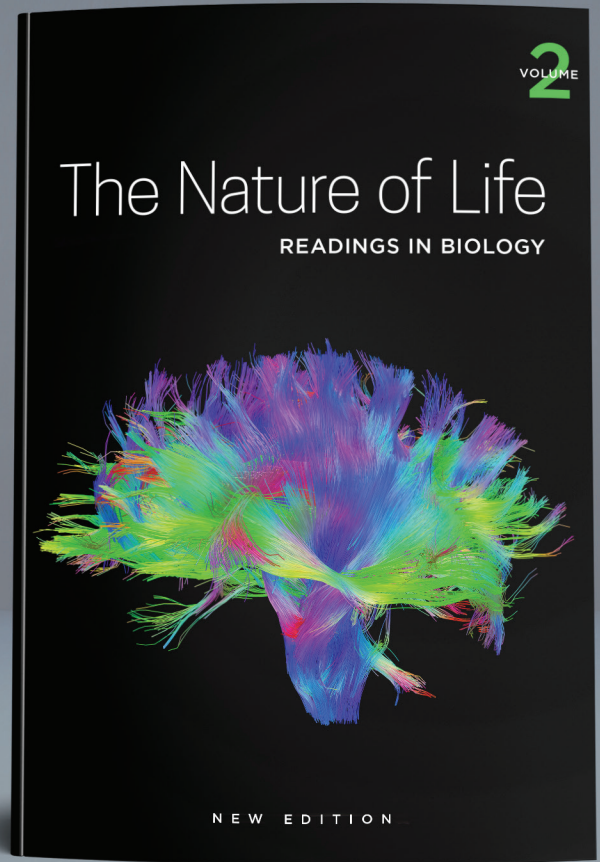
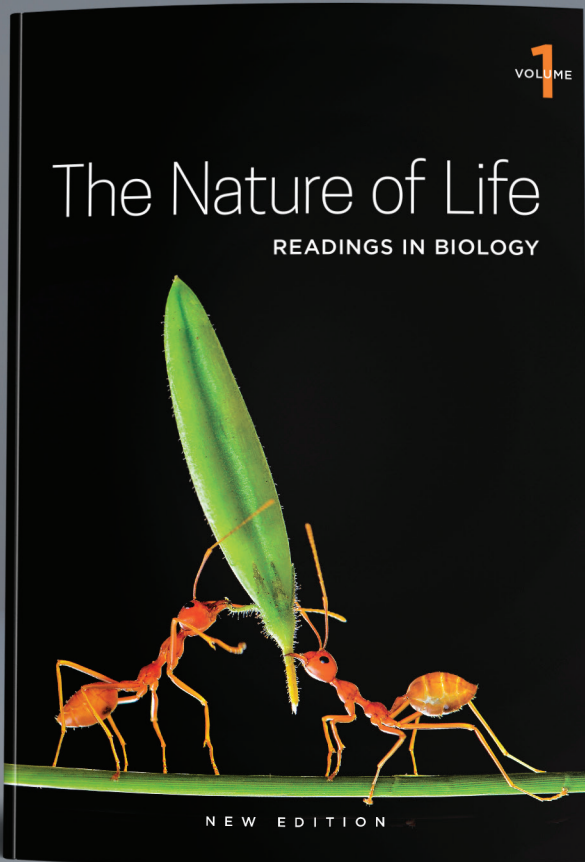


The Nature of Life

READINGS IN BIOLOGY



SAMPLE UNIT

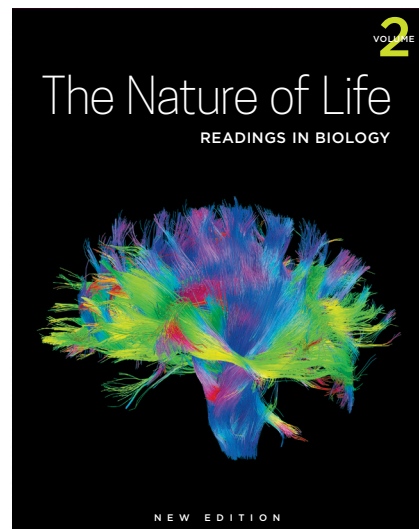
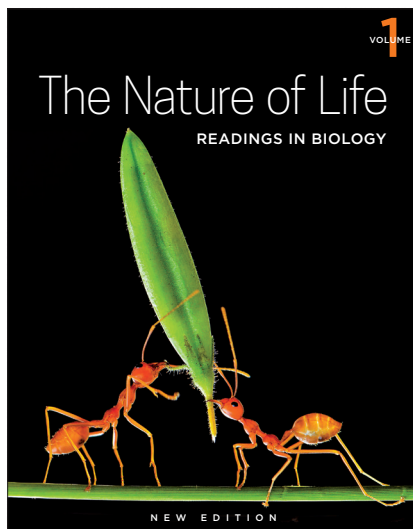


**Great
Books**
Foundation

NEW EDITION
2 VOLUMES

Sample Unit Contents

Page 3	Overview of features and benefits
Pages 4–9	Introductory materials, including correlation with Next Generation Science Standards topics
Pages 10–19	Complete unit from <i>The Nature of Life</i> , Volume 1: Deborah M. Gordon, “Collective Wisdom of Ants”



New Edition!

- ▶ Two-volume set features a variety of topics
- ▶ Includes classic scientific texts and recent discoveries
- ▶ Seven new selections
- ▶ Available in print and digital formats

■ Order today at store.greatbooks.org!

Features	Benefits
Outstanding writing about biology, from the nineteenth century to today	Provides a wide-ranging view of the field and its development
Texts written by working biologists, most explicating their own work	Give insight into scientists' own views of their processes and discoveries
Correlation table to Next Generation Science Standards topics	Shows at a glance how each reading aligns with NGSS topics for high school life sciences
Content and application questions for each reading	Help students understand and use the scientific concepts in each text
Shared Inquiry™ discussion questions for each reading	Support in-depth exploration of overarching ideas
Classroom implementation aids	Expedite planning and support close reading and discussion activities
Professional development resources	Provide teachers with additional tools to engage students in critical thinking about challenging texts

Each volume includes:

- ▶ Suggested classroom schedule
- ▶ Tips for helping students read actively and annotate texts
- ▶ Guidelines for Shared Inquiry discussion
- ▶ Examples of effective follow-up questions
- ▶ Correlation with Next Generation Science Standards topics

Shared Inquiry™ is a trademark of the Great Books Foundation.

About the Great Books Foundation

The Great Books Foundation is an independent, nonprofit educational organization that creates reading and discussion programs for students and adults with the conviction that literacy and critical thinking help form reflective and well-informed citizens. We believe that civil and open discussion of the world's enduring literature promotes empathy, understanding, and community, and that by working to develop reading and thinking skills, we advance the ultimate promise of democracy—participation for all.

The Great Books Foundation was established in 1947 to promote liberal education for the general public. In 1962, the Foundation extended its mission to children with the introduction of Junior Great Books®. Since its inception, the Foundation has helped thousands of people throughout the United States and in other countries begin their own discussion groups in schools, libraries, and community centers. Today, Foundation instructors conduct hundreds of workshops each year, in which educators and parents learn to lead Shared Inquiry™ discussion.

For more information, please visit us at greatbooks.org.

■ ■ ■

“Even the best textbooks can feel removed from the process of science. Reading essays from the scientists doing the discovery and debating the ideas helps ground students in the idea that science is an ongoing process of inquiry—which allows them to see themselves in the process.”

—Stephen Traphagen
Biology Instructor, Oak Park and River Forest High School
Senior Fellow, Knowles Teacher Initiative

About Shared Inquiry

Shared Inquiry is the effort to achieve a better understanding of important ideas in a text by discussing questions, responses, and insights with others. In this method of learning:

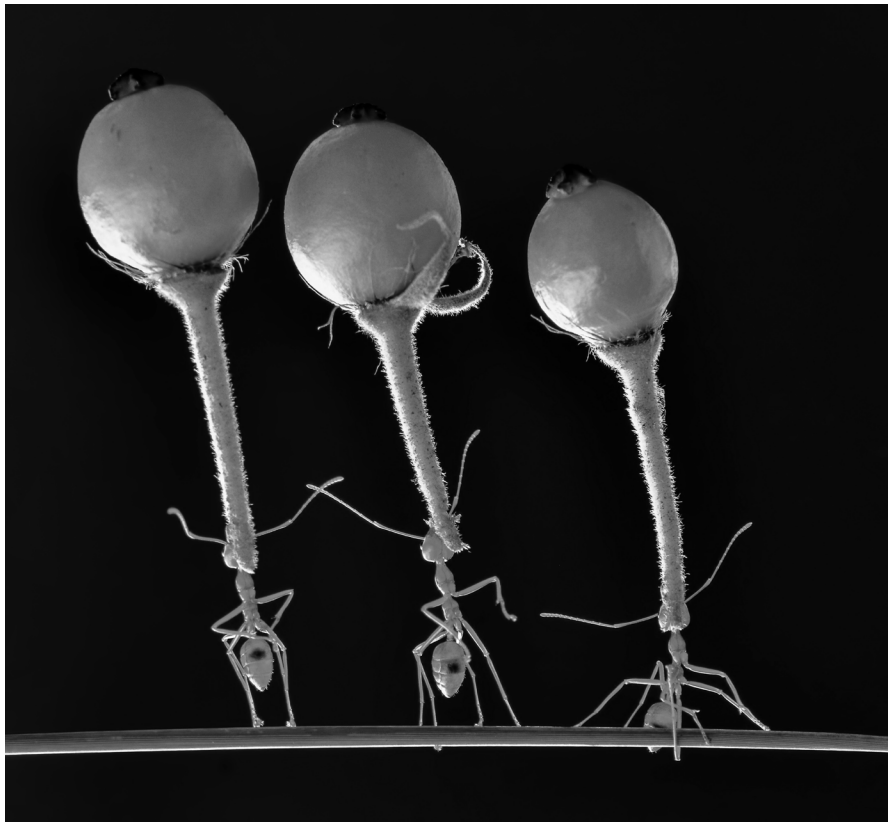
- ▶ Discussion centers on questions about how to interpret the text—questions that have more than one reasonable answer for which there is support in the text.
- ▶ During discussion, the leader focuses on asking questions that prompt group members to deepen their thinking, rather than seeking to impose a specific interpretation of the text.
- ▶ Participants weigh support for different interpretations of the text, frequently returning to specific parts of the text to explain their ideas.
- ▶ Group members do not need to agree on an interpretation of the text; rather, the goal is for each participant to develop an idea that can be supported based on the text.
- ▶ Careful listening by both the leader and the participants is essential.

In this process of communal discovery, ideas that are entertained and then refined or abandoned are not thought of as mistakes but as valuable parts of the thinking process. Everyone in the group contributes to the discussion and gains experience in communicating complex ideas and in supporting, testing, and expanding their thoughts. While participants may disagree, they treat one another's ideas respectfully. And as your group reads and thinks together about important works, you are joining in a great conversation that extends across the centuries.

What does Shared Inquiry contribute to the study of science?

Scientists advance knowledge by asking questions and posing and testing hypotheses. They are constantly building on the ideas and discoveries of predecessors and working collaboratively with others

in their field. Shared Inquiry mirrors the scientific process as group members explore questions about the text, weigh support for answers, and refine their ideas in response to others' insights. And because *The Nature of Life* emphasizes scientists' explanations of their own work, you can trace the evolution of their ideas and the connections they make to the discoveries of others. We hope that reading and discussing the readings in this anthology will increase both your knowledge of biology and your appreciation of the scientific process.



Using the Questions for Each Reading

Content questions

These questions concern the scientific information in each reading and can be answered using the information in the texts themselves; no additional sources are needed.

Application questions

These questions go beyond the material covered in the reading and are designed to foster a deeper and more practical understanding of the significance of the ideas in the text. Answering these questions requires information from other sources and may entail some research.

Discussion questions

These questions are the focus of Shared Inquiry discussion and have more than one reasonable answer that can be supported based on the text. Discussion questions require participants to develop ideas about the issues raised in the text, weigh support for different answers, and judge for themselves which answer is most satisfying. Working with these questions builds skills in close reading, critical thinking, and oral communication.



Next Generation Science Standards Topic Correlation Table

This table shows how the readings in this anthology address the Next Generation Science Standards topics for high school life sciences as well as an additional topic, Scientific Ethics and Procedure.

Reading	Structure and Function	Inheritance and Variation of Traits	Matter and Energy in Organisms and Ecosystems
Volume 1			
Mendel, "Experiments in Plant Hybridization"		●	
Carson, "Silent Spring"	○		
Watson, "The Double Helix"	○	●	
Colinvaux, "Why Big Fierce Animals Are Rare"			●
Dawkins, "The Selfish Gene"		●	
Blaser, "The Human Microbiome"	○		
Gordon, "Collective Wisdom of Ants"		○	●
Wilson, "The Wholly Different Aqueous World"	○		●
Skinner, "Unified Theory of Evolution"		●	
Volume 2			
Darwin, "On the Origin of Species"	○	○	
Bernard, "An Introduction to the Study of Experimental Medicine"	○		
Eiseley, "The Snout"	○	○	
Lorenz, "Ecce Homo!"		○	
Gould, "Just in the Middle"	●		
Margulis, "Life from Scum"	●		
Nabhan, "Why Science Needs Poetry"	○		
Doudna, "My Whirlwind Year with CRISPR"	○	○	
Sapolsky, "Adolescence; or, Dude, Where's My Frontal Cortex?"	●	○	

The symbol ● indicates the central topic in each text; the symbol ○ indicates additional topics in each text.

Interdependent Relationships in Ecosystems	Natural Selection and Evolution	Scientific Ethics and Procedure	Reading
Volume 1			
		○	Mendel, "Experiments in Plant Hybridization"
●		○	Carson, "Silent Spring"
		○	Watson, "The Double Helix"
○	○		Colinvaux, "Why Big Fierce Animals Are Rare"
	○		Dawkins, "The Selfish Gene"
●	○		Blaser, "The Human Microbiome"
○	○		Gordon, "Collective Wisdom of Ants"
○			Wilson, "The Wholly Different Aqueous World"
○			Skinner, "Unified Theory of Evolution"
Volume 2			
	●		Darwin, "On the Origin of Species"
		●	Bernard, "An Introduction to the Study of Experimental Medicine"
	●		Eiseley, "The Snout"
○	●		Lorenz, "Ecce Homo!"
		○	Gould, "Just in the Middle"
	○		Margulis, "Life from Scum"
○		●	Nabhan, "Why Science Needs Poetry"
		●	Doudna, "My Whirlwind Year with CRISPR"
	○		Sapolsky, "Adolescence; or, Dude, Where's My Frontal Cortex?"

Deborah M. Gordon

Deborah M. Gordon's (1955–) research on the behavior of ant colonies has changed the understanding of how ants communicate and cooperate. She has established that ant colonies have no central control and that ants communicate with one another about changes in the environment, sometimes altering their roles in response. Gordon's 1999 book, *Ants at Work: How an Insect Society Is Organized*, is based on many years of research on red harvester ants in Arizona.

Gordon is a professor of biology at Stanford University, where she also directs the Gordon Lab. In addition to studying how ants communicate about and respond to change, Gordon and her colleagues explore how insights into ant behavior may relate to other systems that function without central control, such as the immune system, the brain, and the internet.

Gordon received an MS in biology from Stanford University and a PhD in zoology from Duke University, and she was a research fellow at Harvard University and the University of Oxford. She was awarded a Guggenheim Fellowship in 2001, and she currently serves as an adviser to the Microbes Mind Forum, which brings together the work of scientists studying collaborative intelligence.

Collective Wisdom of Ants

In the 2015 summer blockbuster *Ant-Man*, the character Hank Pym, a scientist who has invented a suit that can shrink a person to the size of an insect, remarks that ants can perform amazing feats, but they need a leader to tell them what to do. Pym wears a small device behind his ear that allows him to instruct the ants to act as a phalanx of attackers that helps the ant-sized human hero defeat an evil mastermind.

The idea that ants have commanders that set the agenda and orchestrate their activities resonates because of the hierarchical way in which many human organizations work, and it provides a convenient premise for a Hollywood film whose heroes are people. There's just one problem: it's wrong. Ants never march in lockstep, united in obedience to a single command. In the real world, the often random and apparently inept actions of individual ants, each without any sense of a common goal, combine to allow colonies to find and collect food, build nests, form trails and bridges, defend their host plants from herbivores, or cultivate gardens—all without supervision. Ants do not need a leader, and no ant ever tells another what to do.

Ant colonies are not the only systems in nature to operate without central control. Collective behavior, without instruction from on high, occurs everywhere, from the flock of starlings that wheels in the sky to the network of neurons that allows you to read this sentence to the molecules that work with genes to make proteins. All the many outcomes of collective behavior are accomplished through simple interactions among the individual actors, whether they are ants, birds, neurons, or molecules.

When as a graduate student I began to study systems without central control, I looked for a system in which the interactions were easy to observe—and ants were not hard to find. There are more than fourteen thousand species distributed across every terrestrial habitat on Earth. They build nests in the ground, in hollow twigs and acorns, under rocks, and in leaves high up in the forest canopy. They vary enormously in what they eat, from nectar to fungi to other insects. All ant species exhibit collective behavior, so they provide an excellent opportunity to learn how such behavior has evolved to solve the diverse ecological problems that ant colonies encounter.

My studies of several kinds of ants in a variety of ecological settings, from desert to tropical forest, show that they each use interactions differently—for example, to ramp up activity, slow it down, or just keep it going. These findings suggest a fit between the ecological situation and the way that simple interactions adjust collective behavior. Evolution may have converged in a range of systems without central control to produce similar algorithms to meet similar environmental challenges.

Simple Interactions

All ant species have certain characteristics in common, including similarities in how the ants carry out tasks. Ants live in colonies composed of many sterile female workers (the ants you see walking around) and one or more fertile females that remain inside the nest. Although these fertile females are called queens, they do not wield any political power—all they do is lay the eggs. Neither the queen nor any other ant can assess what needs to be done and give orders to others. In addition, all ants possess a keen sense of smell capable of distinguishing among hundreds of chemicals. Ants smell with their antennae. When one ant touches another with its antennae, it assesses the odor carried in the other ant's greasy outer coating of so-called cuticular hydrocarbons, which help to prevent desiccation. Scientists know that in some species the chemistry of the cuticular hydrocarbons responds to environmental conditions. A harvester ant that forages out in the hot desert sun comes to smell differently from an ant that spends most of its time in the nest. As a result, an ant's odor reflects its task.

To learn how ants use antennal contacts, Michael Greene of the University of Colorado–Denver and I conducted experiments in which we coated

small glass beads with extracts of the cuticular hydrocarbons from ants that carry out particular tasks, and then we introduced the beads inside ant nests. We found that when one ant touches another with its antennae, the message it receives is simply that it has met an ant of that particular odor. It turns out the rate of interactions is key to how the insect responds. In our experiments we were able to elicit changes in a colony's behavior by changing the frequency of the ants' encounters with the glass beads.

How do ant colonies organize their work using only simple olfactory interactions? For the past thirty years I have been studying harvester ants in the southwestern United States. It seems that for harvester ants, the need to conserve water has been a driving force in the evolution of the process that uses interactions to regulate foraging activity. Harvester ants subsist on the seeds of grasses and annual plants, which provide both food and water to the colony. But a colony must spend water to get water. Foragers lose water just by being outside searching for seeds. An outgoing forager does not leave the nest until it has had enough encounters with foragers returning with food. Because each forager searches until it finds food, this feedback from returning foragers links foraging activity to the amount of food: the more food is available, the shorter the search time, the more quickly foragers return, and the more foragers go out to search.

My long-term study of a population of harvester ant colonies has made it possible to learn how evolution is shaping their collective behavior. To understand how natural selection is currently acting, we needed to know whether the way that a colony regulates its foraging activity influences its ability to produce offspring colonies. The first step was to figure out which colonies were the offspring of which parent colonies. No one had ever made such a determination for ant colonies before. But since 1985 I have been following a population of about three hundred colonies at a site in southeastern Arizona. Every year I find all the colonies that were there the year before, say goodbye to the ones that have died, and put the newly founded colonies on a map. These long-term data show that a colony lives for twenty-five to thirty years. Each year there is a mating aggregation that brings together the males, which live only long enough to mate, and unmated queens, from all the colonies in the population. After mating, the males die, and the newly mated queens fly off to start new colonies. Each queen produces a new batch of sterile workers—and, once the colony is large enough, the fertile males and females—every year

for the rest of her life, using the sperm she obtains at that original mating session. Based on DNA obtained from about 250 colonies, Krista Ingram of Colgate University, Anna Pilko of the University of California–San Diego, and I were able to link offspring colonies to their parent colonies and thus learn how a colony’s foraging activity relates to its reproductive success.

We found that the colonies with offspring colonies tend to be those that conserve water by reducing foraging on hot, dry days, sacrificing food intake to conserve water. This result surprised us because many studies of animals assume that the more food they get, the better. But the colonies that for years I thought were unreliable and wimpy, because they do not forage much when it is hot and dry, turned out to be great-grandmothers, whereas our most stellar colonies, which forage steadily every day, had failed to reproduce. Because colonies can store seeds for a long time, there is no survival cost for not foraging on some days.

Natural selection operates on traits that can be passed from parent to offspring, and there is intriguing evidence for the heritability of collective behavior in harvester ants: offspring colonies resemble parent colonies in which days they choose to reduce foraging. Thus, our findings have provided what is, to my knowledge, the first demonstration of the current evolution of collective behavior in a wild population of animals.

Ecological Solutions

Different species of ants show how the regime of interactions a species uses is related to its ecology. I also study turtle ants that live in the trees in the tropical forest of western Mexico. The air is very humid, and food is plentiful in the tropics, so operating costs of foraging are low there compared with the desert. But competition is high because many other ant species are exploiting the same resources. I found that turtle ant colonies create arboreal foraging trails along which ants perpetually circle from one nest or food source to another. Unlike harvester ants, turtle ant foragers keep going unless interactions lead them to stop or slow down. For example, interactions with ants of other species inhibit activity. A turtle ant is likely to leave the nest and to continue on the trail unless it meets an ant of another species. Just one *Pseudomyrmex* ant strutting back and forth on a branch, sleek and severe like a sports car, can meet enough of the stockier

yet more timid turtle ants to completely shut down a branch of their trail. Colonies are so persistent in maintaining the flow of ants on a trail when all is clear, and starting it again once a threat disappears, that perhaps it is easiest to avoid conflict.

Simple interactions among ants create the turtle ant colony's network of trails within the tangled vegetation of the forest canopy. Those interactions make the network both resilient and flexible. Every ant marks its route with a chemical trail pheromone as it goes and follows the scent of the ants that came before it. Saket Navlakha of the Salk Institute for Biological Studies and I are working to understand the algorithm that the ants use to maintain and repair their trails. When an ant reaches a junction between one twig, stem, or vine and another, it tends to take the path that smells the strongest of trail pheromone, which is the path most recently traveled by the most ants. Often a tenuous bridge between one stem and another falls away because of the wind, a passing lizard, a break in a rotting branch, or, sometimes, an experimental intervention from my scissors. The ants recover quickly. It seems that when they reach the first broken edge, the ants go back to the next available node and search for the pheromone trail from there until they form and eventually prune a new path to join the other side of the path.

Collective behavior in ants has evolved in response to how resources such as food are distributed in the environment, as well as to the costs of foraging and the behavior of other species that they meet. Some resources are clustered together in a single patch, whereas others are scattered at random. Ants of many species excel at exploiting patchy resources such as picnics. They use interactions based on pheromones in which one ant follows another, producing recruitment trails. Recruitment makes sense when the resource is patchy—after all, where there are sandwiches, there are likely to be cookies. In contrast, ants that forage for scattered resources, like seeds, do not use recruitment trails, because finding one seed is no guarantee of finding another nearby.

To find food in the first place also requires specialized collective behavior. Because ants operate mostly by smell, an ant must get close to food to find it. The broader the range of places where food might be, the more area the ants must cover. But the more different places it could be tucked away, the more thoroughly searchers must scour the ground. I found that Argentine ants manage this tradeoff beautifully, by adjusting

their paths according to density. When there are few ants in a small space, each ant takes a convoluted path, allowing it to search the local area very thoroughly. But when there are few ants in a large space, they use straighter paths, which allows the entire group to cover more ground. Individuals could sense density by a simple cue: the rate of interactions with others. The more antennal contacts they make, the more convoluted a route they take. The Argentine ant has invaded Mediterranean climates throughout the world. Perhaps its effectiveness at getting to new food resources first explains why this invasive species tends to outcompete native species wherever it invades.

Lessons from Ants

The ways ants use simple interactions to thrive in particular environments could suggest solutions to problems that arise in other systems. Computer scientist Balaji Prabhakar of Stanford University and I noticed that the harvester ants use an algorithm to regulate foraging that is similar to the transition-control protocol / internet protocol (TCP/IP) used in the internet to regulate data traffic. We called the analogy the “Anternet.” TCP/IP was designed in an environment with high operating costs: the early internet was so small that there was little redundancy, and ensuring that no data packet would be lost was crucial. Just as a forager will not leave on its next trip unless it has a sufficient number of interactions with returning foragers that have found food, so a data packet will not leave the source computer unless it receives an acknowledgment from the router that the previous packet had the bandwidth to travel on toward its destination. It seems likely that 130 million years of ant evolution have produced many other useful algorithms that humans have not yet thought of and that could help us figure out ways to organize data networks using simple interactions involving minimal information.

I think that we will probably see a similar fit between algorithm and ecological situation in many other kinds of collective behavior. For example, cancers evolve in response to the conditions in their local micro-environment. A type of cancer that tends to metastasize to a particular kind of tissue probably evolves to use resources clustered in that tissue. These forms of cancer, like the species of ants that have evolved to use patchy resources, may be the most likely to send cells back to the primary

tumor to recruit more cells, as breast cancer cells do. In that case, cells that recruit to patchy resources would be the best target for poison baits.

Throughout biology and engineering there is an explosion of interest in how collective behavior draws on simple interactions. It is becoming clear that such interactions are tuned to changing conditions. The field of systems biology, building on a century of work that showed in detail what happens inside a cell, is shifting its focus to interactions among cells, aided by amazing advances in imaging. In neuroscience, new techniques allow recordings that show patterns in the timing of thousands of neurons firing. We humans can see certain kinds of movement and hear certain sounds because circuits of neurons in our brains have evolved to respond collectively to features of the environment such as the rate at which crucial objects, such as parents and predators, usually move, and to the range of frequencies that it was most important to be able to hear. Engineered systems evolve as well; enormous increases in the size of the internet and the number of devices connected to it, as well as the speed of interactions, require new, decentralized solutions.

Scientists are now ready to look for trends in the ways that different natural systems have evolved similar collective behavior to meet similar ecological challenges. We may be able to apply that knowledge to intervene in processes that work without central control—and solve some of society's problems in the process.

Content Questions

1. How do ants use their sense of smell to assess the tasks of other ants in the colony?
2. How does an “outgoing forager” harvester ant use the foraging activity of other ants in its colony to assess the amount of available food? (13)
3. How does a harvester ant colony’s foraging activity relate to its reproductive success?
4. What “intriguing evidence” does Gordon give to support the idea that collective behavior in harvester ants is heritable? (14)
5. What does Gordon mean when she says that the simple interactions among ants make the turtle ant colony’s network of trails “both resilient and flexible”? (15)
6. How do Argentine ants adjust their foraging tactics based on “density”? (16)
7. According to Gordon, how is the foraging behavior of the harvester ant similar to the way TCP/IP regulates internet data traffic?

Application Questions

1. Investigate how an organism other than an ant relies on collective behavior. How is the collective behavior of this organism adapted to its environment?
2. Other than the examples Gordon lists, describe a process in human society that works without central control.
3. Gordon mentions that natural selection operates on traits that can be passed from parent to offspring. How does the evolution of collective behavior benefit succeeding generations of organisms?
4. Gordon observes that ants’ collective behavior “has evolved in response to how resources such as food are distributed in the environment, as well as to the costs of foraging and the behavior of other species that they meet.” (15) Use Darwin’s theory of natural selection to explain how the collective behavior of ants might have evolved.

5. What advantages to survival and reproduction would the collective behaviors Gordon describes confer on individual ants and to colonies as a whole?
6. What has Gordon's study of harvester ant colonies demonstrated about how evolution shapes collective behavior?

Discussion Questions

1. Why is it significant that ant colonies operate without central control?
2. How is it possible for natural selection to favor sterility as a trait, as it does in ant colonies?
3. How might studying ants help humans "figure out ways to organize data networks using simple interactions involving minimal information"? (16)
4. What can the collective behavior of ants teach us about systems biology?
5. Why does Gordon conclude that studying the evolution of collective behavior in natural systems may "solve some of society's problems"? (17)

NEW EDITION

The Nature of Life: Readings in Biology

Volume 1

Experiments in Plant Hybridization
(*excerpt*)

- Gregor Mendel

Silent Spring (*excerpt*)

- Rachel Carson

The Double Helix (*excerpt*)

- James D. Watson

Why Big Fierce Animals Are Rare

- Paul Colinvaux

The Selfish Gene (*excerpt*)

- Richard Dawkins

The Human Microbiome

- Martin J. Blaser

Collective Wisdom of Ants

- Deborah M. Gordon

The Wholly Different Aqueous World

- Edward O. Wilson

Unified Theory of Evolution

- Michael Skinner

Volume 2

On the Origin of Species (*excerpt*)

- Charles Darwin

An Introduction to the Study of
Experimental Medicine (*excerpt*)

- Claude Bernard

The Snout

- Loren Eiseley

Ecce Homo!

- Konrad Lorenz

Just in the Middle

- Stephen Jay Gould

Life from Scum

- Lynn Margulis

Why Science Needs Poetry: Fitting
New Metaphors to Nature When Old
Clichés Fail

- Gary Paul Nabhan

My Whirlwind Year with CRISPR

- Jennifer Doudna

Adolescence; or, Dude, Where's My
Frontal Cortex?

- Robert M. Sapolsky



**Great
Books
Foundation**

70
YEARS

Inspiring ideas,
dialogue, and lives

233 N. Michigan Avenue, Suite 420
Chicago, IL 60601
800.222.5870 • greatbooks.org