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TEACHERS' CHOICE AWARD TCA FOR THE CLASSROOM 2019 LEARNING MAGAZINE

Explorer

ADVENTURER

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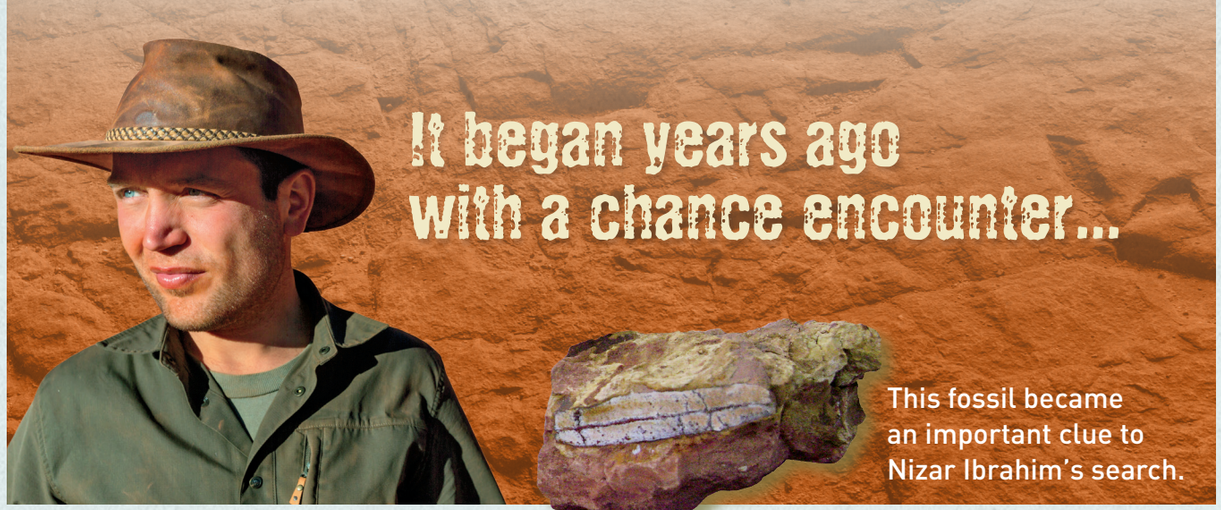
SCIENTIFIC PROCESS

As you read, think about how scientists evaluate new evidence to develop a new theory about *Spinosaurus*.

Rethinking Spinosaurus

Follow a scientist's quest to reveal the secrets of this mysterious dinosaur.

By National Geographic staff



It began years ago with a chance encounter...

This fossil became an important clue to Nizar Ibrahim's search.

Nizar Ibrahim was in a small town in Morocco in 2006. He's a paleontologist—a scientist who studies fossils. He's also a National Geographic Explorer.

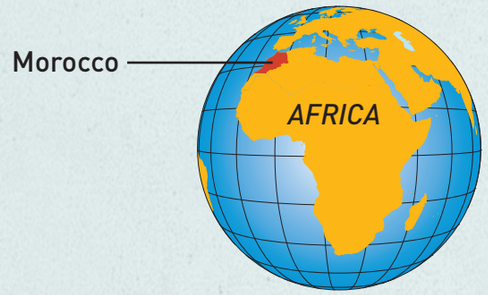
He just finished collecting fossils in the nearby Sahara. He was about to leave Morocco and head home to study them. But before he left, he wanted to talk to some of the local fossil hunters. He wondered if any of them had found fossils that might provide clues to the fossils he had found.

Ibrahim was approached by a man who had a box of fossils he had collected. The man had a mustache. Ibrahim was more interested in what was in the box than the man. He had no way of knowing that the man's mustache would become very important to this story later.

The box was full, but one fossil caught the explorer's eye. It was long and flat. He had never seen one like it before. He thought that it might be part of a spine or a rib. He wasn't sure. He thought it might be important, so he bought the box.

After the sale, the man with the mustache disappeared. Years would pass before Ibrahim thought about this fossil or the man again. Yet, that fossil would lead him on an amazing journey. In the end, he would discover one of the oddest dinosaurs that ever lived.

Ibrahim used the fossils that had been found to piece together an unknown dinosaur.



Picturing the Past

Ibrahim has made dinosaurs his life's work. He often travels to the Sahara to look for fossilized bones. Ibrahim uses the scientific process to piece together the past. He studies the bones and **observes** the shape of the bones and where they are found, and he thinks about what part of the animal they came from. He asks key questions to form a **hypothesis,** or explanation, for how these ancient animals used to live.

To others, the Sahara might look windy, desolate, and dry. Yet, when Ibrahim looks out across the desert, he sees something else. He pictures what this place looked like 95 million years ago. Instead of sand, he sees rivers and swamps teeming with life. There were giant turtles, huge crocodiles, and fish the size of cars. Here, flying reptiles filled the sky. Three of the world's largest meat-eating dinosaurs walked on land.

Something Urgent

One day, Ibrahim received a message from some paleontologists in Italy. These friends described a number of fossils they had seen that they thought Ibrahim would want to see, too.

When he arrived, several fossils were laid out for him in the basement of a museum. They were long, flat bones. His friends thought the bones may have come from Morocco. These bones looked familiar. They looked a lot like the fossil he bought from the stranger with the mustache years ago.

These bones reminded Ibrahim of something else, too. They reminded him of some drawings and photos of a dinosaur that he had seen in a book when he was a child. Could these things be connected? Ibrahim was beginning to form a new hypothesis.

Searching for *Spinosaurus* took hard work and perseverance.

A Different Dinosaur

The bones Ibrahim remembered from the book had been discovered by a German scientist. He had uncovered these unusual dinosaur bones in the Sahara.

This dinosaur was bigger than *T. rex.* It had long jaws and sharp teeth shaped like cones. It also had a huge sail on its back. The scientist named it *Spinosaurus.*

Only two partial skeletons of *Spinosaurus* had ever been found. A museum in Germany put them on display, but they were destroyed during World War II. Only the scientist's notes and old photos remained.

Ibrahim thought his fossil and the ones in Italy might be from *Spinosaurus,* but he needed proof. He needed more bones. He would have to return to Morocco. He would have to find the man with the mustache.

On the Trail

It was crazy. Ibrahim knew that. Five years had passed. He didn't know the fossil hunter's name or address. All he knew was that the man had a mustache. That wasn't much to go on. Still, Ibrahim wouldn't let go of the idea. If he could find the fossil hunter again, maybe he could find *Spinosaurus*.

Ibrahim traveled back to the small town in Morocco and, against all odds, began his search. Days went by without success. No one seemed to know who or where the fossil hunter was.

Time was running out. Ibrahim's spirits sank. The task seemed impossible. On his last day in Morocco, Ibrahim sat with two friends in a small café, sipping tea. He could feel his dream slipping away.

Then suddenly, he looked up. A tall man, wearing white, passed by his table. The man looked familiar, and he had a mustache.

Ibrahim leaped up and chased after him. Ibrahim's heart beat wildly. He caught up to the man and looked at his face. It was the fossil hunter! Now, if only the fossil hunter would lead him to the fossils.

Ibrahim was led into the desert to find *Spinosaurus*.

Discovery!

The man with the mustache listened closely to Ibrahim. He understood what Ibrahim was trying to do and how important it was. He agreed to lead Ibrahim to the place where he had found the fossils.

The next day, the two men drove a short distance into the Sahara. Then the fossil hunter stopped their vehicle. They would have to make the rest of the trip on foot. They climbed a steep slope that couldn't be seen from the main road. Near the top, they reached what looked like a small cave carved into the hillside. This was where the fossil hunter had been digging.

Trembling, Ibrahim climbed into the hole. He took a deep breath. Using special tools, he gently picked away at some of the sand and rock. Within minutes, he discovered several bones. Ibrahim studied the bones and smiled. At last, he had found *Spinosaurus!*

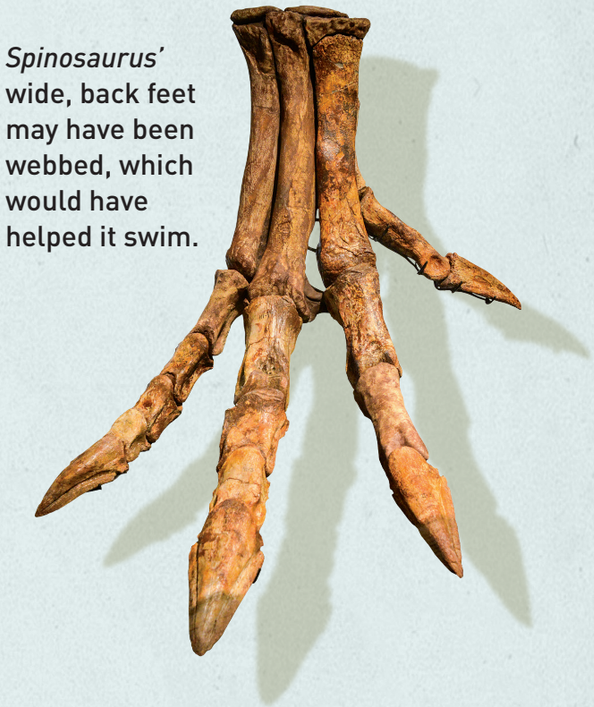
Ibrahim works slowly and carefully.

Building the Beast

Ibrahim's search for *Spinosaurus* was over, but his work on the hillside was just beginning. Many large, predatory dinosaurs seemed to have lived in this area at the same time. Did that mean they were competing for the same prey? Ibrahim began to form a hypothesis for how *Spinosaurus* could have lived among other big predators. To prove his theory, though, he had to conduct an **experiment.** Ibrahim had to recreate *Spinosaurus*.

First, he took all the fossils he'd gathered and put them together to see what this dinosaur might have looked like. He didn't have all the pieces, but he had enough to get started. His **method** was to create a digital model on a computer based on what he knew so far.

Then, working with other scientists, he made a skin for his model skeleton. Now he had a complete *Spinosaurus*. What he had created surprised him. It looked very different from all the other dinosaurs he had ever seen.



Spinosaurus' wide, back feet may have been webbed, which would have helped it swim.

Making a Model

The *Spinosaurus'* neck and body were longer than other dinosaurs'. The *Spinosaurus* had short hind legs and powerful forearms. Its back feet were wide and flat. To Ibrahim, they looked like paddles.

Ibrahim studied *Spinosaurus'* skull closely. It had a long snout, but its nostrils were halfway up the skull. And then there was the sail. It was about 1.8 meters (5.9 feet) long and rose more than 1.8 meters (5.9 feet) from its back.

Until Ibrahim had created this model, scientists had assumed that *Spinosaurus* spent most of its time on land. Seeing the way this dinosaur actually looked made Ibrahim realize that it probably didn't spend much time there.

Ibrahim made a **conclusion** that this dinosaur spent most of its time in water. Its long tail may have helped propel it through the water. *Spinosaurus* probably had webbed feet that it used to paddle through water. High nostrils allowed it to keep most of its head underwater while it hunted. This is why *Spinosaurus* could exist with the other meat-eating dinosaurs. It hunted in the water.

Spinosaurus' head was long and thin.

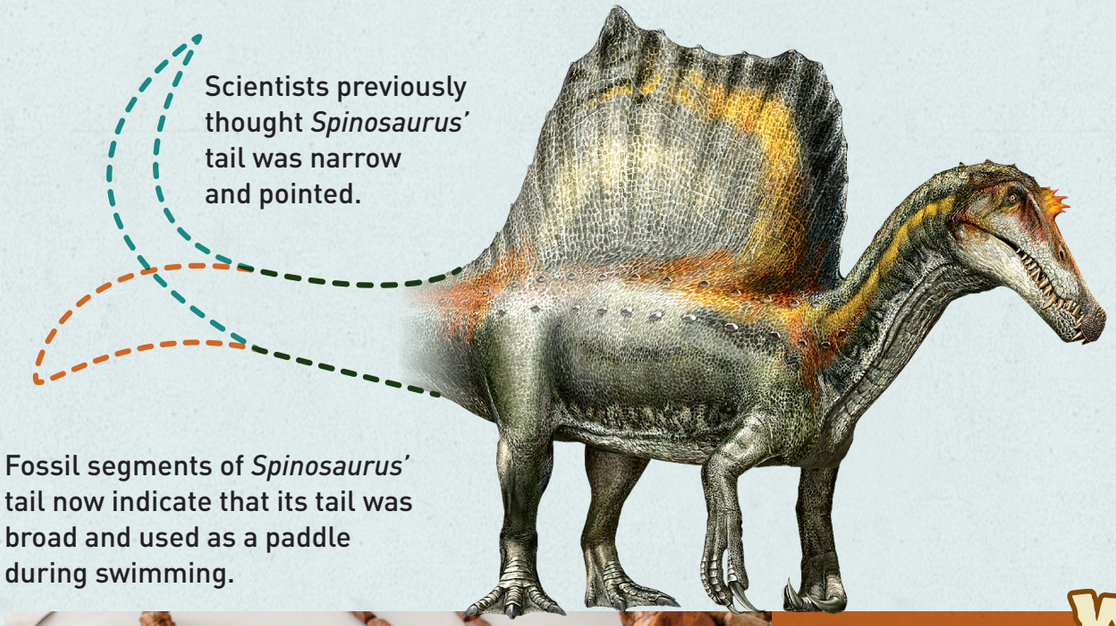
Life in Water

Not every scientist agreed with Ibrahim. So, with a grant from the National Geographic Society, Ibrahim returned to the spot again in search of more *Spinosaurus* fossils. The work was very difficult, but it became rewarding after the team discovered more pieces of a *Spinosaurus* tail.

What they found was striking. In other dinosaurs, the tail narrows to a point. In *Spinosaurus,* the tail is broad. It looks like a paddle. The tiny bumps that appear toward the tail's end may have allowed the tail to move back and forth while swimming. Long, thin bones connect to the tail, not unlike the tailbones in a fish.

With the fossil evidence he had now, Ibrahim teamed up with more scientists. Could they help him with another experiment? This time, he wanted to know how this tail might have worked in the water.

Through digital modeling and a real model tested in water, the team made an important discovery. *Spinosaurus*' tail delivers more than eight times the forward thrust in water than the tails of other dinosaurs on land. The test left Ibrahim even more certain that *Spinosaurus* spent most of its time in the water, not on land.



Scientists previously thought *Spinosaurus*' tail was narrow and pointed.

Fossil segments of *Spinosaurus*' tail now indicate that its tail was broad and used as a paddle during swimming.

Scientists attempt to create a life-size model of *Spinosaurus*, showcasing what is now known about its tail.

Questions Remain

Ibrahim hasn't finished his research yet. One of the other newly discovered fossils may hold another important clue. It is a bone from the dinosaur's foot. With it, the team can now recreate the dinosaur's whole foot. Ibrahim believes it was widely splayed and possibly webbed. Perfect for an aquatic dinosaur.

Ibrahim continues to dig to find answers to his *Spinosaurus* questions. For now, one thing appears clear—the more impossible the questions seem, the more determined Ibrahim is to find the answers.

WORDWISE

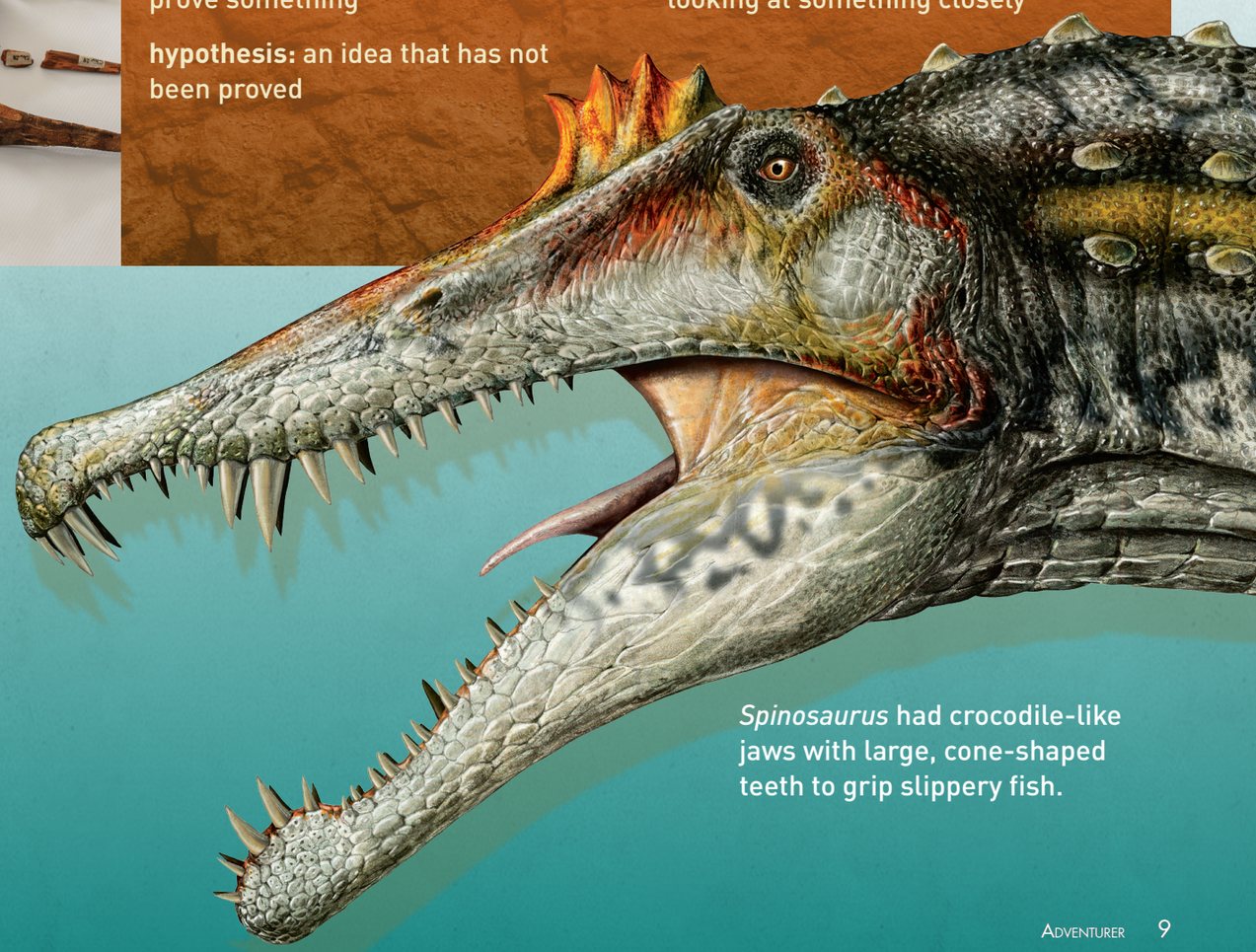
conclusion: an opinion formed after careful research and thinking

experiment: a test used to find or prove something

hypothesis: an idea that has not been proved

method: a step-by-step plan to find out if an idea is true or not

observe: to gather information by looking at something closely



Spinosaurus had crocodile-like jaws with large, cone-shaped teeth to grip slippery fish.

Wildlife and Wild Places

LIFE SCIENCE

As you read, think about how the food sources of the dragonfly change at different stages in this insect's life cycle.

If you look at them side-by-side, you might not know they are different versions of the same thing.

The Transformer

Discover how a dragonfly transforms itself.

By Brenna Maloney

The older version has three body segments, like all insects: the head, thorax, and abdomen. It has six legs. It has two pairs of wings. Its huge, complex eyes are so close together on the top of its head, they touch. The colors of its body are brilliant.

The younger version also has three body segments. It has six legs, too. However, its wings have not yet formed. Its eyes are set far apart. It's not as colorful.

This is the same animal—the southern hawker dragonfly. You are just seeing it at different points of its life.

Changes Ahead

All insects undergo **metamorphosis** as part of their life cycles. This is a process of change that takes place as an insect approaches adulthood. More than 80 percent of insects experience what is known as a **complete metamorphosis.** Their bodies move through four stages: egg, larva, pupa, and adult. Dragonflies experience **incomplete metamorphosis.** Their bodies only go through three stages: egg, **nymph,** and adult. Dragonflies skip the pupa stage—when many insects encase themselves in a chrysalis or cocoon.

Southern hawkers are one of the most common and widespread dragonflies in Europe. They live near small ponds and open woodland. Each dragonfly begins life as an egg.

After a male and female mate in late summer or early fall, the female lays her eggs inside the stems or leaves of a water plant to keep them safe from predators. She lays her eggs one at a time.

To hatch in the spring, the young dragonfly swallows water that it draws through tiny holes in the casing of the egg. That causes the egg to swell. The young dragonfly has a sharp pointer on its head, which it uses to burst the egg open.

What emerges is called a prolarva. It is covered by a thin membrane. As soon as it frees itself from the membrane and enters the water, it **molts**, or sheds its skin. It is now a nymph.

A southern hawker nymph's body is brown and green. These colors make the nymph harder to see in the water.

A southern hawker nymph's eyes are set far apart.

Nymphs must molt a number of times as they grow. That's because their outer layer, called an exoskeleton, cannot stretch or grow. When the insect gets too big for its skin, the skin splits open.

The nymph's muscles contract. It takes deep breaths that cause the split in its old skin to widen. When the tear is big enough, the southern hawker shrugs out of the old skin. It's like taking off a sweater. Now the dragonfly nymph is slightly larger.

Molting is helpful in another way. It allows damaged tissue to heal and missing limbs to regenerate, or grow again. Yet, molting can be a dangerous time for the southern hawker. During the process, this insect cannot move. Its new skin is soft. Until the new exoskeleton hardens, the nymph is vulnerable to predators.

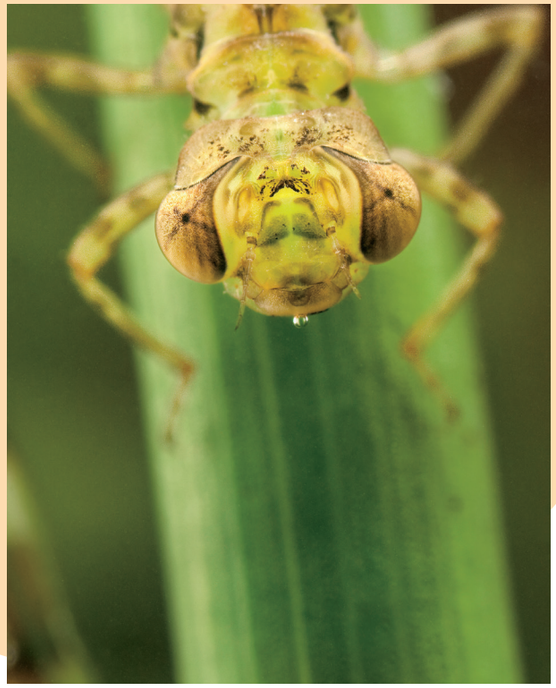
More Mobile

A dragonfly nymph can zip through the water. Believe it or not, it moves by squirting water out of its back end. This propels it forward. These rapid bursts of speed cause its sleek, torpedo-shaped body to glide. It needs to move quickly, because it is an active hunter.

The nymph's body is brown and green. These colors help it blend in with pond or lake water. It is difficult for both predators and prey to spot it. Yet, the nymph can see them quite well.

At this stage in its life, the southern hawker's large eyes are set far apart. They are specialized to detect movement. Those eyes are constantly scanning for prey.

The nymph needs to eat constantly. What it is looking for is aquatic insects, small tadpoles, invertebrates, and even small fish.



When resting, the southern hawker nymph's lower lip is folded under its jaw.

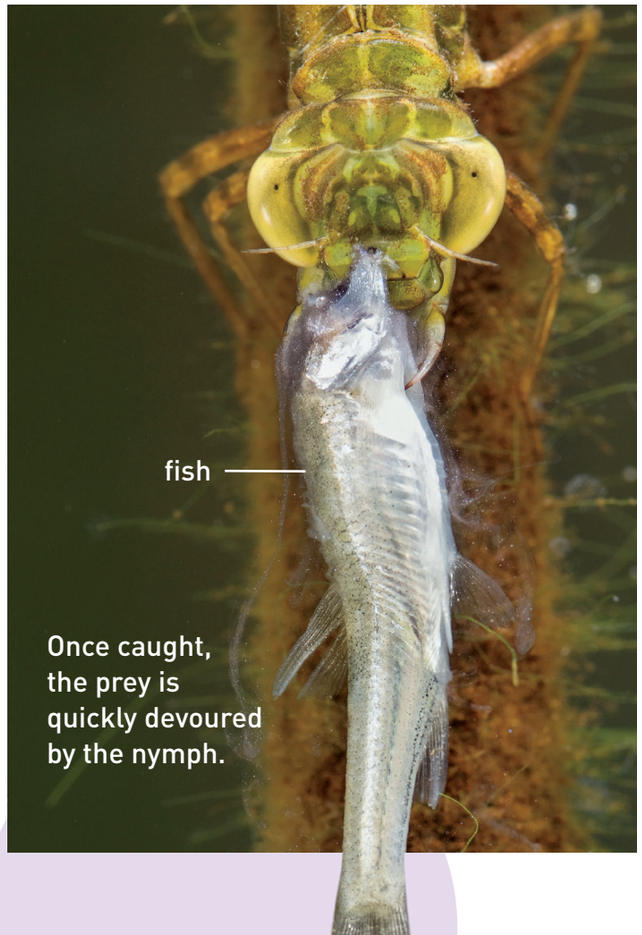
When hunting, the nymph shoots its lower lip forward to reach prey.

Catching Prey

As a nymph, the southern hawker has a special way of catching prey. Its lower lip has a hinge at its base and another about halfway along its length. This arrangement allows the nymph to fold the lip beneath its head when not hunting. When it sees prey, the lip shoots forward, stabbing the prey with sharp spines.

The lip can move in less than 25 milliseconds. It's so fast, the nymph can strike the prey several times before it registers what is happening. Once the prey is impaled, the nymph pulls its lower lip back toward its jaws. The jaws are strong and tough and lined with teeth. They cut the prey into pieces.

As the nymph eats, it grows. And as it grows, it must molt. A nymph may molt as many as eight times, growing slightly larger each time. The period of growth between each molt is called an **instar.** Life as a nymph is long. The southern hawker only spends a few weeks as an egg, but it will spend several years as a nymph.



Once caught, the prey is quickly devoured by the nymph.

A Final Change

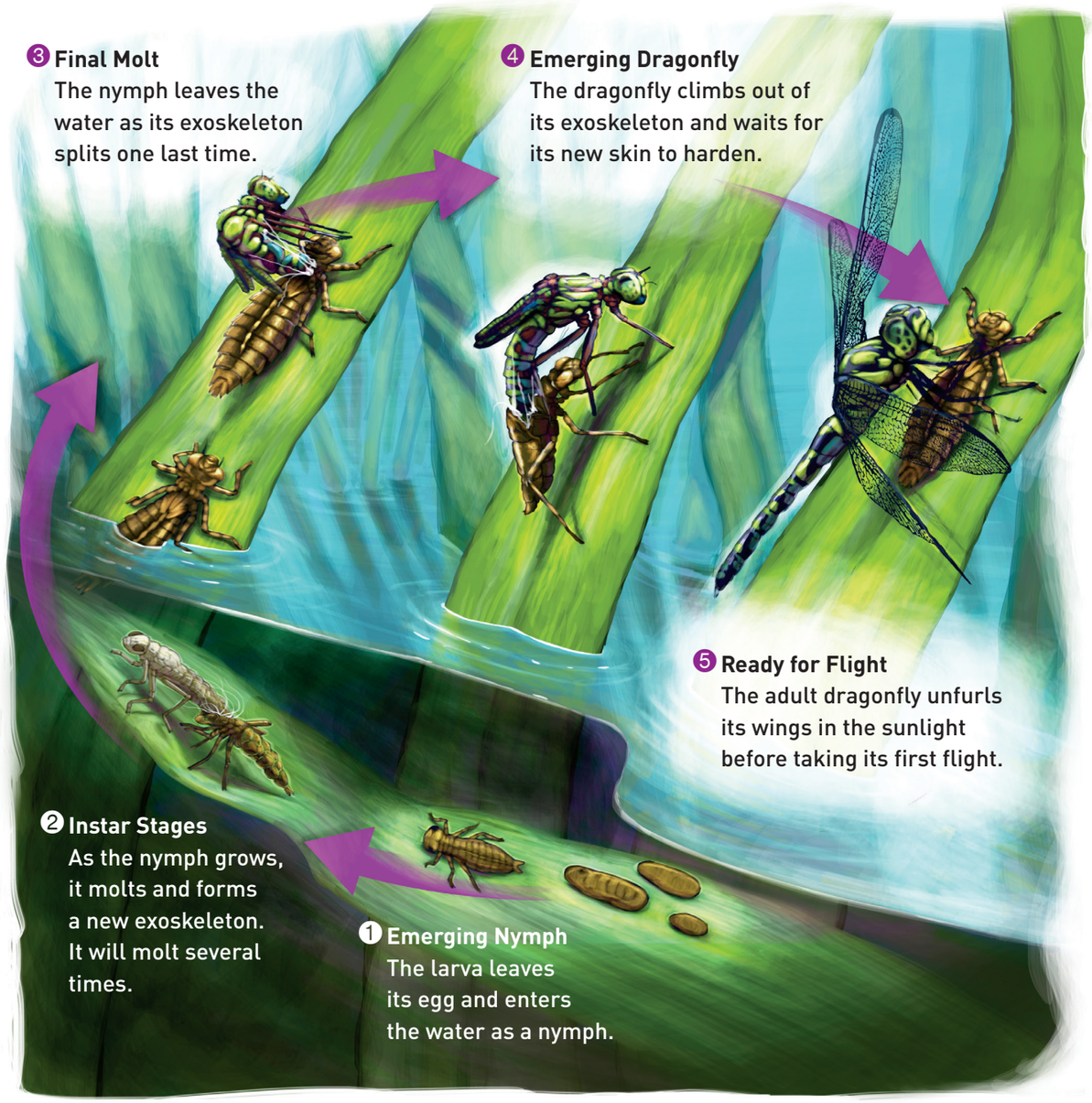
During the final stages of metamorphosis, the southern hawker's lower lip contracts. It can no longer hunt and eat. It needs to molt one last time. To protect itself from predators, the southern hawker waits until night before leaving the water. It climbs up the stem of a water plant. What happens next almost defies description.

The southern hawker pumps fluids into its body. It starts to swell. The exoskeleton splits along lines of weakness on the head and thorax. It thrusts its body through this newly formed gap, and its head and legs follow.

It gingerly steps out of its old skin and rests. Then it slowly pumps fluids into the hollow veins of its new wings to expand them.

From Larva to Adult

Take a closer look at the journey of a dragonfly:



An adult southern hawker's eyes have thousands of lenses.

Dragonflies have six legs, but most cannot walk.

Females lay their eggs in the water.

In Flight

The dragonfly that you recognize flitting over fields looks very different from its nymph form. The male dragonfly's black body is about 70 millimeters (2.8 inches) long and dotted with dashes of apple green and turquoise. Its bright colors are designed to attract a mate. Its two sets of wings stretch out nearly 110 millimeters (4.3 inches) from its body.

In the insect world, the dragonfly's sight is unmatched. Its two compound eyes are made up of thousands of individual lenses. The front of each eye is dedicated to forward flight. The top of each eye searches for prey.

In addition to the compound eyes, dragonflies have three simple eyes. Each consists of a single lens. These eyes form a triangle on the top of the head between the compound eyes. Nerves connect these eyes directly to the dragonfly's flight muscles. They give information about the dragonfly's relative position to prey.

Like other dragonflies, the southern hawker uses its two sets of wings to fly forward, backward, and sideways. It can swoop, hover, and soar. It can beat its wings together or move each one separately. To fly, the wings twist in a figure-eight motion.

Having two sets of wings means the dragonfly doesn't have to work as hard as some insects to keep itself airborne. For the southern hawker, that's about 30 beats a second. For the average mosquito, it's more like 800 beats a second. It might take the southern hawker less effort, but it can certainly fly fast—up to 54 kilometers (34 miles) an hour.

Focused Hunter

When the southern hawker hunts, it becomes a deadly predator. A dragonfly's success rate is about 95 percent. Compare that to other top predators like lions—at 25 percent—and you can see how successful this insect is.

All prey is caught and eaten "on the wing," meaning while the dragonfly is in flight. The ability to intercept prey while flying at top speeds is a complicated process.

Since both predator and prey are moving, the dragonfly has to be able to predict where the prey will be in order to catch it. To do so, it must calculate three things: the distance to its prey; the direction the prey is moving; and the speed that it is flying. In the span of milliseconds, the dragonfly plots its course.

The dragonfly holds its legs forward, just under its jaw, to form a basket. It scoops up the prey. The long spines on its legs grip the prey. The dragonfly bites off and discards the prey's wings before eating its body. Dragonflies can eat hundreds of insects in a day.

Eating and mating are an adult southern hawker's only two jobs. The females quickly lay their eggs. Within two months, the southern hawker adults die. Their eggs are waiting, though, for the life cycle to begin again.

WORDWISE

complete metamorphosis: a process of change that takes place for an insect in four stages (egg, larva, pupa, adult)

incomplete metamorphosis: a process of change that takes place for an insect in three stages (egg, nymph, adult)

instar: the stage between molts of the exoskeleton

metamorphosis: the changes that occur as an insect transforms from an immature form to an adult form

molt: to shed an outer covering, such as skin, hair, or feathers, that is replaced by new growth

nymph: the immature form of an insect with simple metamorphosis

TURNING TRASH INTO TREASURE

By Glen Phelan

Meet Arthur Huang. This architect, engineer, and National Geographic Explorer has some bold plans for Earth's mounting piles of plastic trash.

As you read, think about how people are working to find new ways to protect Earth's resources and environments.

Building With Plastic Bottles

What could you do with one and a half million plastic bottles? Arthur Huang constructed a nine-story building with them! He called it the EcoArk. It's a special name for a special building in Taiwan, Asia.

The EcoArk is a sleek, modern structure that really catches the eye. From a distance, you might think it's made of glass, with white dots decorating the outer walls in a repeating pattern. But up close, you see that those dots are actually bottle caps! They cap some of the plastic bottles that make up the walls. There is no glass.

The bottles that make up the walls of the EcoArk are not your ordinary plastic bottles. They are called Polli-Bricks. They are made of recycled plastic from water bottles, soft drink bottles, and other plastic containers that were thrown away. The plastic trash was chopped up and melted down. Huang and his team invented a way to reshape and strengthen the melted plastic into a new type of building blocks that are shaped like bottles.

The Polli-Bricks have grooves so that they fit together tightly and lock in place. They are assembled into panels about the size of large windows. A coating on the panels helps protect against fire and the weather. The panels weigh one-fifth as much as panels made of glass or other materials, yet they are incredibly strong. The strength comes from the honeycomb pattern made by the interlocking bottles.

These kinds of safety features are a must for the EcoArk. That's because it was built in a part of the world that experiences some of nature's most extreme forces. It's located in Huang's homeland of Taiwan. This island off the coast of mainland China is rocked every year by dozens of earthquakes strong enough to shake buildings. In addition, several violent storms, called typhoons, batter Taiwan during the summer months. Huang's structure stands up to earthquakes that crumble other buildings. The EcoArk braves the howling winds and pounding rains of typhoons with no damage.

Eco-Friendly

Huang designed the EcoArk to be **eco-friendly**—in other words, to not harm the environment. The Polli-Brick walls use plastic trash that would otherwise end up in landfills or as litter on the ground, in rivers, or in the ocean.

The Polli-Bricks keep the EcoArk eco-friendly in other ways, too. The bottles are filled with air. Heat doesn't pass through air easily, so the bottles help keep heat from entering the building. That's important in a place like Taiwan that has long, sweltering summers.

Most buildings use a lot of electricity for air conditioning, and that electricity usually comes from burning oil, coal, or natural gas at a power plant. Burning these fossil fuels adds carbon dioxide and other gases to the air.

The gases trap energy from the sun, which keeps our planet warm enough to support life. It's called the **greenhouse effect.** But too much of a good thing can be a bad thing. Burning fossil fuels has added a lot of heat-trapping gases to the air, increasing the greenhouse effect. That increase has warmed Earth's air temperatures in many places. As a result, some climates around the world have begun to change. Huang didn't want to contribute to that problem with this building.

Huang's Polli-Bricks are made out of plastic bottles.

The grooved Polli-Bricks lock together to form panels.

EcoArk

The Polli-Brick panels are lightweight but strong. Huang demonstrates by jumping up and down on them.

A New Philosophy

Arthur Huang designs buildings and other products to have the smallest **carbon footprint** possible. This means he wants a product to produce as little carbon dioxide gas as possible when that product is being used. Guess what the carbon footprint of the EcoArk is? Zero!

The building runs without producing any carbon dioxide. Even systems that require electricity, like the fans, pumps, and lights, get their power from wind and solar energy, not by burning fossil fuels.

Upcycling

The EcoArk is just one example of how Arthur Huang turns trash into treasure. He is convinced that most of the waste people produce can be used as resources to make something else. And the new product can be more valuable than the original. This idea is called **upcycling.**

To turn this idea into action, Huang started the company Miniwiz. The name comes from the company's motto: "It is wise to minimize." His goal is to help people minimize their carbon footprint by using upcycled products. That will also reduce the amount of waste in the world, especially plastic. Plastic drink bottles, for instance, were upcycled to make polli-bricks. This is only one of about 1,200 new materials Miniwiz has created from trash.

The Sky's the Limit

When it comes to materials and products that can be made of upcycled trash, the sky's the limit. Literally. Miniwiz has developed a material from plastic waste that is used to make wings for a one-person airplane. That's one invention that really puts the "up" in upcycling!

What other wonders have come out of Miniwiz's "trash lab?" How about furniture made out of cigarette butts—the most littered item in the world? Then there are sunglasses made from CDs. And don't forget sneakers made from upcycled plastic that come packaged in a clear shoebox that can be refolded into a backpack.

Trashpresso

Often the trickiest part of upcycling is figuring out how to do it. How do you actually change plastic garbage into a useful material or product? Sometimes, you have to invent a machine and a whole new way of doing things. That's exactly what the creative minds at Miniwiz did.

Trashpresso is an assembly line of several machines working together. The process begins by shredding the plastic trash, usually bottles, into flakes. The flakes are then washed, dried, and placed into molds. The flakes are melted in an oven and pressed into the shape of the mold. Most of the shapes are six-sided tiles that people can use to build walls, floors, or ceilings, or for decoration. Trashpresso is designed to have a zero carbon footprint. It doesn't burn fossil fuels. Instead, solar panels capture sunlight and turn it into electricity.

One of the most important features of Trashpresso is that it can go just about anywhere. This portability allows Huang to use his invention to educate people everywhere about the problem of plastic trash and to inspire them to do what they can to be part of the solution.

WORDWISE

carbon footprint: the total amount of greenhouse gases caused by a person or product

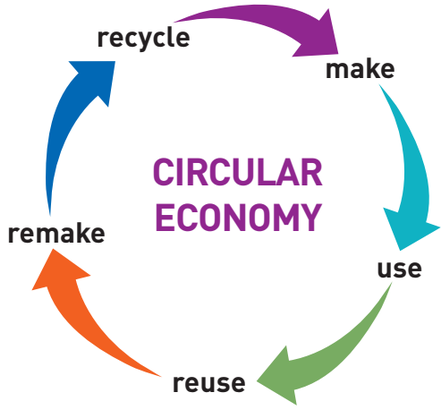
eco-friendly: not harming the environment

greenhouse effect: the trapping of heat by certain gases in the air

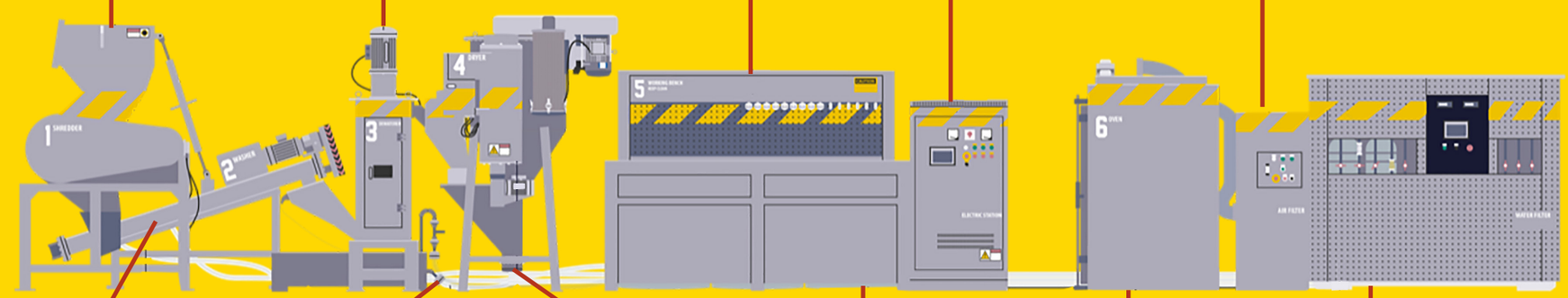
upcycling: recycling a material to make a product that is more valuable than the original

CIRCULAR ECONOMY

Most economies today are linear. This means resources are used to make a product. The product is used and then thrown away, producing waste and pollution. But in a circular economy, waste is used as a resource to make the product again or to make another product. So there really is no such thing as waste in a circular economy.



TRASHPRESSO



SHREDDER breaks down plastic trash into tiny flakes.

DEHUMIDIFIER dries the wet flakes.

WORK BENCH is where flakes are placed into molds.

ELECTRICAL STATION contains the electrical system to make the machine operate.

AIR FILTER prevents the release of toxic vapors that might be produced during the melting stage.

WASHER cleans trash to remove impurities.

WATER PIPING carries dirty water away.

DRYER further reduces moisture.

WATER TANKS store water for the process.

OVEN is where flakes melt in their molds, forming finished tiles.

WATER FILTER purifies the water and cycles the water back through the system.

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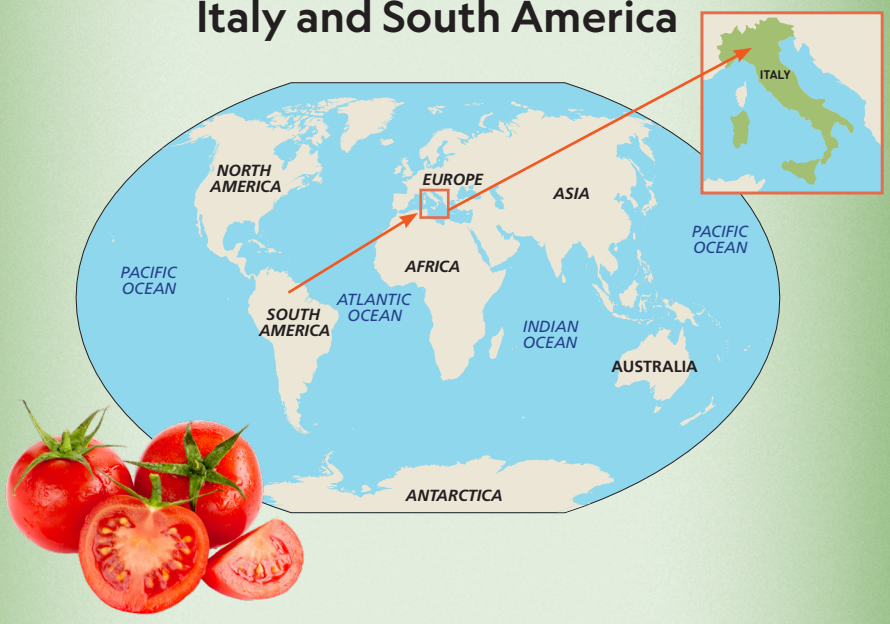
Connections:
Italy and South America



Italians are known for using tomatoes in their cooking. Think of pizza and pasta sauces. But, if you think the tomato is from Italy, think again! It is believed that tomatoes came from South America and were first brought to Europe by Spanish explorers in the 15th century. At first, tomatoes were used for decoration, as Europeans loved their color. However, tomatoes grew well in the warm Mediterranean climate and by the 16th century, they were being used by Italian cooks. So, if you love tomato sauce on your pizza, you have South American farmers from long ago to thank.

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