Mastering Academic Reading
Lawrence J. Zwier with contributions by Matthew S. Weltig
http://www.press.umich.edu/titleDetailDesc.do?id=178523
Michigan ELT, 2009

UNIT 1

Species

This unit explores ways in which human beings—the species *Homo sapiens*—have affected the development of other animals and plants. The unit is organized as follows:

- FIRST TIER: An Introduction
  Introductory passage: **Humanity's Companion Species**
- SECOND TIER: Potatoes and People
  Book chapter: **The Botany of Desire: The Potato**
  by Michael Pollan
- THIRD TIER: Foxes and Dogs
  Journal article: **Early Canid Domestication: The Farm Fox Experiment**
  by Lyudmila Trut

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First Tier: An Introduction

Pre-Reading

DISCUSSION

This reading discusses the role of humans in the evolution of some plants and animals. Before you read, discuss the questions in a small group. Use a dictionary and other reference sources as necessary.

1. Bees need flowers and flowers need bees. List some other examples of how species need each other.
2. List some similarities between dogs and wolves. List some differences.
3. Do you think that humans could have caused wolves to evolve into dogs? If so, how?

Reading

Humanity's Companion Species

1 Life is, very obviously, interdependent. Down to the level of the single cell, one species needs another—or, more likely, many others—for food, shade, protection, even entertainment. Bees need flowers, and flowers need bees. Coral polyps may be small things, but the grand reefs they build make life possible for hundreds of other species, from bacteria to sharks. If coral goes extinct, so may they. Something similar could be said for the entire ecosystems that hum around the Asian elephant, the baobab tree, or the human.

2 The far-reaching role of humans in the evolution of some plants is eloquently described by Michael Pollan in his landmark book *The Botany of Desire*. Thinking of domesticated crops like apples and potatoes, he remarks, "We automatically think of domestication as something we do to other species, but it makes just as much sense to think of it as something certain plants and animals have done to us, a clever evolutionary strategy for advancing their own interests. The species that have spent the last ten thousand or so years figuring out how best to feed, heal, clothe, intoxicate, and otherwise delight us have made themselves some of nature's greatest success stories."[1]

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[1] From *The Botany of Desire: A Plant's Eye View of the World* by M. Pollan, 2001.

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3 The time period Pollan mentions is a rough approximation of the span during which settled agricultural life has been common. His focus on plants has made him too conservative, perhaps by a few thousand years. One grave in the Middle East contains the bones of a pup—either a dog or a wolf—buried along with a human about 14,000 years ago. A skeleton that is distinctively from a dog, not a wolf, was discovered in a Middle Eastern cave and dated by archaeologists to about 12,000 years ago. Both of these dates precede the point at which other companion species, such as sheep or cattle, probably became adjunct to human communities (more in line with Pollan's 10,000 years). Horses probably did not get domesticated until some 4,500 years ago. The evidence, then, points to the dog as the first species to employ Pollan's "clever evolutionary strategy" of systematically conforming to human wishes.

4 Speculation as to exactly how that happened remains lively, partly because reliable evidence allows for several credible scenarios. Almost no one doubts that domesticated dogs, the species known as *Canis familiaris*, descended from the wolf, *Canis lupus*. A longstanding belief held that dogs diverged from the wolf line as a result of artificial selection by humans. Or, more accurately, natural selection along Darwinian lines was redirected as the wishes of humans became a factor in determining which organisms were the "fittest" in certain environmental niches. This scenario places humans in the driver's seat, choosing to welcome certain docile wolves and breeding them selectively until they were different enough from wild wolves to constitute a new species.

5 It is also possible that this divergence happened in response to canine initiative, not human. For example, those individual wolves that neither ran away nor attacked at the sight of humans may have been tolerated as they ate garbage tossed out at the margins of human camps. This would confer a great survival advantage by securing a relatively constant and easy-to-get supply of food. These human-compatible individuals mated and had pups that grew up able to co-exist with humans, and the development of a companion species was underway. This scenario is bolstered by DNA analyses, which have found a one percent difference between the genome (basic genetic structure) of dogs and that of wolves. According to standard formulas regarding the rate of genetic change, the wolf-dog separation point would then be between 100,000 and 135,000 years ago. At such an early point, any human societies were probably like hunting packs themselves and were probably too rudimentary to undertake the deliberate domestication of any animal, even one as well-suited to it as the wolf-dog. A more accidental cozying-up between the two species is a lot easier to believe at that stage in human development.

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6 Still, strong evidence from unique experiments in Siberia suggests that the human-dog connection could have been formed on a much shorter time scale, regardless of what the DNA analyses say. The late Dmitry Bulyaev began a series of breeding experiments in the 1950s that, over the course of a mere 40 years, achieved remarkable results. He worked with silver foxes, a close relative of wolves and dogs, captured in the wild and then housed at his research facility in Novosibirsk. This experiment is described in detail by Lyudmila Trut later in this unit. The long and short of it is that it shows how a population of canids can be dramatically transformed in a very short time simply by selecting for the trait of tameness. It further suggests that extremely small genetic shifts, far smaller than one percent of the total genome, may be enough to nudge a wild species into the fold of human companions.

Post-Reading

Basic Comprehension

SHORT ANSWER

Answer the questions in your own words.

1. Paragraph 2 contains a long quote from Michael Pollan. What is Pollan's main point?

   ____

   ____

   ____

2. What evidence suggests that the separation of wolves and dogs into two species was not caused entirely by artificial selection?

   ____

   ____

   ____

3. What kind of experiments did Dmitry Bulyaev conduct?

   ____

   ____

   ____

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MATCHING

Complete each sentence with the best number from the box. One number will be used twice.

4,500	10,000	12,000	14,000	100,000–135,000

1. A fossil that shows dogs and wolves had become noticeably different is about __________ years old.
2. A fossil that suggests humans and wolves or dogs lived together is about __________ years old.
3. DNA analyses suggest dogs and wolves began to separate as species __________ years ago.
4. Horses began to be domesticated about _________ years ago.
5. Humans began to live together with some farm animals about _________ years ago.
6. Plants began to be domesticated about __________ years ago.

Vocabulary

MULTIPLE CHOICE

Choose the word or phrase closest in meaning to each italicized word.

1. "Thinking of *domesticated* crops like apples and potatoes, he remarks. . . ."
   a. adapted for human use
   b. common
   c. different from each other
   d. nutritious

2. "The time period Pollan mentions is a *rough* approximation of the span during which settled agricultural life has been common."
   a. amazing
   b. not exact
   c. simple
   d. very long

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3. "A skeleton that is *distinctively* from a dog, not a wolf, was discovered in a Middle Eastern cave and dated by archaeologists to about 12,000 years ago."
   a. easily identified as
   b. probably
   c. thought to be
   d. unusually

4. "Still, strong evidence from *unique* experiments in Siberia suggests that the human-dog connection could have been formed on a much shorter time scale, regardless of what the DNA analyses say."
   a. detailed
   b. long-running
   c. overlooked
   d. one-of-a-kind

PARAPHRASING

Restate each numbered sentence in the paragraphs using the word in parentheses. Refer to a dictionary if necessary.

① (speculation) In the twentieth century, archaeologists gave much thought to the question of how domestication of plant species began. ② (speculated) Because domestication of plants occurred around the same time in different parts of the world, some hypothesized that global climate played a role. ③ (speculative) Although global climate seems almost certain to have played some role, scientists remained uncertain of the exact mechanism by which climate affected domestication. Archaeologists also debated where domestication took place. ④ (speculated) Some theorists suggested that agriculture began in areas where plant species such as wild wheat were plentiful. However, other research showed that agriculture may have begun near the edges of the species' habitat rather than near the center.

⑤ (divergence) No matter exactly where and how plant species were first domesticated, as domestication progressed,

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differences between traits of the domesticated species and its wild relative emerged. ⑥ (diverged) There are several ways domesticated wheat has become different from wild wheat: it stays on its stalk longer when it is ripe, it has thinner husks, and each plant produces many more seeds. ⑦ (divergence) Early agricultural practices likely encouraged the separation between wild and domesticated wheat. ⑧ (divergent) Early agriculturalists may have selected mutant plants with the new traits and intentionally or unintentionally provided a situation more favorable to their growth than to that of plants with wild traits.

1. ____________________

2. ____________________

3. ____________________

4. ____________________

5. ____________________

6. ____________________

7. ____________________

8. ____________________

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Reading Focus

Grouping Information

Grouping information can help readers understand the material. Grouped material is also easier to remember because it is logical and consistent.

CATEGORIZING

Arrange these events into three groups. Which of the events do you think were **unintentional**? Which were **deliberate**? Which were probably a combination of the two? Discuss your answers in a small group. Optional: Try adding two other events (from your own knowledge of human development) to each group.

development of agriculture
development of writing
discovery of penicillin
domestication of the dog
invention of the airplane
invention of the wheel
use of fire

Unintentional	Deliberate	Combination

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Second Tier: Potatoes and People

Pre-Reading

DISCUSSION

This reading deals with genetically modified food crops. Before you read, discuss the questions in a small group. Use a dictionary and other reference sources as necessary.

1. Distinguish between the members of each pair given.

   Example: plant / crop

   "Plant" is a more general word, meaning any kind of vegetation. It could be wild or it could be deliberately grown on a farm. A "crop" is a type of plant that humans grow so they can gather all or parts of it for some specific use (for food, fuel, fiber, etc.).

   a. genetically modified species / hybrid species
   b. species / individual
   c. species / variety

2. How do you think genetically modified crops differ from traditional crops?

Reading

The Botany of Desire: The Potato

1 For nature as much as for people, the garden has always been a place to experiment, to try out new hybrids and mutations. Species that never cross in the wild will freely hybridize on land cleared by people. That's because a novel hybrid has a hard time finding a purchase in the tight weave of an established meadow or forest ecosystem; every possible niche is apt to be already filled. But a garden—or a roadside or a dump heap—is by comparison an "open" habitat in which a new hybrid has a much better shot, and if it happens to catch our fancy, to gratify a human desire, it stands to make its way in the world. One theory of the origins of agriculture holds that domesticated plants first emerged on dump heaps, where the discarded seeds of the wild plants that people gathered and ate—already unconsciously selected for sweetness or size or power—took root,

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flourished, and eventually hybridized. In time people gave the best of these hybrids a place in the garden, and there, together, the people and the plants embarked on a series of experiments in coevolution that would change them both forever. . . .

2 It is only by trial and error that my garden ever improves, so I continue to experiment. Recently I planted something new—something very new, as a matter of fact—and embarked on my most ambitious experiment to date. I planted a potato called "NewLeaf" that has been genetically engineered (by the Monsanto corporation) to produce its own insecticide. This it does in every cell of every leaf, stem, flower, root, and—this is the unsettling part—every spud.

3 The scourge of potatoes has always been the Colorado potato beetle, a handsome, voracious insect that can pick a plant clean of its leaves virtually overnight, starving the tubers in the process. Supposedly, any Colorado potato beetle that takes so much as a nibble of a NewLeaf leaf is doomed, its digestive tract pulped, in effect, by the bacterial toxin manufactured in every part of these plants.

4 I wasn't at all sure I really *wanted* the NewLeaf potatoes I'd be digging at the end of the season. In this respect my experiment in growing them was very different from anything else I've ever done in my garden—whether growing apples or tulips or [anything else]. All of those I'd planted because I really wanted what the plants promised. What I wanted here was to gratify not so much a desire as a curiosity: Do they work? Are these genetically modified potatoes a good idea, either to plant or to eat? If not mine, then whose desire *do* they gratify? And finally, what might they have to tell us about the future of the relationship between plants and people? To answer these questions, or at least begin to, would take more than the tools of the gardener (or the eater); I'd need as well the tools of the journalist, without which I couldn't hope to enter the world from which these potatoes had come. So you could say there was something fundamentally artificial about my experiment in growing NewLeaf potatoes. But then, artificiality seems very much to the point.

5 Certainly my NewLeafs are aptly named. They're part of a new class of crop plant that is transforming the long, complex, and by now largely invisible food chain that links everyone of us to the land. By the time I conducted my experiment, more than fifty million acres of American farmland had already been planted to genetically modified crops, most of it corn, soybeans, cotton, and potatoes that have been engineered either to produce their own pesticide or to withstand herbicides. The not-so-distant future will, we're told, bring us potatoes genetically modified to absorb less fat when fried, corn that can withstand drought, lawns that don't ever have to be mowed, "golden rice" rich in Vitamin A, bananas and potatoes

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that deliver vaccines, tomatoes enhanced with flounder genes (to withstand frost), and cotton that grows in every color of the rainbow.

6 It's probably not too much to say that this new technology represents the biggest change in the terms of our relationship with plants since people first learned how to cross one plant with another. With genetic engineering, human control of nature is taking a giant step forward. The kind of reordering of nature represented by the rows in a farmer's field can now take place at a whole new level: within the genome of the plants themselves. Truly, we have stepped out onto new ground.

7 Or have we?

8 Just how novel these plants really are is in fact one of the biggest questions about them, and the companies that have developed them give contradictory answers. The industry simultaneously depicts these plants as the linchpins of a biological revolution, part of a "paradigm shift" that will make agriculture more sustainable and feed the world—and, oddly enough, as the same old spuds, corn, and soybeans, at least so far as those of us at the eating end of the food chain should be concerned. The new plants are novel enough to be patented yet not so novel as to warrant a label telling us what it is we're eating. It would seem they are chimeras: "revolutionary" in the patent office and on the farm, "nothing new" in the supermarket and the environment. . . .

9 Here at the planter's end of the food chain, where I began my experiment after Monsanto agreed to let me test-drive its NewLeafs, things certainly look new and different. After digging two shallow trenches in my vegetable garden and lining them with compost, I untied the purple mesh bag of seed potatoes Monsanto had sent and opened the grower's guide tied around its neck. Potatoes, you will recall from kindergarten experiments, are grown not from actual seeds but from the eyes of other potatoes, and the dusty, stone-colored chunks of tuber I carefully laid at the bottom of the trench looked much like any other. Yet the grower's guide that comes with them put me in mind not so much of planting vegetables as booting up a new software release.

10 By "opening and using this product," the card informed me, I was now "licensed" to grow these potatoes, but only for a single generation; the crop I would water and tend and harvest was mine, yet also not mine. That is, the potatoes I would dig come September would be mine to eat or sell, but their genes would remain the intellectual property of Monsanto, protected under several U.S. patents, including 5,196,525; 5,164,316; 5,322,938; and 5,352,605. Were I to save even one of these spuds to plant next year—something I've routinely done with my potatoes in the past—I would be breaking federal law. (I had to wonder, what would be the legal status of any "volunteers"—those plants that, with no prompting from the

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gardener, sprout each spring from tubers overlooked during the previous harvest?) The small print on the label also brought the disconcerting news that my potato plants were *themselves* registered as a pesticide with the Environmental Protection Administration (U.S. EPA Reg. No. 524–474).

11 If proof were needed that the food chain that begins with seeds and ends on our dinner plates is in the midst of revolutionary change, the small print that accompanied my NewLeafs will do. That food chain has been unrivaled for its productivity: on average, an American farmer today grows enough food each year to feed a hundred people. Yet that achievement—that power over Nature—has come at a price. The modern industrial farmer cannot grow that much food without large quantities of chemical fertilizers, pesticides, machines, and fuel. This expensive set of "inputs," as they're called, saddles the farmer with debt, jeopardizes his health, erodes his soil and ruins its fertility, pollutes the groundwater, and compromises the safety of the food we eat. Thus the gain in the farmer's power has been trailed by a host of new vulnerabilities.

12 All this I'd heard before, of course—but always from environmentalists or organic farmers. What is new is to hear the same critique from industrial farmers, government officials, and the agribusiness companies that sold farmers on all those expensive inputs in the first place. Taking a page from Wendell Berry, of all people, Monsanto declared in a recent annual report that "current agricultural technology is unsustainable."

13 What is to rescue the American food chain is a new kind of plant. Genetic engineering promises to replace expensive and toxic chemicals with expensive but apparently benign genetic information: crops that, like my NewLeafs, can protect themselves from insects and diseases without the help of pesticides. In the case of the NewLeaf, a gene borrowed from one strain of a common bacterium found in the soil—B*acillus thuringiensis*, or "Bt" for short—gives the potato plant's cells the information they need to manufacture a toxin lethal to the Colorado potato beetle. This gene is now Monsanto's intellectual property. With genetic engineering, agriculture has entered the information age, and Monsanto's aim, it would appear, is to become its Microsoft—supplying the proprietary "operating systems"—the metaphor is theirs—to run this new generation of plants.

14 The metaphors we use to describe the natural world strongly influence the way we approach it, the style and extent of our attempts at control. It makes all the difference in (and to) the world if one conceives of a farm as a factory or a forest as a farm. Now we're about to find out what happens when people begin approaching the genes of our food plants as software.

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Andean Origins

15 The patented potatoes I was planting are descended from wild ancestors growing on the Andean altiplano, the potato's "center of diversity." It was here that *Solanum tuberosum* was first domesticated more than seven thousand years ago by ancestors of the Incas. Actually, some of the potatoes in my garden are closely related to those ancient potatoes. Among the half dozen or so different varieties I grow are a couple of ancient heirlooms, including the Peruvian blue potato. This starchy spud is about the size of a golf ball; when you slice it through the middle the flesh looks as though it has been tie-dyed the most gorgeous shade of blue. . . .

16 Since the margins and hedgerows of the Andean farm were, and still are, populated by weedy wild potatoes, the farmer's cultivated varieties have regularly crossed with their wild relatives, in the process refreshing the gene pool and producing new hybrids. Whenever one of these new potatoes proves its worth—surviving a drought or storm, say, or winning praise at the dinner table—it is promoted from the margins to the fields and, in time, to the neighbors' fields as well. Artificial selection is thus a continual local process, each new potato the product of an ongoing back-and-forth between the land and its cultivators, mediated by the universe of all possible potatoes: the species' genome.

17 The genetic diversity cultivated by the Incas and their descendants is an extraordinary cultural achievement and a gift of incalculable value to the rest of the world. A free and unencumbered gift, one might add, quite unlike my patented and trademarked NewLeafs. "Intellectual property" is a recent, Western concept that means nothing to a Peruvian farmer, then or now.[1] Of course, Francisco Pizarro was looking for neither plants nor intellectual property when he conquered the Incas; he had eyes only for gold. None of the conquistadores could have imagined it, but the funny-looking tubers they encountered high in the Andes would prove to be the single most important treasure they would bring back from the New World. . . .

18 All domesticated plants are in some sense artificial, living archives of both cultural and natural information that people have helped to "design." Any given type of potato reflects the human desires that have been bred into it. One that's been selected to yield long, handsome french fries or unblemished, round potato chips is the expression of a national food chain and a culture that likes its potatoes highly processed. At the

[1] In fact, "intellectual property" has been defined under recent trade agreements in such a way as to specifically exclude any innovations that are not the private, marketable property of an individual or corporation. Thus a corporation's new potato qualifies as intellectual property, but not a tribe's.

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same time, some of the more delicate European fingerlings growing beside my NewLeafs imply an economy of small-market growers and a cultural taste for eating potatoes fresh—for none of these varieties can endure much travel or time in storage. I'm not sure exactly what cultural values to ascribe to my Peruvian blues; perhaps nothing more than a craving for variety among a people who ate potatoes morning, noon, and night.

19 "Tell me what you eat," Anthelme Brillat-Savarin famously claimed, and "I will tell you what you are." The qualities of a potato—as of any domesticated plant or animal—are a fair reflection of the values of the people who grow and eat it. Yet all these qualities already existed in the potato, somewhere within the universe of genetic possibilities presented by the species *Solanum tuberosum*. And though that universe may be vast, it is not infinite. Since unrelated species in nature cannot be crossed, the breeder's art has always run up against a natural limit of what a potato is willing, or able, to do—that species' essential identity. Nature has always exercised a kind of veto over what culture can do with a potato.

20 Until now. The NewLeaf is the first potato to override that veto. Monsanto likes to depict genetic engineering as just one more chapter in the ancient history of human modifications of nature, a story going back to the discovery of fermentation. The company defines the word *biotechnology* so broadly as to take in the brewing of beer, cheese making, and selective breeding: all are "technologies" that involve the manipulation of life-forms.

21 This new biotechnology has overthrown the old rules governing the relationship of nature and culture in a plant. Domestication has never been a simple one-way process in which our species has controlled others; other species participate only so far as their interests are served, and many plants (such as the oak) simply sit the whole game out. That game is the one Darwin called "artificial selection:" and its rules have never been any different from the rules that govern natural selection. The plant in its wildness proposes new qualities, and then man (or, in the case of natural selection, nature) selects which of those qualities will survive and prosper. But about one rule Darwin was emphatic; as he wrote in *The Origin of Species*, "Man does not actually produce variability."

22 Now he does. For the first time, breeders can bring qualities at will from anywhere in nature into the genome of a plant: from fireflies (the quality of luminescence), from flounders (frost tolerance), from viruses (disease resistance), and, in the case of my potatoes, from the soil bacterium known as *Bacillus thuringiensis*. Never in a million years of natural or artificial selection would these species have proposed those qualities. "Modification by descent" has been replaced by . . . something else.

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23 Now, it is true that genes occasionally move between species; the genome of many species appears to be somewhat more fluid than scientists used to think. Yet for reasons we don't completely understand, distinct species do exist in nature, and they exhibit a certain genetic integrity—sex between them, when it does occur, doesn't produce fertile offspring. Nature presumably has some reason for erecting these walls, even if they are permeable on occasion. Perhaps, as some biologists believe, the purpose of keeping species separate is to put barriers in the path of pathogens, to contain their damage so that a single germ can't wipe out life on Earth in a stroke.

24 The deliberate introduction into a plant of genes transported not only across species but across whole phyla means that the wall of that plant's essential identity—its irreducible wildness, you might say—has been breached, not by a virus, as sometimes happens in nature, but by humans wielding powerful new tools. . . .

25 What is perhaps most striking about the NewLeafs coming up in my garden is the added human intelligence that the insertion of the B*acillus thuringiensis* gene represents. In the past that intelligence resided outside the plant, in the minds of the organic farmers and gardeners (myself included) who used Bt, commonly in the form of a spray, to manipulate the ecological relationship between certain insects and a certain bacterium in order to foil those insects. One way to look at genetic engineering is that it allows a larger portion of human culture and intelligence to be incorporated into the plants themselves. From this perspective, my NewLeafs are just plain smarter than the rest of my potatoes. The others will depend on my knowledge and experience when the Colorado potato beetles strike. The NewLeafs, already knowing what I know about bugs and Bt, will take care of themselves. So while my genetically engineered plants might at first seem like alien beings, that's not quite right; they're more like us than other plants because there is more of us in them. . . .

26 My NewLeafs are clones of clones of plants that were first engineered more than a decade ago in a long, low-slung brick building on the bank of the Missouri that would look like any other corporate complex if not for its stunning roofline. What appear from a distance to be shimmering crenellations of glass turn out to be the twenty-six greenhouses that crown the building in a dramatic sequence of triangular peaks. The first generation of genetically altered plants—of which the NewLeaf potato is one—has been grown under this roof, in these greenhouses, since 1984. Especially in the early days of biotechnology, no one knew for sure if it was safe to grow these plants outdoors, in nature. Today this research and development facility is one of a small handful of such places—Monsanto

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has only two or three competitors in the world—where the world's crop plants are being redesigned.

27 Dave Starck, one of Monsanto's senior potato people, escorted me through the clean rooms where potatoes are genetically engineered. He explained that there are two ways of splicing foreign genes into a plant—by infecting it with agrobacterium, a pathogen whose modus operandi is to break into a plant cell's nucleus and replace its DNA with some of its own, or by shooting it with a gene gun. For reasons not yet understood, the agrobacterium method seems to work best on broadleaf species such as the potato, the gene gun better on grasses, such as corn and wheat. The gene gun is a strangely high-low piece of technology, but the main thing you need to know about it is that the gun here is not a metaphor: a .22 shell is used to fire stainless-steel projectiles dipped in a DNA solution at a stem or leaf of the target plant. If all goes well, some of the DNA will pierce the wall of some of the cells' nuclei and elbow its way into the double helix: a bully breaking into a line dance. If the new DNA happens to land in the right place—and no one yet knows what, or where, that place is—the plant grown from that cell will express the new gene. T*hat's it?*

28 That's it.

29 Apart from its slightly more debonair means of entry, the agrobacterium works in much the same way. In the clean rooms, where the air pressure is kept artificially high to prevent errant microbes from wandering in, technicians sit at lab benches before petri dishes in which fingernail-sized sections of potato stem have been placed in a clear nutrient jelly. Into this medium they squirt a solution of agrobacteria, which have already had their genes swapped with the ones Monsanto wants to insert (specific enzymes can be used to cut and paste precise sequences of DNA). In addition to the Bt gene being spliced, a "marker" gene is also included—typically this is a gene conferring resistance to a specific antibiotic. This way, the technicians can later flood the dish with the antibiotic to *see* which cells have taken up the new DNA; any that haven't simply die. The marker gene can also serve as a kind of DNA fingerprint, allowing Monsanto to identify its plants and their descendants long after they've left the lab. By performing a simple test on any potato leaf in my garden, a Monsanto agent can prove whether or not the plant is the company's intellectual property. I realized that, whatever else it is, genetic engineering is also a powerful technique for transforming plants into private property, by giving everyone of them what amounts to its own Universal Product Code.

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Post-Reading

Basic Comprehension

SHORT ANSWER

Answer the questions in your own words.

1. What is the purpose of the genetic modification to the NewLeaf potato?

2. Pollan compares genetically modified crops to computer software. Why do you think he makes this comparison?

3. In Paragraph 20, Pollan states that "Monsanto likes to depict genetic engineering as just one more chapter in the ancient history of human modifications of nature, a story going back to the discovery of fermentation." However, he seems to disagree with this depiction. What does Pollan see as the fundamental difference between genetic modification and the development of hybrids by natural and artificial selection?

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MULTIPLE CHOICE

Circle the choice that best answers each question.

1. Which statement is closest to the main idea of the reading?
   a. Developments in genetic modification allow corporations greater control over agriculture.
   b. Genetic modifications enable farmers to produce higher crop yields than is possible using traditional crops.
   c. Genetically modified organisms are harmful because of the toxins they contain.
   d. The varieties of potato that evolved in the Andes are being replaced by a global monoculture.

2. Which statement best describes the attitude Pollan expresses toward genetically modified crops?
   a. mild curiosity about a scientific process
   b. powerful opposition to a harmful change
   c. slight mistrust of an inevitable advance
   d. strong support of an important discovery

3. Which statements describe what Pollan considered artificial about his planting NewLeaf potatoes? (Choose two.)
   a. The potatoes contain artificial genes.
   b. The potatoes don't gratify a desire.
   c. The potatoes require artificial fertilizers.
   d. The potatoes were planted in deliberate rows.

4. According to Paragraph 10, which warnings were included in the grower's guide Pollan received with his NewLeaf potatoes? (Choose two.)
   a. A government agency listed the potato plants a pesticide.
   b. He could not keep and replant the potatoes he grew.
   c. He would be able to eat or sell the potatoes he harvested.
   d. The potatoes might grow back as "volunteers" the next year.

5. According to Paragraphs 11–13, what problem in modern agriculture does genetic engineering seek to solve?
   a. decreasing productivity on American farms
   b. plant diseases caused by *Bacillus thuringiensis* infections
   c. rising food and seed prices
   d. unsustainability of farming using vast amounts of inputs

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6. Why is there such a wide variety of Andean potatoes?
   a. Ancestors of the Incas, unlike other early farmers, valued diversity of species.
   b. Domesticated potatoes regularly cross with wild potatoes on the Andean antiplano.
   c. The farmers continually crossed their plants to produce new types.
   d. The potatoes on the Andean antiplano had been collected from various different areas.

7. What does Paragraph 18 suggest about the type of potato that "yields long, handsome french fries or unblemished, round potato chips"?
   a. They are difficult to grow.
   b. They are unrelated to European fingerlings.
   c. They can be stored a long time.
   d. They have been genetically modified.

8. Which statement best expresses the most important limitation farmers faced in cross-breeding potatoes prior to genetic engineering technology?
   a. It took a long time to produce hybrids with desired traits.
   b. The potato species contained few genetic possibilities for different traits.
   c. They could breed for traits a species possessed but not for traits from other species.
   d. They had to obtain intellectual property permission to use varieties developed by other farmers.

9. According to Paragraph 21, what characterizes natural and artificial selection in the process of domestication?
   a. Artificial selection generally serves human interests but natural selection generally doesn't.
   b. Natural selection acts only in wild species and artificial selection only in domesticated species.
   c. They both involve one-way processes of a species controlling another.
   d. They both select for features found in nature but neither produces new qualities.

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10. What can be inferred from Paragraph 23 about what some biologists believe?
    a. If different species could exchange genes easily, all species would be more vulnerable to disease.
    b. Life on Earth is likely to be eliminated by a single germ someday.
    c. Additional legal barriers are needed to keep species separate because of the danger pathogens pose.
    d. Genes are never transmitted between different species in nature.

11. According to Paragraph 25, why are Pollan's NewLeafs "just plain smarter than the rest of [his] potatoes"?
    a. The "knowledge" that Bt will protect them is built into them.
    b. They have a larger amount of genetic information than other potatoes.
    c. Genetic engineers inserted human DNA into them.
    d. Farmers save time and money, making NewLeafs a wise choice.

12. According to Paragraph 29, which statement is NOT a result of inserting marker genes into plants?
    a. Plant varieties become private property.
    b. Researchers are able to determine which cells contain the modified genes.
    c. Company representatives can figure out what plants contain their genes.
    d. The plants develop a resistance to certain bacteria.

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Vocabulary

MULTIPLE CHOICE

Choose the word or phrase closest in meaning to each italicized word in the sentences from the reading.

1. "Thus the gain in the farmer's power has been trailed by a host of new *vulnerabilities*."
   a. needs
   b. promises
   c. responsibilities
   d. weaknesses
2. "Nature presumably has some reason for *erecting* these walls, even if they are permeable on occasion."
   a. changing
   b. building
   c. selecting
   d. wanting
3. "Nature presumably has some reason for erecting these walls, even if they are *permeable* on occasion."
   a. falling apart
   b. difficult to understand fully
   c. penetrable; have holes that allow things through
   d. maintained artificially
4. "The deliberate introduction into a plant of genes transported not only across species but across whole phyla means that the wall of that plant's essential identity—its irreducible wildness, you might say—has been *breached*, not by a virus, as sometimes happens in nature, but by humans wielding powerful new tools."
   a. broken through
   b. erased
   c. made unhealthy
   d. reduced

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5. "Apart from its slightly more *debonair* means of entry, the agrobacterium works in much the same way."
   a. calm
   b. controlled
   c. natural
   d. sophisticated
6. "In the clean rooms, where the air pressure is kept artificially high to prevent *errant* microbes from wandering in, technicians sit at lab benches before petri dishes in which fingernail-sized sections of potato stem have been placed in a clear nutrient jelly."
   a. disease-causing
   b. different
   c. aimlessly moving
   d. numerous

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PARAPHRASING

Use the best vocabulary item from the list to rephrase each statement. Change as much of the original as necessary to use the item you have chosen, but do not change the meaning of the original. Use each item from the list only once.

Vocabulary Items

ancestors	*deliberate* (adj.)	*subsist*
commodity	*intractable/intractability*	*succumbed*
cultivate	*modify*	*vulnerable*

1. Researchers have managed to change the genetic code of crops so that patented varieties are sterile.

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2. The price of products bought and sold on the market like corn or pork determines the profitability of farmers' yields.

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3. The progenitors of modern potatoes were harvested in the Andes.

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4. Unlike natural selection, artificial selection occurs when humans make an intentional choice of one trait over another and help individuals with that trait to thrive.

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5. In spite of the thousands of years' experience humans have with agriculture, nature remains difficult to control.

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6. Pollan describes his attempt to grow and care for genetically modified potatoes.

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Reading Focus

Polysemy ("Many meanings")

Dictionaries often list several definitions for a word. Sometimes the different meanings of homonyms (words that have the same sound and spelling, but have different meanings) are so distinct that it is easy to tell which definition is intended by the author. For example, you probably know whether the word *right* means "in accordance with the facts" or "the opposite of left." However, it might be more difficult to determine whether it means "in conformity with the facts" or "in accordance with what is proper." Even more difficult might be the distinction between "in accordance with what is proper" and "tending to do what is good." Still, the distinction is important to accurate reading.

MULTIPLE CHOICE

In this activity, many of the options are accurate definitions for the word they follow. However, only one conforms to the intended meaning of the word in the reading (see paragraph numbers). Choose the definition that best defines the word as it is used in the reading.

1. *compromises* (Paragraph 11)
   a. causes danger
   b. finds a solution between two extremes
   c. provides a harmful thing
   d. gives in so an agreement can be reached
2. *host* (Paragraph 11)
   a. organism that a parasite lives on
   b. person who has invited guests
   c. person who leads a TV show or event
   d. very large number
3. *descended from* (Paragraph 15)
   a. act less dignified than expected of one's position
   b. in a logical progression
   c. come from an older version
   d. go from a higher place to a lower one
4. *yield* (Paragraph 18)
   a. break under pressure
   b. give over control of
   c. give way
   d. produce

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Building a Text Model

PART 1: ORGANIZATIONAL TECHNIQUE

SHORT ANSWER

Answer the questions about the reading.

1. Authors use various techniques and combinations of techniques to present and support their points. Which of the following best describes the organization of the actual passage?
   a. alternating between analysis (scientific, economic, and historical) and personal narrative
   b. arguing about use of genetically engineered products through the presentation of advantages and disadvantages
   c. chronologically describing advances in evolution and biological science
   d. presenting a thesis followed by historical and scientific data in support of the thesis

2. What advantages and disadvantages does this organizational technique present as far as the reader is concerned? In your answer, consider such factors as the ease and difficulty of processing information, maintaining interest in the topic, and overall comprehension.

   ____

   ____

   ____

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PART 2: PARAGRAPH ORGANIZATION

COMPLETION

Next to each set of paragraph numbers, list the organizational descriptor that best applies. Then list the main idea of those paragraphs. The first two have been done for you as examples.

Paragraph Number(s)	Organizational Descriptor	Main Idea
1	*historical/ scientific analysis*	*Hybrid plants have developed through a process of coevolution with humans.*
2–4	*personal narrative*	*Genetically modified potatoes can produce their own insecticides, but Pollan has questions about their safety and desirability.*
5–8		
9–10		
11–14		
15–19		

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20–25		
26		
27–28		
29		

Putting Reading to Work

WRITING

Michael Pollan indirectly raises two questions. Do some research on ONE of these questions. Use one or two reference sources outside this chapter to gather information about the environmental situation in that country. You may use print or online sources. Present your findings in a one- or two-page paper or in a short three-to-five-minute oral presentation.

1. Can genetic modification reduce the environmentally harmful inputs needed for modern farming?
2. What effects will result from the growing corporate control over agriculture?

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Third Tier: Foxes and Dogs

Pre-Reading

DISCUSSION

This reading by Lyudmila Trut is mentioned in Tier 1. It describes some experiments involving foxes. From these experiments, the researchers drew conclusions about dogs. Before you read, discuss the questions in a small group. After you read, see which of your predictions were correct.

1. What are possible reasons why the scientists studying the domestication of dogs chose to experiment on foxes rather than wolves?
2. How do you think they might have conducted their experiment?
3. What questions do you think their experiment might have answered?

Reading

Early Canid Domestication: The Farm Fox Experiment

1 Foxes bred for tamability in a 40-year experiment exhibit remarkable transformations that suggest an interplay between behavioral genetics and development. When scientists ponder how animals came to be domesticated, they almost inevitably wind up thinking about dogs. The dog was probably the first domestic animal, and it is the one in which domestication has progressed the furthest—far enough to turn *Canis lupus* into *Canis familiaris*. Evolutionary theorists have long speculated about exactly how dogs' association with human beings may have been linked to their divergence from their wild wolf forebears, a topic that anthropologist Darcy Morey has discussed in some detail. As Morey pointed out, debates about the origins of animal domestication tend to focus on "the issue of intentionality"—the extent to which domestication was the result of deliberate human choice. Was domestication actually "self-domestication," the colonization of new ecological niches by animals such as wolves? Or did it result from intentional decisions by human beings? How you answer those questions will determine how you understand the morphological and physiological changes that domestication has brought about—whether as the

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results of the pressure of natural selection in a new niche, or as deliberately cultivated advantageous traits. In many ways, though, the question of intentionality is beside the point. Domestication was not a single event but rather a long, complex process. Natural selection and artificial selection may both have operated at different times or even at the same time. For example, even if prehistoric people deliberately set out to domesticate wolves, natural selection would still have been at work. The selective regime may have changed drastically when wolves started living with people, but selective pressure continued regardless of anything H*omo sapiens* chose to do.

2 Another problem with the debate over intentionality is that it can overshadow other important questions. For example, in becoming domesticated, animals have undergone a host of changes in morphology, physiology and behavior. What do those changes have in common? Do they stem from a single cause, and if so, what is it? In the case of the dog, Morey identifies one common factor as pedomorphosis, the retention of juvenile traits by adults. Those traits include both morphological ones, such as skulls that are unusually broad for their length, and behavioral ones, such as whining, barking and submissiveness—all characteristics that wolves outgrow but that dogs do not. Morey considers pedomorphosis in dogs a byproduct of natural selection for earlier sexual maturity and smaller body size, features that, according to evolutionary theory, ought to increase the fitness of animals engaged in colonizing a new ecological niche.

3 The common patterns are not confined to a single species. In a wide range of mammals—herbivores and predators, large and small—domestication seems to have brought with it strikingly similar changes in appearance and behavior: changes in size, changes in coat color, even changes in the animals' reproductive cycles. Our research group at the Institute of Cytology and Genetics in Novosibirsk, Siberia, has spent decades investigating such patterns and other questions of the early evolution of domestic animals. Our work grew out of the interests and ideas of the late director of our institute, the geneticist Dmitry K. Belyaev. Like Morey, Belyaev believed that the pattems of changes observed in domesticated animals resulted from genetic changes that occurred in the course of selection. Belyaev, however, believed that the key factor selected for was not size or reproduction, but behavior; specifically amenability to domestication, or tamability. More than any other quality, Belyaev believed, tamability must have determined how well an animal would adapt to life among human beings. Because behavior is rooted in biology, selecting for tameness and against aggression means selecting for physiological changes in the systems that govem

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the body's hormones and neurochemicals. Those changes, in turn, could have had far-reaching effects on the development of the animals themselves, effects that might well explain why different animals would respond in similar ways when subjected to the same kinds of selective pressures.

4 To test his hypothesis, Belyaev decided to turn back the clock to the point at which animals received the first challenge of domestication. By replaying the process, he would be able to see how changes in behavior, physiology and morphology first came about. Of course, reproducing the ways and means of those ancient transformations, even in the roughest outlines, would be a formidable task. To keep things as clear and simple as possible, Belyaev designed a selective-breeding program to reproduce a single major factor, a strong selection pressure for tamability. He chose as his experimental model a species taxonomically close to the dog but never before domesticated: *Vulpes vulpes*, the silver fox. Belyaev's fox-breeding experiment occupied the last 26 years of his life. We are carrying his work forward. Through genetic selection alone, our research group has created a population of tame foxes fundamentally different in temperament and behavior from their wild forebears. In the process we have observed some striking changes in physiology, morphology and behavior, which mirror the changes known in other domestic animals and bear out many of Belyaev's ideas.

Belyaev's Hypothesis

5 Belyaev began his experiment in 1959, a time when Soviet genetics was starting to recover from the anti-Darwinian ideology of Trofim Lysenko. Belyaev's own career had suffered. In 1948, his commitment to orthodox genetics had cost him his job as head of the Department of Fur Animal Breeding at the Central Research Laboratory of Fur Breeding in Moscow. During the 1950s he continued to conduct genetic research under the guise of studying animal physiology. He moved to Novosibirsk, where he helped found the Siberian Department of the Soviet (now Russian) Academy of Sciences and became the director of the Department's Institute of Cytology and Genetics, a post he held from 1959 until his death in 1985. Under his leadership the institute became a center of basic and applied research in both classical genetics and modern molecular genetics. His own work included groundbreaking investigations of evolutionary change in animals under extreme conditions (including domestication) and of the evolutionary roles of factors such as stress, selection for behavioral traits and the environmental photoperiod, or duration of natural daylight. Animal domestication was his lifelong project, and fur bearers were his favorite subjects.

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6 Early in the process of domestication, Belyaev noted, most domestic animals had undergone the same basic morphological and physiological changes. Their bodies changed in size and proportions, leading to the appearance of dwarf and giant breeds. The normal pattern of coat color that had evolved as camouflage in the wild altered as well. Many domesticated animals are piebald, completely lacking pigmentation in specific body areas. Hair turned wavy or curly, as it has done in Astrakhan sheep, poodles, domestic donkeys, horses, pigs, goats and even laboratory mice and guinea pigs. Some animals' hair also became longer (Angora type) or shorter (rex type).

7 Tails changed, too. Many breeds of dogs and pigs carry their tails curled up in a circle or semicircle. Some dogs, cats and sheep have short tails resulting from a decrease in the number of tail vertebrae. Ears became floppy. As Darwin noted in Chapter 1 of *On the Origin of Species*, "not a single domestic animal can be named which has not in some country drooping ears"—a feature not found in any wild animal except the elephant. Another major evolutionary consequence of domestication is loss of the seasonal rhythm of reproduction. Most wild animals in middle latitudes are genetically programmed to mate once a year, during mating seasons cued by changes in daylight. Domestic animals at the same latitudes, however, now can mate and bear young more than once a year and in any season.

8 Belyaev believed that similarity in the patterns of these traits was the result of selection for amenability to domestication. Behavioral responses, he reasoned, are regulated by a fine balance between neurotransmitters and hormones at the level of the whole organism. The genes that control that balance occupy a high level in the hierarchical system of the genome. Even slight alterations in those regulatory genes can give rise to a wide network of changes in the developmental processes they govern. Thus, selecting animals for behavior may lead to other, far-reaching changes in the animals' development. Because mammals from widely different taxonomic groups share similar regulatory mechanisms for hormones and neurochemistry, it is reasonable to believe that selecting them for similar behavior—tameness—should alter those mechanisms, and the developmental pathways they govern, in similar ways.

9 For Belyaev's hypothesis to make evolutionary sense, two more things must be true. Variations in tamability must be determined at least partly by an animal's genes, and domestication must place that animal under strong selective pressure. We have looked into both questions. In the early 1960s our team studied the patterns and

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nature of tamability in populations of farm foxes. We cross-bred foxes of different behavior, cross-fostered newborns and even transplanted embryos between donor and host mothers known to react differently to human beings. Our studies showed that about 35 percent of the variations in the foxes' defense response to the experimenter are genetically determined. To get some idea of how powerful the selective pressures on those genes might have been, our group has domesticated other animals, including river otters (*Lutra lutra*) and gray rats (*Rattus norvegicus*) caught in the wild. Out of 50 otters caught during recent years, only eight of them (16 percent) showing weak defensive behavior made a genetic contribution to the next generation. Among the gray rats, only 14 percent of the wild-caught yielded offspring living to adulthood. If our numbers are typical, it is clear that domestication must place wild animals under extreme stress and severe selective pressure.

The Experiment

10 In setting up our breeding experiment, Belyaev bypassed that initial trauma. He began with 30 male foxes and 100 vixens, most of them from a commercial fur farm in Estonia. The founding foxes were already tamer than their wild relatives. Foxes had been farmed since the beginning of this century, so the earliest steps of domestication—capture, caging and isolation from other wild foxes—had already left their marks on our foxes' genes and behavior.

11 From the outset, Belyaev selected foxes for tameness and tameness alone, a criterion we have scrupulously followed. Selection is strict; in recent years, typically not more than 4 or 5 percent of male offspring and about 20 percent of female offspring have been allowed to breed. To ensure that their tameness results from genetic selection, we do not train the foxes. Most of them spend their lives in cages and are allowed only brief "time dosed" contacts with human beings. Pups are caged with their mothers until they are one-half to 2 months old. Then they are caged with their litter mates but without their mothers. At three months, each pup is moved to its own cage.

12 To evaluate the foxes for tameness, we give them a series of tests. When a pup is one month old, an experimenter offers it food from his hand while trying to stroke and handle the pup. The pups are tested twice, once in a cage and once while moving freely with other pups in an enclosure, where they can choose to make contact either with the human experimenter or with another pup. The test is repeated monthly until the pups are six or seven months old.

13 At seven or eight months, when the foxes reach sexual maturity, they are scored for tameness and assigned to one of three classes. The least domesticated

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foxes, those that flee from experimenters or bite when stroked or handled, are assigned to Class III. (Even Class III foxes are tamer than the calmest farm-bred foxes. Among other things, they allow themselves to be hand fed.) Foxes in Class II let themselves be petted and handled but show no emotionally friendly response to experimenters. Foxes in Class I are friendly toward experimenters, wagging their tails and whining. In the sixth generation bred for tameness we had to add an even higher-scoring category. Members of Class IE, the "domesticated elite," are eager to establish human contact, whimpering to attract attention and sniffing and licking experimenters like dogs. They start displaying this kind of behavior before they are one month old. By the tenth generation, 18 percent of fox pups were elite; by the 20th, the figure had reached 35 percent. Today elite foxes make up 70 to 80 percent of our experimentally selected population.

14 Now, 40 years and 45,000 foxes after Belyaev began, our experiment has achieved an array of concrete results. The most obvious of them is a unique population of 100 foxes (at latest count), each of them the product of between 30 and 35 generations of selection. They are unusual animals, docile, eager to please and unmistakably domesticated. When tested in groups in an enclosure, pups compete for attention, snarling fiercely at one another as they seek the favor of their human handler. Over the years several of our domesticated foxes have escaped from the fur farm for days. All of them eventually returned. Probably they would have been unable to survive in the wild.

Physical Changes

15 Physically, the foxes differ markedly from their wild relatives. Some of the differences have obvious links to the changes in their social behavior. In dogs, for example, it is well known that the first weeks of life are crucial for forming primary social bonds with human beings. The "window" of bonding opens when a puppy becomes able to sense and explore its surroundings, and it closes when the pup starts to fear unknown stimuli. According to our studies, nondomesticated fox pups start responding to auditory stimuli on day 16 after birth, and their eyes are completely open by day 18 or 19. On average, our domesticated fox pups respond to sounds two days earlier and open their eyes a day earlier than their nondomesticated cousins. Nondomesticated foxes first show the fear response at 6 weeks of age; domesticated ones show it after 9 weeks or even later. (Dogs show it at 8 to 12 weeks, depending on the breed.) As a result, domesticated pups have more time to become incorporated into a human social environment.

16 Moreover, we have found that the delayed development of the fear response is linked to changes in

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plasma levels of corticosteroids, hormones concerned with an animal's adaptation to stress. In foxes, the level of corticosteroids rises sharply between the ages of 2 to 4 months and reach adult levels by the age of 8 months. One of our studies found that the more advanced an animal's selection for domesticated behavior was, the later it showed the fear response and the later came the surge in its plasma corticosteroids. Thus, selection for domestication gives rises to changes in the timing of the postnatal development of certain physiological and hormonal mechanisms underlying the formation of social behavior.

17 Other physical changes mirror those in dogs and other domesticated animals. In our foxes, novel traits began to appear in the eighth to tenth selected generations. The first ones we noted were changes in the foxes' coat color, chiefly a loss of pigment in certain areas of the body, leading in some cases to a star-shaped pattern on the face similar to that seen in some breeds of dog. Next came traits such as floppy ears and rolled tails similar to those in some breeds of dog. After 15 to 20 generations we noted the appearance of foxes with shorter tails and legs and with underbites or overbites. The novel traits are still fairly rare. Most of them show up in no more than a few animals per 100 to a few per 10,000. Some have been seen in commercial populations, though at levels at least a magnitude lower than we recorded in our domesticated foxes.

Alternative Explanations

18 What might have caused these changes in the fox population? Before discussing Belyaev's explanation, we should consider other possibilities. Might rates and patterns of changes observed in foxes be due, for example, to inbreeding? That could be true if enough foxes in Belyaev's founding population carried a recessive mutant gene from the trait along with a dominant normal gene that masked its effects. Such mixed-gene, or heterozygous, foxes would have been hidden carriers, unaffected by the mutation themselves but capable of passing it on to later generations.

19 As Morey pointed out, inbreeding might well have been rampant during the early steps of dog domestication. But it certainly cannot explain the novel traits we have observed in our foxes, for two reasons. First, we designed the mating system for our experimental fox population to prevent it. Through outbreeding with foxes from commercial fox farms and other standard methods, we have kept the inbreeding coefficients for our fox population between 0.02 and 0.07. That means that whenever a fox pup with a novel trait has been born into the herd, the probability that it acquired the trait through inbreeding (that is, by

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inheriting both of its mutant genes from the same ancestor) has varied between only 2 and 7 percent.

20 Second, some of the new traits are not recessive: They are controlled by dominant or incompletely dominant genes. Any fox with one of those genes would have shown its effects; there could have been no "hidden carriers" in the original population. Another, subtler possibility is that the novelties in our domesticated population are classic by-products of strong selection for a quantitative trait. In genetics, quantitative traits are characteristics that can vary over a range of possibilities; unlike Gregor Mendel's peas, which were either smooth or wrinkly with no middle ground, quantitative traits such as an animal's size, the amount of milk it produces or its overall friendliness toward human beings can be high, low or anywhere in between. What makes selecting for quantitative traits so perilous is that they (or at least the part of them that is genetic) tend to be controlled not by single genes but by complex systems of genes, known as polygenes. Because polygenes are so intricate, anything that tampers with them runs the risk of upsetting other parts of an organism's genetic machinery. In the case of our foxes, a breeding program that alters a polygene might upset the genetic balance in some animals, causing them to show unusual new traits, most of them harmful to the fox. Note that in this argument, it does not matter whether the trait being selected for is tameness or some other quantitative trait. Any breeding program that affects a polygene might have similar effects.

21 The problem with that explanation is that it does not explain why we see the particular mutations we do see. If disrupted polygenes are responsible, then the effects of a selection experiment ought to depend strongly on which mutations already existed in the population. If Belyaev had started with 130 foxes from, say, North America, then their descendants today would have ended up with a completely different set of novelties. Domesticating a population of wolves, or pigs, or cattle ought to produce novel traits more different still. Yet as Belyaev pointed out, when we look at the changes in other domesticated animals, the most striking things about them are not how diverse they are, but how similar. Different animals, domesticated by different people at different times in different parts of the world, appear to have passed through the same morphological and physiological evolutionary pathways. How can that be?

22 According to Belyaev, the answer is not that domestication selects for a quantitative trait but that it selects for a behavioral one. He considered genetic transformations of behavior to be the key factor entraining other genetic events. Many of the polygenes determining behavior may be regulatory, engaged in stabilizing an organism's early

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development, or ontogenesis. Ontogenesis is an extremely delicate process. In principle, even slight shifts in the sequence of events could throw it into chaos. Thus the genes that orchestrate those events and keep them on track have a powerful role to play. Which genes are they? Although numerous genes interact to stabilize an organism's development, the lead role belongs to the genes that control the functioning of the neural and endocrine systems. Yet those same genes also govern the systems that control an animal's behavior, including its friendliness or hostility toward human beings. So, in principle, selecting animals for behavioral traits can fundamentally alter the development of an organism.

23 As our breeding program has progressed, we have indeed observed changes in some of the animals' neurochemical and neurohormonal mechanisms. For example, we have measured a steady drop in the hormone-producing activity of the foxes' adrenal glands. Among several other roles in the body, the adrenal cortex comes into play when an animal has to adapt to stress. It releases hormones such as corticosteroids, which stimulate the body to extract energy from its reserves of fats and proteins.

24 After 12 generations of selective breeding, the basal levels of corticosteroids in the blood plasma of our domesticated foxes had dropped to slightly more than half the level in a control group. After 28 to 30 generations of selection, the level had halved again. The adrenal cortex in our foxes also responds less sharply when the foxes are subjected to emotional stress. Selection has even affected the neurochemistry of our foxes' brains. Changes have taken place in the serotonin system, thought to be the leading mediator inhibiting animals' aggressive behavior. Compared with a control group, the brains of our domesticated foxes contain higher levels of serotonin; of its major metabolite, 5-oxyindolacetic acid; and of tryptophan hydroxylase, the key enzyme of serotonin synthesis. Serotonin, like other neurotransmitters, is critically involved in shaping an animal's development from its earliest stages: Selection and Development

25 Evidently, then, selecting foxes for domestication may have triggered profound changes in the mechanisms that regulate their development. In particular, most of the novel traits and other changes in the foxes seem to result from shifts in the rates of certain ontogenetic processes—in other words, from changes in timing. This fact is clear enough for some of the novelties mentioned above, such as the earlier eye opening and response to noises and the delayed onset of the fear response to unknown stimuli. But it also can explain some of the less obvious ones. Floppy ears, for example, are characteristic of newborn fox pups but may get carried over to adulthood.

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26 Even novel coat colors may be attributable to changes in the timing of embryonic development. One of the earliest novel traits we observed in our domesticated foxes was a loss of pigment in parts of the head and body. Belyaev determined that this piebald pattern is governed by a gene that he named Star. Later my colleague Lyudmila Prasolova and I discovered that the Star gene affects the migration rate of melanoblasts, the embryonic precursors of the pigment cells (melanocytes) that give color to an animal's fur. Melanocytes form in the embryonic fox's neural crest and later move to various parts of the embryo's epidermis. Normally this migration starts around days 28 to 31 of the embryo's development. In foxes that carry even a single copy of the Star gene, however, melanoblasts pass into the potentially depigmented areas of the epidermis two days later, on average. That delay may lead to the death of the tardy melanoblasts, thus altering the pigmentation in ways that give rise to the distinctive Star pattern.

27 One developmental trend to which we have devoted particular attention has to do with the growth of the skull. In 1990 and 1991, after noticing abnormal developments in the skulls and jaws of some of our foxes, we decided to study variations in the animals' cranial traits. Of course, changes in the shape of the skull are among the most obvious ways in which dogs differ from wolves. As I mentioned earlier, Morey believes that they are a result of selection (either natural or artificial) for reproductive timing and smaller body size.

28 In our breeding experiment, we have selected foxes only for behavior, not size; if anything, our foxes may be slightly longer, on average, than the ones Belyaev started with 40 years ago. Nevertheless, we found that their skulls have been changing. In our domesticated foxes of both sexes, cranial height and width tended to be smaller, and snouts tended to be shorter and wider, than those of a control group of farmed foxes. Another interesting change is that the cranial morphology of domesticated adult males became somewhat "feminized." In farmed foxes, the crania of males tended to be larger in volume than those of females, and various other proportions differed sharply between the sexes. In the domesticated foxes the sexual dimorphism decreased. The differences in volume remained, but in other respects the skulls of males became more like those of females. Analysis of cranial allometry showed that the changes in skull proportions result either from changes in the timing of the first appearance of particular structures or from changes in their growth rates. Because we studied the skulls only of adult foxes, however, we cannot judge whether any of these changes are pedomorphic, as Morey believes they are in dogs.

29 The most significant changes in developmental timing

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in our foxes may be the smallest ones: those that have to do with reproduction. In the wild, foxes reach sexual maturity when they are about 8 months old. They are strict seasonal breeders, mating once a year in response to changes in the length of the day (in Siberia the mating season runs from late January to late March) and giving birth to litters ranging from one to 13 pups, with an average of four or five. Natural selection has hard-wired these traits into foxes with little or no genetic variation. Fur farmers have tried for decades to breed foxes that would reproduce more often than annually, but all their attempts have failed. In our experimental fox population, however, some reproductive traits have changed in a correlated manner. The domesticated foxes reach sexual maturity about a month earlier than nondomesticated foxes do, and they give birth to litters that are, on average, one pup larger. The mating season has lengthened. Some females breed out of season, in November–December or April–May, and a few of them have mated twice a year. Only a very small number of our vixens have shown such unusual behavior, and in 40 years, no offspring of an extraseasonal mating has survived to adulthood.

30 Nevertheless, the striking fact is that, to our knowledge, out-of-season mating has never been previously observed in foxes experiencing a natural photoperiod. Forty years into our unique lifelong experiment, we believe that Dmitry Belyaev would be pleased with its progress. By intense selective breeding, we have compressed into a few decades an ancient process that originally unfolded over thousands of years. Before our eyes, "the Beast" has turned into "Beauty," as the aggressive behavior of our herd's wild progenitors entirely disappeared. We have watched new morphological traits emerge, a process previously known only from archaeological evidence. Now we know that these changes can burst into a population early in domestication, triggered by the stresses of captivity, and that many of them result from changes in the timing of developmental processes. In some cases the changes in timing, such as earlier sexual maturity or retarded growth of somatic characters, resemble pedomorphosis. Some long-standing puzzles remain. We believed at the start that foxes could be made to reproduce twice a year and all year round, like dogs. We would like to understand why this has turned out not to be quite so. We are also curious about how the vocal repertoire of foxes changes under domestication. Some of the calls of our adult foxes resemble those of dogs and, like those of dogs, appear to be holdovers from puppyhood, but only further study will reveal the details.

31 The biggest unanswered question is just how much further our selective-breeding experiment

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can go. The domestic fox is not a domestic dog, but we believe that it has the genetic potential to become more and more doglike. We can continue to increase that potential through further breeding, but the foxes will realize it fully only through close contact with human beings. Over the years, other investigators and I have raised several fox pups in domestic conditions, either in the laboratory or at home as pets. They have shown themselves to be good-tempered creatures, as devoted as dogs but as independent as cats, capable of forming deep-rooted pair bonds with human beings—mutual bonds, as those of us who work with them know. If our experiment should continue, and if fox pups could be raised and trained the way dog puppies are now, there is no telling what sort of animal they might one day become.

32 Whether that will happen remains to be seen. For the first time in 40 years, the future of our domestication experiment is in doubt, jeopardized by the continuing crisis of the Russian economy. In 1996 the population of our breeding herd stood at 700. In 1998, with no funds to feed the foxes or to pay the salaries of our staff, we had to cut the number to 100. Earlier we were able to cover most of our expenses by selling the pelts of the foxes culled from the breeding herd. Now that source of revenue has all but dried up, leaving us increasingly dependent on outside funding at a time when shrinking budgets and changes in the grant-awarding system in Russia are making long-term experiments such as ours harder and harder to sustain. Like many other enterprises in our country, we are becoming more entrepreneurial. Recently we have sold some of our foxes to Scandinavian fur breeders, who have been pressured by animal-rights groups to develop animals that do not suffer stress in captivity. We also plan to market pups as house pets, a commercial venture that should lead to some interesting, if informal, experiments in its own right. Many avenues of both applied and basic research remain for us to pursue, provided we save our unique fox population.

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Post-Reading

Basic Comprehension

MULTIPLE CHOICE

Circle the choice that best answers each question.

1. Why does Trut believe that "[i]n many ways, though, the question of intentionality is beside the point" (Paragraph 1)?
   a. Her research group is not interested in the morphological and behavioral changes in dogs.
   b. It may be impossible and unnecessary to separate natural from artificial selection.
   c. Once wolves and humans started to live together, only artificial selection and not natural selection took place.
   d. Scientists have long ignored the question of intentionality.

2. Which trait was NOT identified by Morey as a result of natural selection operating on some dogs?
   a. The bone structure of their heads was different from that of other dogs.
   b. Their bodies did not become as large as adult wolves.
   c. They became sexually mature at a later age than did wolves.
   d. They continued to whine, bark, and be submissive as they grew older.

3. According to Paragraph 5, Bulyaev's approach to genetics was
   a. similar to Trofim Lysenko's
   b. different in 1959 from what it was in 1948
   c. more closely related to animal physiology
   d. in agreement with Darwinian ideas

4. According to Belyaev's theory, selecting for tame behavioral responses results in similar changes across widely different mammal species. This happens because
   a. in all different species, tameness is related to the control of certain chemicals
   b. all the different species have the same hormones and neurotransmitters
   c. widely different animals are from the same taxonomic groups
   d. many different species share the same set of regulatory genes

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5. What can be most strongly inferred from Paragraph 9 about defensive behavior in animals?
   a. It is more strongly affected by an embryo's pre-birth environment than by genes.
   b. It is stronger and more obvious in domestic individuals than in wild individuals.
   c. Trut and her colleagues believed it weakened as tamability increased.
   d. Trut and her colleagues believed a strong form of it helped animals reproduce successfully.

6. Which is the most likely reason why the researchers did not train the foxes used in the domestication study? (see Paragraph 11)
   a. The foxes, which came from fox farms, had already been trained.
   b. The researchers did not have enough time to train as many foxes as were used in the study.
   c. Mother foxes might reject any pups that had been trained by humans.
   d. Training by itself can result in greater tameness regardless of inherent tamability.

7. In Paragraph 14, Trut mentions foxes that ran away from the farm. What does she most strongly imply about these foxes?
   a. That they were treated cruelly during the experiment
   b. That they had originally come from the wild and wanted to return
   c. That they lacked the abilities necessary to feed and protect themselves in the wild
   d. That they were sick or injured when they came back to the farm

8. What reasons does Trut give to explain why changes in the fox population were probably not caused by inbreeding? (Paragraphs 18–20) (Choose two.)
   a. Some of the new traits would have been observed in the founding population if these traits had come from there.
   b. The fox population was so large that genetically related foxes almost never mated with each other.
   c. The new traits observed among Trut's foxes differed from those of foxes domesticated at different places and times.
   d. The researchers mated experimental foxes with non-experimental foxes from time to time.

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9. According to the reading's description of neurochemical and neurohormonal mechanisms in the experimental foxes in Paragraphs 23 and 24, which of the following is true?
   a. The behavior of domesticated foxes is not greatly influenced by neurohormones or neurotransmitters.
   b. Domesticated foxes are fatter and less energetic than wild foxes.
   c. Populations selected for domestic behaviors develop chemical characteristics different from those of unselected populations.
   d. Selecting for chemical characteristics is scientifically more reliable than selecting for behaviors.

10. According to Trut's explanation, what do loss of pigment in parts of the body, earlier eye opening, and floppy ears in domesticated foxes have in common?
   a. They are unique to foxes among domesticated species.
   b. They involve the migration of melanoblasts.
   c. They result from selecting for certain physical traits.
   d. They can be explained by changes in developmental timing.

SHORT ANSWER

Answer the questions in your own words.

1. According to the introduction, what aspect of canine domestication do evolutionary theorists have questions about?

____

____

____

2a. According to Trut's and Belyaev's theory of domestication, what selective factor causes the changes observed in domesticated species?

____

____

____

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2b. How does selecting for this factor lead to physical, behavioral, and morphological changes?

2c. According to this theory, why are the changes to different domesticated species similar in nature?

3. How is Belyaev's theory of domestication similar to and different from Morey's theory?

4. Cross out all of the following that are NOT pieces of evidence Trut uses to support her theory and explain how she uses the evidence to support her theory.
   a. behavioral signs of domestication such as friendliness and eagerness to be around humans
   b. changes to the physical bodies of domesticated foxes
   c. similarities between traits developed by unrelated groups of foxes subjected to the same conditions
   d. changes to the biochemical mechanisms of the domesticated foxes
   e. trainability of the domesticated foxes

5. Why was the future of the fox domestication experiment in jeopardy at the time the article was written?

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TEXTUAL EVIDENCE

Part 1. Put an X next to each of the questions that Trut's article answers.

____ Can silver foxes be domesticated?

____ Were dogs domesticated deliberately?

____ How many generations does it take to domesticate silver foxes?

____ Do domesticated foxes demonstrate similar traits to domesticated dogs?

____ Does selection for pedomorphic traits explain most of the tameness in domesticated horses, cats, etc.?

____ Can a wide range of changes to domesticated species result from selection for a behavioral trait?

____ Might domesticated foxes make good pets?

Part 2. Which of the questions marked with an X in Part 1 do you think Belyaev was most interested in answering? Rank them with the one being most interesting to Belyaev at the top of your ranking. Discuss your ranking with a partner or in a small group.

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Vocabulary

NEAR SYNONYMS

Read the paraphrases of some of the points Trut makes in the reading. Cross out the word or phrase in parentheses that is most different in meaning from the others. Then write a new sentence using the crossed-out word appropriately.

1. Theorists wonder whether the domestication of dogs was (drastic, deliberate, intentional, planned).

   ____
   ____
   ____

2. We are left to (bear out, consider, ponder, speculate about) what additional changes might occur to silver foxes if they continue to be bred for tamability.

   ____
   ____
   ____

3. Part of the purpose of the experiment was to determine whether observed differences between domesticated animals and their wild ancestors (are attributable to, are triggered by, interact with, stem from) selection for a behavioral trait.

   ____
   ____
   ____

4. The domesticated foxes (display, exhibit, mirror, show) friendliness toward humans.

   ____
   ____
   ____

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MULTIPLE CHOICE

Choose the word or phrase closest in meaning to the italicized words in each sentence from the reading.

1. "To test his hypothesis, Belyaev decided to turn back the clock to the point at which animals received the first *challenge of domestication*."
   a. pressure to become domesticated
   b. difficulty caused by being domesticated
   c. experiments to domesticate them
   d. physical changes due to domestication

2. "In 1948, his commitment to *orthodox* genetics had cost him his job as head of the Department of Fur Animal Breeding at the Central Research Laboratory of Fur Breeding in Moscow."
   a. conventional
   b. cutting-edge
   c. mammalian
   d. scientific

3. "Now, 40 years and 45,000 foxes after Belyaev began, our experiment has achieved *an array* of concrete results."
   a. a final conclusion
   b. a great reward
   c. a interesting finding
   d. a wide range

4. "Another, subtler possibility is that the novelties in our domesticated population are classic *by-products* of strong selection for a quantitative trait."
   a. research reports
   b. direct causes
   c. population characteristics
   d. extra results

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5. "In some cases the changes in timing, such as earlier sexual maturity or *retarded* growth of somatic characters, resemble pedomorphosis."
   a. decreased
   b. delayed
   c. earlier
   d. increased

6. "Before our eyes, 'the Beast' has turned into 'Beauty,' as the aggressive behavior of our *herd's* wild progenitors entirely disappeared."
   a. group's
   b. experiment's
   c. country's
   d. audience's

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PARAPHRASING

According to the article, "When scientists ponder how animals came to be domesticated, they almost inevitably wind up thinking about dogs." If something is *inevitable*, it always happens or is unavoidable. *Inevitably* is the adverb form. Paraphrase the sentences to use the word *inevitable* or *inevitably.*

1. It seems domestication of animals always involves physiological and morphological changes as well as behavioral changes.

   ___

   ___

2. Every fox that escaped the farm came back. ___

   ___

   ___

3. If the scientists don't receive more funding, they will be forced to shut down their experiment. ___

   ___

   ___

According to the article, "Belyaev believed that similarity in the patterns of these traits was the result of selection for amenability to domestication." If something is *amenable to* something, it is readily acted on by that thing. *Amenable to* should be followed by a noun phrase, not by a verb. *Amenability* is the noun form. Paraphrase the sentences to use the word *amenable* or *amenability.*

4. Some species seem incapable of being domesticated because they are not suited to domestication. ___

   ___

   ___

5. One behavioral difference between the domestic species *Canis familiaris* and *Felis domesticus* is that dogs submit to human orders more readily than cats. ___

   ___

   ___

6. Faced with funding cuts, some of the researchers reacted favorably to the suggestion that the lab make money by selling foxes as pets.

   ___

   ___

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Reading Focus

Putting Reading to Work

COMPLETION

Lyudmila Trut's article describes a number of morphological, physiological, and behavioral differences between her experiments on the domesticated foxes and other foxes. In Column A, write a sentence describing the difference in each category listed. All the information can be found in the reading. In Column B, write an explanation of how the changes might support Morey's and/or Belyaev's theories. This information can also be found in the reading, but it may be stated indirectly or implied. In Column C, write at least one question that still remains and keeps Belyaev's theory from being confirmed. These questions may not be directly or indirectly stated in the reading but will come from deep understanding and analysis of the text. The first set has been done for you as an example.

A. Differences between domesticated foxes and farmed or wild foxes	B. How these differences support Morey's and/or Belyaev's theories	C. Questions that are not answered by these findings
Behavior: *The domesticated foxes are tame and seek to please humans and to receive human attention.*	*This behavior includes whining, submissiveness, and pedomorphic traits, which could support Morey's theory. It is also behavior that is influenced by changes to developmental mechanisms, which could support Belyaev's theory.*	*Would similar behavior emerge if species taxonomically more different from dogs were selected for tamability?*
Development in early life:		

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A. Differences between domesticated foxes and farmed or wild foxes	**B. How these differences support Morey's and/or Belyaev's theories**	**C. Questions that are not answered by these findings**
Appearance:		
Biochemical mechanisms:		
Reproduction:		

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DISCUSSION

Share your questions from Column C with a partner or in a small group. Decide the top five outstanding questions that remain to be answered before Belyaev's theory can be confirmed. Then design an experiment that would answer as many of these questions as possible.

FOLLOW UP

In her conclusion, published in 1999, Trut stated that the future of the silver fox domestication experiments were in jeopardy. Do some research and answer one of the questions. Your answer could be given in writing or as a presentation in class.

1. What happened to the foxes used in the study or their descendents? How does this relate to points made in Trut's article?
2. Have Trut and her colleagues continued their domestication research? How do recent findings relate to the findings published in the article?
3. How has research by other researchers confirmed, expanded on, or refuted Trut's findings?

Integrating Information

The readings in this unit have discussed ways in which species can be altered so they possess traits useful to humans. Trut's article focused on a process for domesticating a wild species, while Pollan's piece focused on issues surrounding genetic engineering of an already domesticated species and increased corporate control over agriculture.

Companies are looking for new ways to produce food while reducing the toll human food production takes on the environment. Some are attempting to domesticate wild species prized by humans as food, such as the bluefin tuna. Others are adding genes to make crops like rice more nutritious or more hardy.

WRITING

Do some research about one such attempt to genetically modify food. Use one or two reference sources to write a paragraph explaining how issues raised in this unit are related to that attempt. You may use print or online sources.

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