Frontiers for Young Minds

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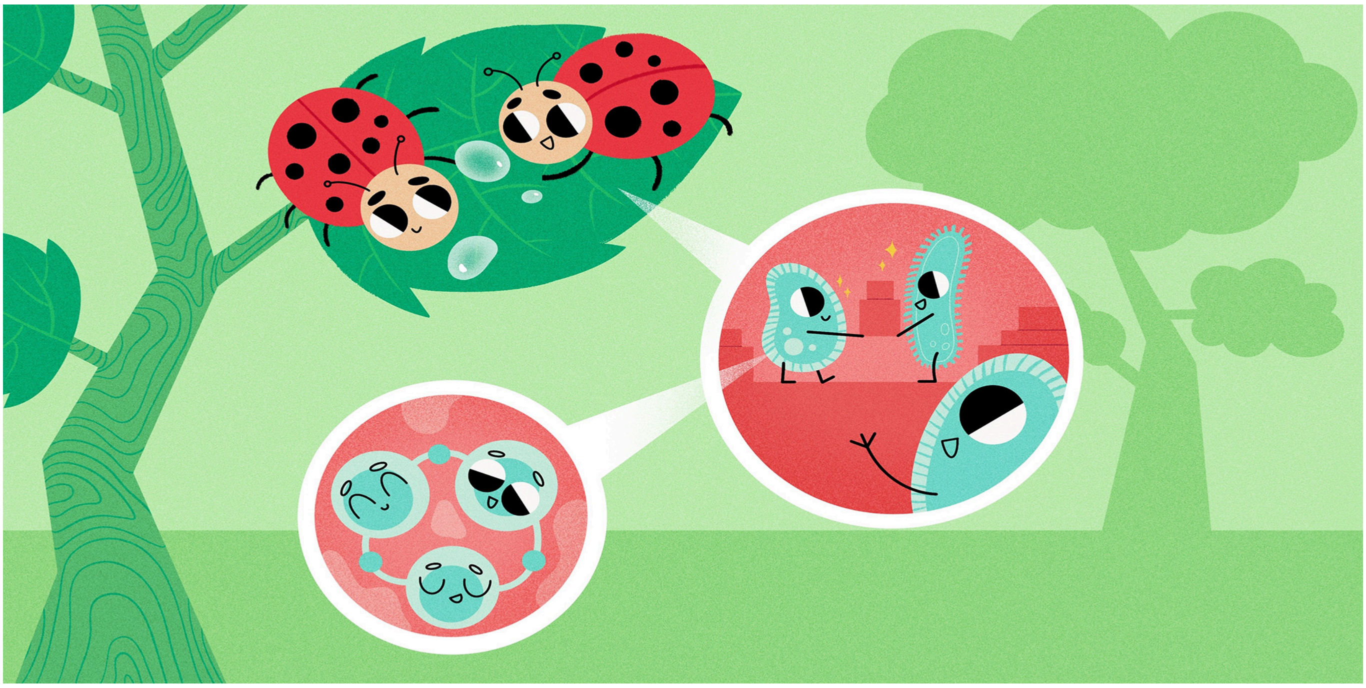

NATURAL SELECTION FROM MOLECULES TO ECOSYSTEMS

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YOUNG REVIEWERS:

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There are so many living things on the Earth, including animals, microbes, plants, and fungi. All of this diversity mainly came about from a process of evolution called natural selection. According to natural selection, organisms with helpful traits reproduce more and have more offspring than organisms without those helpful traits. But did you know that natural selection does not just happen at the level of the organism? A theory called multilevel selection explains how natural selection happens at more than one level of life, from molecules to ecosystems. Selfish organisms may do better on their own, but groups of organisms that cooperate with each other can beat selfish groups in the long run. Scientists have proved this theory in labs and in nature, in all kinds of organisms. In this article, I explain the theory of multilevel selection and the evidence that supports it.

EVOLUTION THROUGH NATURAL SELECTION

Life has existed on our planet for a long time—3.7 billion years, to be precise. Earth has many animals, plants, fungi, and tiny microbes. Why are they all so different from each other? The answer is **evolution**, which, among other processes, occurs through a process called **natural selection**. In the process of natural selection, the organisms that have traits that make them the most suited to their environments are the ones that are most likely to survive and pass on those traits. In the generations that follow the helpful traits have become more common.

EVOLUTION

Processes that change the composition of populations of organisms over time.

NATURAL SELECTION

The natural process in which "survival of the fittest" leads to organisms that are better adapted to their environments over time. Helpful traits stick around, harmful traits disappear.

For natural selection to occur, three things must be true. First, the organisms in a group must have some differences from each other. For example, the beaks of a certain type of bird might all be slightly different. Second, those differences must be able to be inherited, or passed on, from parents to offspring. Third, certain differences must help the organisms survive and reproduce more [1]. For example, maybe the beaks of some birds in a group are better suited for eating the types of seeds found in the environment.

Scientists have seen thousands of examples of natural selection happening in living things. For example, some groups of insects quickly develop resistance when exposed to pesticides, because the insects that are more protected against the pesticide survive and reproduce more than those without resistance. The beaks of finches on the Galapagos Islands, studied by Charles Darwin, were adapted to the types of seeds the birds eat. Natural selection helps to explain the impressive diversity of living things on our planet.

MULTILEVEL SELECTION

It is common to think that natural selection only happens at the level of individual organisms, as we have just described. But everything in nature exists as a series of levels, from the simplest to the most complex (Figure 1). Tiny molecules make up cells, cells make up organisms, organisms make up groups, groups make up populations, populations make up communities, and communities make up ecosystems. Interestingly, natural selection can happen at levels much smaller than the individual organism, like single cells *within* an organism, or even molecules… and it can happen at much larger levels, including whole *groups* of organisms. This is called **multilevel selection**, and it affects everything from molecules to entire ecosystems [2]!

MULTILEVEL SELECTION

When natural selection happens at more than one level of life, from molecules to ecosystems.

At the single-cell level, natural selection can happen to individual cells within an organism. For instance, in cancer, some cells mutate and become different from normal healthy cells, and they can reproduce more. This is an example of natural selection, but it is not good for

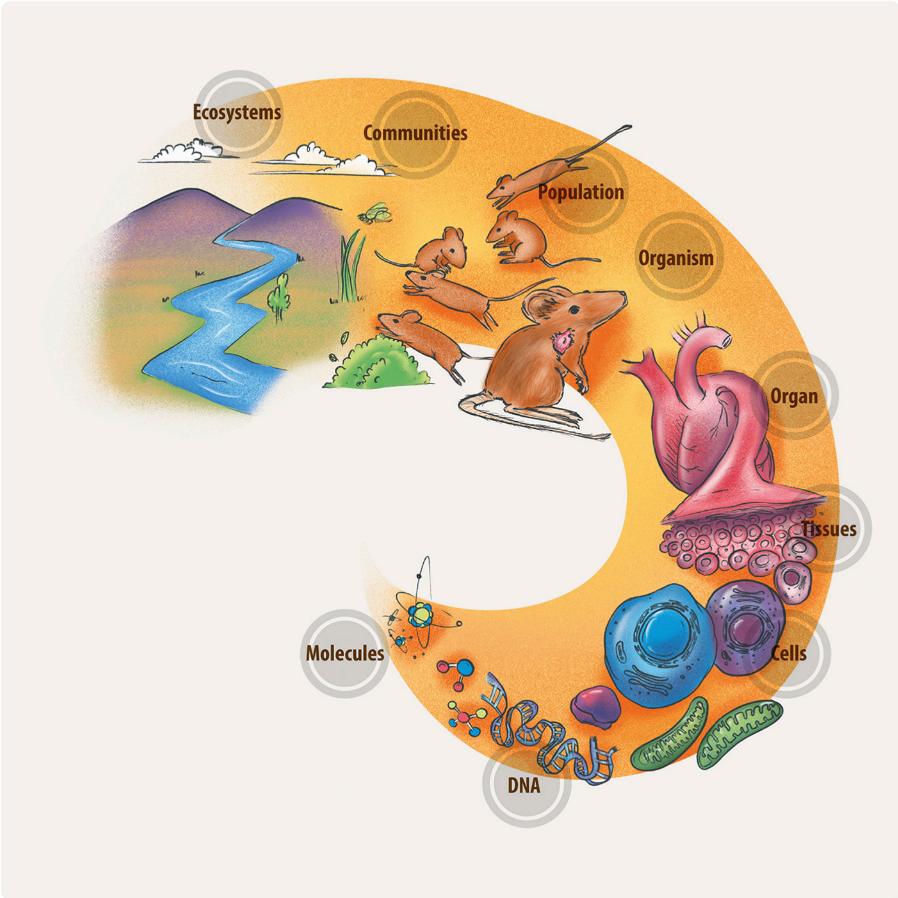

Figure 1

Figure 1

Life on Earth is organized into levels. Each level is more complex than the one below. To get to a more complex level, a major transition had to happen in the process of evolution.

the whole organism—only for the cancer cells. But this damages the whole body. In cancer, natural selection happens mostly at the level of one cell. At the large-scale level, whole groups of organisms can evolve together in a cooperative way. While selfish organisms on their own may beat cooperative organisms by snapping up all the resources for themselves, cooperative groups beat selfish groups in the long run (Figure 2) [3]. For instance, more aggressive hens lay more eggs on their own than less aggressive hens do, but cages containing more peaceful hens lay more *total* eggs than cages with aggressive hens. So, ultimately, an organism's reproduction depends on its own traits *and* its neighbors' traits [4].

ORGANISMS CAN EVOLVE *TOGETHER*: HOLOBIONTS

Did you know that multicellular animals, like humans, need tiny microbes to survive? Many of these microbes live in the digestive system, where they help to break down food in a way that animals cannot do on their own. Helpful microbes also live on or in other parts of an animal, such as the skin, reproductive organs, and even in the lungs (Figure 3). This happens in most plants, too—microbes live

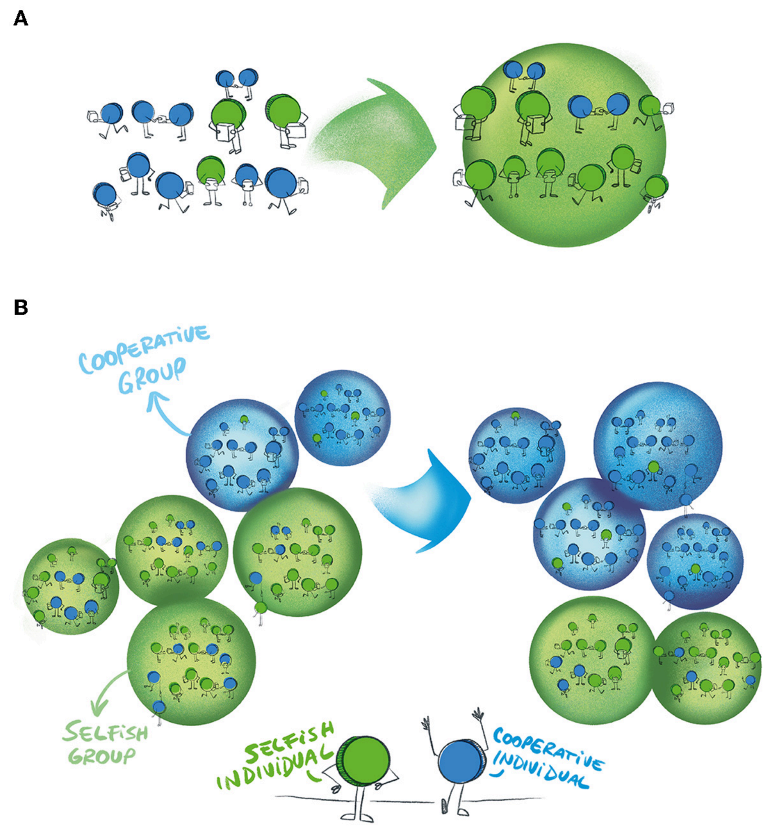

Figure 2

Figure 2

(A) Within a group, selfish individuals (in green) outcompete more cooperative individuals (in blue) over several generations (green arrow). Over time, the whole group becomes more selfish (more green). **(B)** When comparing many groups, cooperative groups (blue circles) outcompete more selfish groups (green circles) after many generations (blue arrow). Over time, most groups become more cooperative (more blue). This constitutes a process of multilevel selection, for example when more cooperative cell colonies formed multi-celled organisms, outcompeting solitary, more selfish ancestors.

inside and around the roots, stems, and leaves, helping the plant to get nutrients that it cannot get on its own. These microbes also protect the plant from getting eaten by plant-eating animals, as well as from drought or parasites. In exchange, the animal or plant in which the microbes live provide the microbes with things they need, like food and good conditions for reproduction. So, a living thing together with the microbes that live on it, or inside it, increases its reproduction, and is called a **holobiont** (Figure 3).

HOLOBIONT

A host organism and the microbes that live on it or inside it, increasing its reproduction.

In a holobiont, the animal (or plant) and the microbes evolve together through multilevel selection. Over time, they become better at surviving as a team. For example, more than 406 million years ago, plants colonized the land with the help of some helpful microbes living in their roots, called mycorrhizal fungi. Today, more than 90% of land plants are associated with these fungi. Most animals and plants cannot survive without microbes and many microbes cannot survive without animals or plants.

MAJOR TRANSITIONS IN EVOLUTION

During evolution, there have been some major transitions, during which the complexity of living things greatly increased [2]. First, molecules started copying themselves, ultimately evolving into DNA.

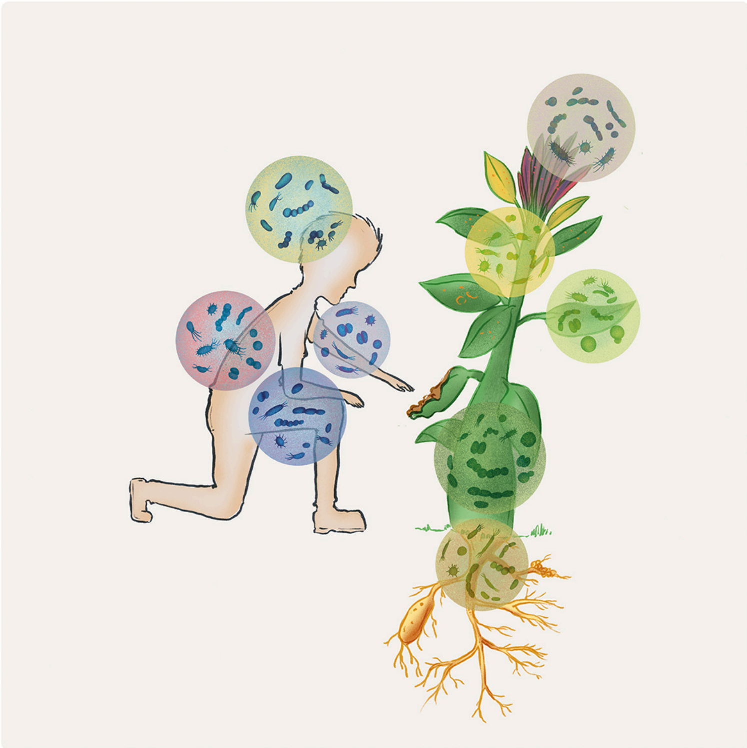

Figure 3

Figure 3

Animals and plants have many microbes living in and on their bodies, some of which help them survive. The combination of an organism and these helpful microbes is called a holobiont. The microbes can help the organism digest food, acquire nutrients, or fend off parasites. In a holobiont, natural selection operates at multiple levels (multilevel selection): at the microbe level, at the plant or animal host level, and at the whole holobiont level.

Later, transitions from simple cells to more complex cells also happened. Then, there was a transition from single-celled organisms to many-celled organisms, and then from organisms that lived independently to organisms that lived in small groups. Small groups then evolved into huge groups, like bee colonies. Even humans went from small hunter-gatherer groups to large societies that developed culture and language.

On these big transitions, first natural selection occurs mainly at the less complex level and after a while, mainly at the more complex level [2, 5]. This is a clear example of multilevel selection explaining life's complexity. Even to arrive to something as complex as a gene or an organism, natural selection happened first in less complex things. One big transition that illustrates this concept is the evolution of mitochondria and chloroplasts. These cellular structures are the powerhouses of cells, providing the energy needed for plant or animal cells to survive, grow, and reproduce. It has been hypothesized that mitochondria and chloroplasts used to be microbes that lived on their own. Over many years, they became a part of cells, and now they do not experience their own natural selection—only the cells they are part of do. Something similar happens in bees. A whole colony of bees works together as one big organism, with different bees doing different jobs. Natural selection happens more at the colony level than at the individual bee level. Like organs in a multi-celled organism, some bees specialize in reproducing while others in defending the colony. Some bees are even willing to die when they sting. This is because natural selection occurs at the colony level.

EVIDENCE OF MULTILEVEL SELECTION IN NATURE AND THE LAB

Over the past 50 years, lab experiments and observations of nature have shown that multilevel selection happens in many types of organisms: plants, insects, fish, birds, and even humans [5]! For example, some groups of plants have evolved to avoid being eaten or to attract insects to help them spread their pollen. Some groups of birds have evolved to hide better from predators. Some groups of more docile chipmunks reproduced more than the more aggressive groups did. The same happened with bugs called water strides. In these examples, the reproduction of an organism increases due to helpful traits of its neighbors.

In the lab, scientists changed the way different organisms interact [5]. They made plants grow for many generations, selecting the best soil microbes living around their roots. Over time, these microbes and their soil (a tiny "ecosystem" in a pot) increased more and more plant growth and tolerance to damages. They reproduced solitary yeasts in lab tubes under some limitations (like no oxygen). Each day, for months or years, scientists selected the yeasts that started to aggregate. After thousands of generations, they formed colonies so tight that they resembled multi-celled organisms. These experiments also add support to multilevel selection theory.

SUMMARY

In the process of natural selection, some helpful traits are passed down from parents to their offspring, which leads the offspring themselves to have more offspring. But natural selection happens at the level of the organism and at other levels of life, from tiny molecules to whole ecosystems. This is the basic definition of multilevel selection, and it happens because lots of things—from molecules to organisms and communities—have helpful traits that help them to reproduce more.

The evolution of life from simple molecules to complex societies cannot be explained without the concept of multilevel selection. This process is happening all the time—both in nature and in the lab. It can help us to understand lots of important things about organisms, like why some organisms do better when they cooperate in groups. Overall, life seems to be a constant balance between cooperation and selfishness at different levels of organization, including us.

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YOUNG REVIEWERS

ARADHYA, AGE: 11
I like playing, reading, and dancing. I like to perform classical dance. I like to travel to new places and know about their history. I love to paint natural life forms. I like to play volleyball and badminton. I like to perform classical dance as it represents my culture.

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