Late Cretaceous, 67.5 to 66.0 million years ago
Habitat:	Western North America

Expedition

From August 30 to September 8, 2013 Naturalis dug up a *Tyrannosaurus rex*. This happened in Montana, USA, in collaboration with the Black Hills Institute.

Naturalis went on an expedition for the first time in the spring of 2013, from April 29 to May 18. In Wyoming, a few nice fossilized bones of the left foot were found. This find was promising, even the small phalanges were still neatly together. These are usually the bones that are lost first. Despite this promising discovery only parts of the left foot and leg of *Tyrannosaurus rex* were found. Why the small bones were preserved, but not the rest of the skeleton, remains a mystery. The whole hill that should have held the rest of the skeleton was excavated. "The layer of sand where the bones should have been, was getting thinner and eventually disappeared," says Anne Schulp. "Perhaps the carcass was eaten at the time, or was taken much further by the river that ran through the area. We do not know."

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Fortunately, the chances of a T. rex for Naturalis was not lost. Pete Larson, paleontologist at the Black Hills Institute in America, pointed Naturalis to another place in Montana, America, where a couple of amateur paleontologists had found remains of T. rex. The lower jaw, loose teeth and a part of the hip joint and tail bone were found by them. The expectation was that there was more material of T. rex buried in the ground. Naturalis had also gone there to dig. Meanwhile, a very complete skeleton has indeed been found!

Exceptional find

Skeletons of T. rex are among the world's rarest fossils. Our T. rex Trix is extra special: Trix is among the top three of most complete skeletons ever found!

What paleontologist doesn't dream of someday finding a tooth or bone of this terrifying predatory dinosaur? Even better: a complete skeleton. But you can keep dreaming: complete *Tyrannosaurus rex* skeletons have never been found and are the world's most coveted fossils. So far, less than ten were found, one more complete than the next. "So far" has been quite some time, if you know that Barnum Brown had the good fortune in 1902 to dig up the first skeleton. If anyone wants to try his luck, they should search the west of North America, home of T. rex, just as Brown.

How did T. rex live?

When did T. rex live and with did he do in a day? How will you find this out? Learn all about the habitat of T. rex.

Time period

Tyrannosaurus rex lived at the end of the Cretaceous. To be exact, in the Maastrichtian, named after the chalk layers of the Mount Saint Peter in Maastricht, approximately between 67.5 and 66 million years ago. He is one of the last dinosaurs. The species was around the moment a meteorite impact wiped these unique reptiles off the face of the earth. The impact took place not too far south of the habitat of T. rex, to be exact at the Mexican Yucatán Peninsula. The meteorite impact also meant the end for other life forms: other species of dinosaurs on land, reptiles, ammonites in the sea and pterosaurs in the sky. n

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Habitat

Tyrannosaurus rex was only found in North America. At least, no fossils of this species were unearthed in any other places. North America was still occasionally connected to Eurasia. This allowed Tyrannosaurus-like species to also conquer this continent. Even in Asia species from the tyrannosauridae family were found. These dinosaurs are similar to the 'real' Tyrannosaurus in many respects. For example, we know about the Tarbosaurus from excavations in Mongolia. This dinosaur is also a robber and is closely related to T. rex.

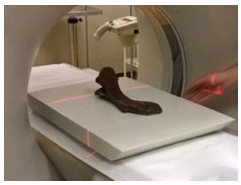
Lifestyle

Little is known about the daily life of T. rex. After all, behavior can only be linked to bones indirectly. For example, it is not clear whether T. rex lived alone (solitary) or in a group of family. So far, there are no indications of a group life, such as multiple skeletons grouped together. Tracks, for example, tell us more about this, but, unfortunately, tracks of T. rex have hardly been found. One find of a few tracks in Canada is indicative of herd behavior.

Nevertheless, a few things can be learned from the construction of the skeleton. T. rex was one hundred percent meat eater, a hyper-carnivore. With such teeth, he simply ate nothing but meat. Grinding plants would not have worked with those pointy teeth.

Interestingly, the front legs were too short to bring food to the mouth, but they were heavily muscled. Possibly T. rex used them during mating. They would use them to hold each other. Another theory states that they used their feet to press up and get up from a lying or squatting position. Possibly they also kept struggling prey at bay, like a lion holding a wildebeest down. The comparison with the lion might continue. Would T. rex also have administered a lethal bite to his victims, or constricted the throat until they choked? Did he let other predatory dinosaurs do the work and feed himself with the remains?

The science behind T. rex



Very few fossil finds of T. rex are known. Each bone of a T. rex that is found, however small or large, can be of vital importance for science.

There is much left to explore about our T. rex. When and where did T. rex live exactly? What was the age of the T. rex of Naturalis? How fast could T. rex run? We want to get insight in the medical file: which bones did T. rex break? Which diseases did he possibly have? What was T. rex's diet like? How did T. rex migrate; for instance, did he reach mountainous areas or the coast?

Using fossils, Naturalis researchers contribute to solving these issues or gaining new insights. "Each bone of every T. rex provides us with more knowledge", says our director Edwin van Huis. "We have years of scientific research left with this."

To floor 13

Paleontologists Dylan Bastiaans and Martijn Guliker, who among others performed preparation work on a Triceratops skull, previously visited the collection tower of Naturalis. Here they keep the T. rex bones that

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have already come from America. Upon seeing and touching the aforementioned tail bones, Dylan and Martijn are thrilled: “These bones are preserved magnificently!” Dylan, a medically trained paleontologist, immediately notices abnormal structures in one of the bones, which may indicate that the T. rex was suffering from an infection. Martijn: “It is interesting to compare the scan of a healthy bone with one of an anomalous bone later on.”

Osteoporosis

How can you find out more about diseases that Trix possibly had? You go to the hospital with the bones! Recently, three paleontologists visited the LUMC to make a CT scan of three bones from the tail of T. rex.

They were the haemapophyses, also known as the chevron bones. These Y-shaped bones were located on the underside of the caudal vertebrae and gave the tail more firmness. Because of this we now know that the tail of T. rex didn’t drag along the ground. Furthermore, they protected the blood vessels and formed an attachment surface for the tail muscles. Dylan is involved in the research into the medical history of T. rex. In studying an earlier CT scan of a tail vertebra, he found a pattern that was similar to osteoporosis in humans. To get more clarity on this, it is important to scan more bones.

Diagnosis

The scans, which were made at the LUMC, show the structure of the inside and outside of the fossil tail bones in detail using a computer program. Dylan can now get to work to formulate a diagnosis of the conditions of the T. rex. In a while a follow-up appointment with a medical specialist will be made to discuss the diagnosis. There is no rush, since the patient has lóng been deceased.

What age did T. rex reach?

Thanks to the growth lines in the bones the age of our T. rex can be determined. Not exactly, unfortunately: you count the minimum age. T. rex Sue is the oldest found T. rex so far, it reached an age of about 28 years old. 23 growth lines were counted in its case, which is considered to correspond to 28 years. Our T. rex was probably older, easily 30 years old.

Drilling or sawing

But how are those growth lines visible in a bone? Naturalis has a unique T. rex that is attended to with great caution. So as to apply the least possible damage to the bone, a drill core from the fibula was obtained. A thin section is made from this. The drill core is then placed back into the bone. This thin section makes it possible to count the growth lines. When a ‘slice’ would be cut out of the bone, a seam would appear in the bone, which would be a shame.

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Verification

During the research, a drill core will probably be taken from other bones as well, such as the thighs or ribs. By counting the growth lines in more places, something can be said about the age of our T. rex with more certainty.

A pleasant surprise

Let's go back to 2013, when Naturalis paleontologists traveled to Wyoming in search of T. rex bones - they found more! A skeleton of a triceratops was also found. Two years later an expedition was organized to dig it out. The excavation surprised everyone: instead of one skeleton, paleontologists found no less than five! A part of these bones were extracted during the 2013 field season and transported to the Netherlands. Since December 2015, these are being excavated and cleaned before the eyes of visitors of Naturalis.

More bones

However, there were indications that there were more bones in the ground than the 600 that were found at first. Therefore, the Naturalis team traveled back to Wyoming to dig up the rest.

Excavating, a big job

Such an expedition is a challenge: it is very hot, and you have to be very careful while digging. Some bones are completely whole and easy to dig up – the ground around the bones of the triceratops wasn't petrified – but others are compressed. The bones are then carefully taken out of the ground.

Updates from the field

The Naturalis excavation team likes to keep all dinosaur fans informed. Thus, around the second triceratops expeditions in June 2016, blog posts were posted on the website regularly and Matthijs Graner, one of the researchers, kept a video blog and shared the findings of the group. For instance, he showed you what tools are used in a dig and he took you to the plains of Wyoming. Here (www.naturalis.nl/nl/over-ons/nieuws/blogs/Triceratops-expeditie-2016/) are his vlogs and blogs of him and colleague Martijn Guliker.

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References

Needed for the lesson

Verwonderpaspoort print island: www.verwonderpaspoort.nl/3d
Verwonderpaspoort open dinosaur world: www.verwonderpaspoort.nl/dinos

Extra

Vlogs Triceratops excavation: http://bit.ly/2go3gof
Why Trix was preserved this well: http://bit.ly/2hlrb8Y
Time-lapse building Trix: www.youtube.com/watch?v=R0koWLUcDPw

Tips

Here are some tips to ensure that printing will go well:

Print not sticking to build plate

When you're experiencing difficulties with prints sticking to the build plate, there could be a few things going on. It could either mean that the first layer just doesn't stick well enough or that the prints gets loose due to "warping" of the plastic. Warping basically happens because of the properties of the plastic. Plastics have the tendency to shrink when cooling down fast (some plastics more than others), which could eventually lead to your print curling up (at the corners). You will especially notice this behaviour when printing ABS, which has a relatively big shrinkage.

There are a few things you could do for a good first layer of a print and to reduce the amount of warping.

Heated bed temperature

With a heated bed, using the correct bed temperature is important for good adhesion. This way you ensure that the first layer of the print doesn't cool too much, due to which it could shrink a lot. A temperature of 60°C is recommend for PLA while ABS needs a temperature of 90°C. The default settings in Cura should be fine for this, but you can always play a bit around with it.

Bed leveling

For printing it is very important that the first layer is nicely squished into the glass plate and sticks well to it. If the distance between the nozzle and build plate is too big, your print won't stick properly to the glass plate. On the other hand, if the nozzle is too close to the build plate it can prevent the filament from extruding from the nozzle.

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In both cases this will lead to a bad first layer, which might eventually lead to adhesion problems. Make sure to re-level the build plate if you're experiencing this issue.

Glass plate

For good adhesion it is important that the glass plate is either completely clean or that glue is applied to the glass plate. For PLA it's not necessary to use glue, although it's recommended when printing bigger objects. When using ABS, it's advised to always have a thin layer of glue on the glass plate.

Using a "Brim"

A nice feature in Cura to help preventing warping is called "Brim". It will place a single layer thick flat area around your object, thus creating a bigger adhesion surface. The Brim can easily be removed once the print has finished.

This option can be selected when using the Full settings in Cura. You can find it at "platform adhesion type" in the basic settings tab.

For errors during printing and how to solve them, click here:
www.ultimaker.com/en/resources/17203-error-messages

If you have any other questions about printing,
please contact your local support team via this link:
www.ultimaker.com/en/company/what-support-means-to-us