1.2 The Nature of Classification

Classification systems are extremely useful. Everyday classification is simply the grouping together or sorting of items into various categories based on some set of criteria.

In everyday life we use, and are surrounded by, many classification systems. In an online music store, for example, digital recordings may be classified according to the many styles of music: classical, jazz, rock, country, hip hop, rap, and so on. Within a category, items can be further divided into subcategories. Rock music might be further divided into indie rock, rock and roll, progressive rock, heavy metal, and so on.

Figure 1 Sorting and classification systems are used often in everyday life, such as in the supermarket.

Classification systems serve many purposes (**Figure 1**). They are very convenient, making it easy to find what you are looking for when shopping, looking for files on your computer, using the Yellow Pages of a phone book, or performing searches on the Internet. Classification systems are also a source of information and a tool for communication—how an item is classified tells you something about the item. You might expect a menu item listed as a dessert to be sweet. Similarly, you know that food listed as seafood came from the ocean. Defined categories show the relationships among items.

Scientists also use classification systems. By using the same classification systems, scientists can share ideas more easily. In chemistry, elements are carefully arranged in the periodic table into families. Chemists classify substances as metals and non-metals, and as acids and bases.

biological classification the systematic grouping of organisms into biological categories based on physical and evolutionary relationships

In biology, organisms can be classified in many ways. The systematic grouping of organisms into categories on the basis of defined criteria is called **biological classification**. Familiar and ecologically important categories include producers, herbivores, carnivores, and scavengers (**Figure 2**). For example, when a biologist describes a massasauga rattlesnake as a carnivore, other biologists immediately know what that means.

Figure 2 Scientists often classify organisms according to their role in ecosystems: (a) kelp is a producer, (b) a sea urchin is a herbivore, (c) a massasauga rattlesnake is a predator, and (d) a vulture is a scavenger.

Classifications are useful in our everyday lives and for scientists. But how are they established? How do you choose a classification system for a particular use? How can you efficiently and accurately group items into chosen categories?

Mini Investigation

Creating a Classification System

Skills: Questioning, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1

Several steps are involved in creating a classification system. First, you must clearly identify each species. You must then select categories that will help you sort the species, based on the end use of your classification system. In this activity you will work in a small group to create a classification system for a variety of living things.

1. Have each member of your group brainstorm a list of 10 species of plants and animals that have been domesticated by humans.
2. As a group, decide on a set of categories into which you will sort or classify your species. Think of an underlying rationale for your categories. For example, you might want to distinguish between species used in agriculture and species found in the home.
3. Work with your group members to sort your species into your chosen categories.

A. Did you have difficulty deciding on your categories? If so, explain the challenge. T/I

B. Did you have difficulty deciding which category a particular species should be placed in? Did some species seem to fit into more than one category? T/I

C. Exchange your list of species and categories from Steps 1 and 2 with another group. Now redo Step 3 using their 10 species and their chosen categories. When you are done, compare your results. Did everyone agree on how to sort species in a set of the chosen categories? T/I

D. Do you think you could fit any domesticated species into your categories? Explain why or why not. T/I C

E. Do you think there might be one "best" classification system for species? Explain your reasoning. T/I C

Taxonomy—Developing a Classification System

The best criteria to use for classifying organisms depend on the purpose of the classification system. For example, a tourist in Costa Rica might be very interested in bird watching. It is essential that a mushroom picker know which varieties of mushrooms are poisonous (**Figure 3**). It might be useful for all members of the public to recognize invasive species.

Although these specialized classification systems are essential for particular purposes, biologists need a more general classification system that they can use to organize all living and fossil species. **Taxonomy** is the science of identifying and classifying all organisms. With millions of species living on Earth, and countless extinct species, taxonomy is a challenging science. Taxonomy is also referred to as the "Science of Systematics."

Figure 3 The "death angel" is one of many species of poisonous mushrooms.

taxonomy the science of classifying all organisms; taxonomists classify both living and fossil species

The Need for Identification

Before you can classify objects or species, you must be able to identify them. One way biologists identify organisms is by observed characteristics—morphology, behaviour, and even geographic location.

You might think that it is easy to recognize species—after all, no one would mistake a dog for a cat, a giraffe for an elephant, or a maple tree for a pine tree. Surely a specialist can tell even the most similar-looking species apart? Or can they? For some categories, there are thousands of species! **Table 1** shows some species numbers.

To make matters even more challenging, individuals of the same species are variable—males differ from females, and individuals change in appearance as they grow (**Figure 4(a)** and **(b)**). Different populations of the same species can also vary, exhibiting striking differences from one location to another (**Figure 4(c)** and **(d)**).

Table 1 Species Variety

Category	No. of species
Ontario mosquitoes	> 50
fish of Lake Malawi, Africa	> 1000
wasps	> 100 000
seed-producing plants	> 260 000

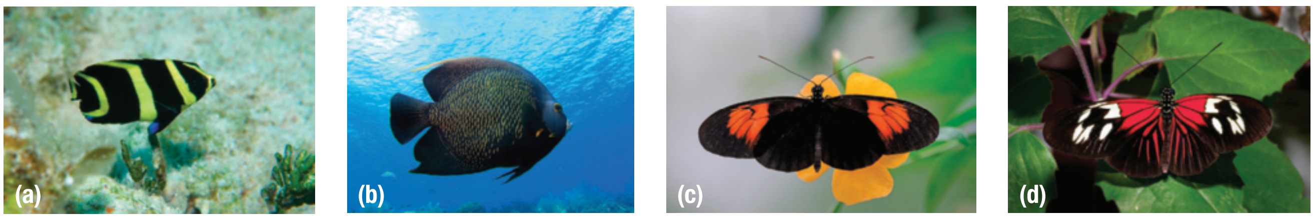


Figure 4 The juvenile (a) and adult grey (b) angel fish are the same species but do not appear similar. These passion-vine butterflies, (c) and (d), belong to the same species, but inhabit different geographic ranges. They have evolved different wing coloration.

Another challenge is that species also evolve over time. Evolutionary change is usually slow and gradual, happening over thousands or millions of years. It must be considered by taxonomists studying the fossil record. It must also be considered by taxonomists studying species that are known to undergo more rapid evolutionary change. For example, evolutionary changes in many micro-organisms can happen over months or even days.

Today, biologists have powerful new tools to use in taxonomy. Every species and most individuals of sexually reproducing species have a unique and characteristic set of genetic instructions in their DNA. Unfortunately, it is not always possible, and not often practical, to try to identify organisms in the field by sampling and examining their DNA. However, with advances in technology, this may soon change.

Early Biological Classification Systems

Many animals that are of direct interest to humans are relatively easy to identify. The same is not true of plants. Many plants look quite similar, and when not in flower can be quite difficult to tell apart. Many plants are also toxic. It is therefore not surprising that the skills of the shaman and other Aboriginal healers depended on their ability to identify and classify plants. The earliest written record of plant names dates back to Ancient Greece, more than two thousand years ago. Today, scientists who specialize in the study of plants are called **botanists**. Botanists study over a quarter of a million species of living organisms.

botanist a scientist specializing in the study of plants; also called a plant biologist

Early names and classification systems were extremely variable. Species were given different names in every language, and there were no agreed-upon criteria for the basis of a common classification system. Biologists, and botanists in particular, wanted to create a system based on a clear set of rules and a rationale that could be applied to all living things.

The first challenge was to develop a scientific name for each species. The everyday or "common" names for species are not always helpful. For example, Europeans and North Americans use the common name "robin" for two different species of birds.

Figure 5 Linnaeus gave the briar rose the scientific name *Rosa canina*.

Carl Linnaeus

Swedish naturalist Carl Linnaeus (1707–1778) is considered the "father" of taxonomy. He introduced a consistent way of grouping species according to their morphological (or physical) similarities. He also established a naming system that is still used today.

Linnaeus considered species to be distinct types of living things that could be grouped into categories called **genera** (singular: genus) according to shared characteristics. This was not a new idea, but previous systems of grouping were often quite arbitrary—for example, placing all farm animals, or all water animals, in the same genus. Linnaeus based his groupings on similarities among the organisms themselves, not on an external relationship such as where they lived.

genus a taxonomic level consisting of a group of similar species

Before Linnaeus, naming practices varied widely. It was common for species to be given one or more long descriptive names. For example, the briar rose (**Figure 5**) was named both *Rosa sylvestris inodora seu canina* (the odourless woodland dog rose) and *Rosa sylvestris alba cum rubore, folio glabro* (the pinkish white woodland rose with smooth leaves).

Linnaeus felt that each species should have a unique name. While he made use of long descriptive names at first, Linnaeus decided for convenience to also assign to each species a binomial (two-word) short-form name. His short name for the briar rose was *Rosa canina*. Using Linnaeus's binomial naming system, the first name is the genus name (*Rosa*) and the second name is the specific name (*canina*). Taken together, the two words form the species name—*Rosa canina*. This **binomial nomenclature** system is now the formal system used to name species.

binomial nomenclature the formal system of naming species whereby each species is assigned a *genus* name followed by a *specific* name; the two words taken together form the species name

Although the classification criteria Linnaeus chose were often flawed, his simple and convenient binomial naming system was a major improvement and quickly became standard. Species in the same genera could be expected to have similar characteristics. As a result, knowing the names of two species, such as *Ursus americanus* (black bear) and *Ursus maritimus* (polar bear), told you that that these species likely share many characteristics. On the other hand, a species of a different genus, *Phascolarctos cinereus* (koala), likely does not share as many features with the *Ursus* genera. In this case the koala "bear" is a marsupial with a dramatically different anatomy and is more closely related to kangaroos than to true bears.

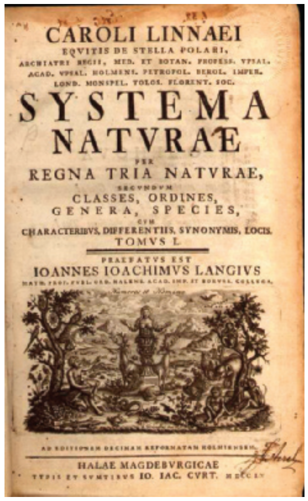


Figure 6 In the first edition of his book *Systema Naturae* (1735), Linnaeus grouped species and genera into orders, classes, and kingdoms.

The Great Chain of Being

Many early classification systems were based on the philosophical assumption that each type of organism held a fixed position, or rank, on a scale from lowest to highest. Humans were positioned at the top, mammals and birds were above frogs and fish, and all animals were above plants. This hierarchy, referred to as the Great Chain of Being, or the *scala naturae*, resulted in very complex plants being positioned below even the simplest animals—an orchid below a flatworm or hydra, for example (**Figure 6**). The philosophy also entrenched the notion that species were fixed, unchanging over time. Many scientists were very reluctant to abandon this belief, even as strong evidence mounted against it.

Later in life, Linnaeus was among the first prominent biologists to doubt this fixed nature of species. He theorized that new species might arise through hybridization and that plants might change as they became acclimatized to new environments.

Traditional Taxonomic Levels

Linnaeus further grouped species into taxonomic ranks, or levels, based on shared characteristics. Each level is called a **taxon** (plural: taxa). Linnaeus's original system consisted of five taxa and was later modified to include seven major levels: similar species were grouped into genera, similar genera into families, similar families into orders, orders into classes, classes into phyla, and phyla into the highest taxonomic level—**kingdom**. Linnaeus placed all organisms into just two kingdoms: plants and animals. At that time all algae and fungi were considered plants. **Table 2** illustrates how four different organisms can be classified using this system.

taxon a category used to classify organisms

kingdom the highest taxonomic level of the traditional Linnaean system of classification

Table 2 Traditional Taxonomic Ranks of Classification

Taxon	Human	Walrus	Bald eagle	Honey bee
kingdom	Animalia	Animalia	Animalia	Animalia
phylum	Chordata	Chordata	Chordata	Arthropoda
class	Mammalia	Mammalia	Aves	Insecta
order	Primates	Carnivora	Accipitriformes	Hymenoptera
family	Hominidae	Odobenidae	Accipitridae	Apidae
genus	*Homo*	*Odobenus*	*Haliaeetus*	*Apis*
species	*Homo sapiens*	*Odobenus rosmarus*	*Haliaeetus leucocephalus*	*Apis mellifera*

LEARNING TIP

Naming Species
The first word of a binomial species name is always capitalized. The second word is always lowercase. Both words are printed in italics. The names of other taxonomic levels are normally capitalized. Binomial species names can also be abbreviated. For example, *Homo sapiens* can be written *H. sapiens*.

In the Linnaean system, each taxonomic rank consists of species that have similar features. For example, all species in the phylum Chordata have a backbone or a primitive backbone. Similarly, all members of class Mammalia are warm-blooded and feed milk to their young.

In an effort to further refine the classification of more than one million species, taxonomists have created many intermediate taxonomic levels, such as superorders and subfamilies.

Dichotomous Keys

Figure 7 *Blarina brevicauda* is the only poisonous mammal in Canada. Its venomous bite is not dangerous to humans but can be painful!

dichotomous key a series of branching, two-part statements used to identify organisms (or objects)

Classifying organisms into various taxa with defined criteria provides a framework for identifying organisms. Imagine that you present a taxonomist with a small woodland animal. The taxonomist notes that the animal has four legs and is hairy, so it must belong to the class Mammalia. Its teeth are sharp and needle-like, its eyes are very small, and it has no obvious ears. These features belong to the Order Insectivora, which includes the common shrews and moles. Based on the animal's size and limbs, the taxonomist determines that is it likely a shrew in the Family Soricidae. With even more detailed examination and measurements, she classifies it as a short-tailed shrew, *Blarina brevicauda* (**Figure 7**). You look up the species on the Internet and discover that it is very common in Ontario and is an important member of forest ecosystems. It is also one of the only poisonous mammals on Earth! But what if you want to make the identification yourself, or what if even the expert was not familiar with the characteristics of the particular group of organisms?

Biologists use dichotomous keys to help them identify organisms. A **dichotomous key** is a structure in which a large set of items is broken down into smaller subsets, ultimately leading to the smallest available classification unit (**Figure 8**). At each step in the identification process, the user must choose between two defining statements. Each alternative leads to a result or another choice. Eventually, the key ends with the classification of the organism into a given taxonomic level. As illustrated in Figure 8, a dichotomous key identifies an organism based on the presence or absence of carefully chosen characteristics. These keys can take different forms.

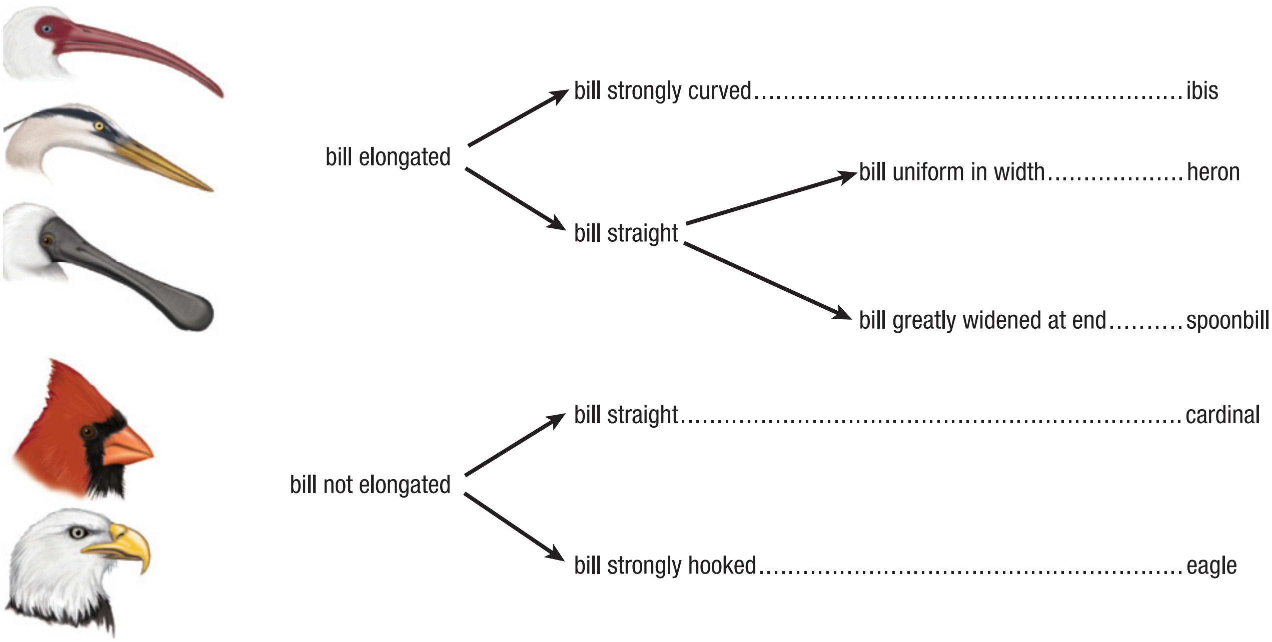


Figure 8 A dichotomous key for classifying birds.

The dichotomous key above provides an easy method of identifying these five bird species. In practice, however, most dichotomous keys used by scientists are more difficult to construct and use. In order to distinguish between each of the thousands of different bird species—there are more than 60 different species of herons alone—the keys must use more detailed criteria. Before scientists construct the key, they must agree on the features that distinguish each species. They must also learn the terminology used to name and describe these features.

Creating and using dichotomous keys to classify other groups of organisms can be even more challenging. For example, many plants can be distinguished from each other only by a dissection and close examination of their flower parts, and this can be done only at certain times of the year. Even with the flowers in hand, scientists need expertise to use a dichotomous key. The glossary of a well-known plant key of North American plants includes more than 800 technical terms, beginning with terms such as *abaxial*, *acaulescent*, *accrescent*, *achene*, and *achlamydeous*.

A key challenge that traditional taxonomists face is deciding and agreeing on what criteria to use to define each taxon. What feature or features should be used as the basis for including one species while excluding another? The choice of criteria is often hotly debated. As a result, there is often significant disagreement about the arrangement of species within taxa.

Once the features to be used in a dichotomous key are chosen, another challenge arises—these features may be difficult to observe. Internal anatomical and physiological similarities, for example, are considered more significant than outward appearances, but they are not always easily observed. For instance, the horseshoe crab has crab-like legs and pincers, but its blood chemistry and internal structures indicate that it is more closely related to spiders than to true crabs (**Figure 9**).

Also, decisions are often influenced and limited by available information, as well as by the interest in a particular group of species. For example, the approximately 9000 species of living birds are traditionally classified into some 160 different families (**Figure 10(b)**). In contrast to this very well studied group, more than 60 000 species of parasitic wasps have been placed in a single family—the Ichneumonidae (**Figure 10(b)**)! Such a dramatic difference highlights some of the challenges and limitations of using classification systems.

Figure 9 Despite its name, the horseshoe crab is more closely related to spiders than to true crabs.

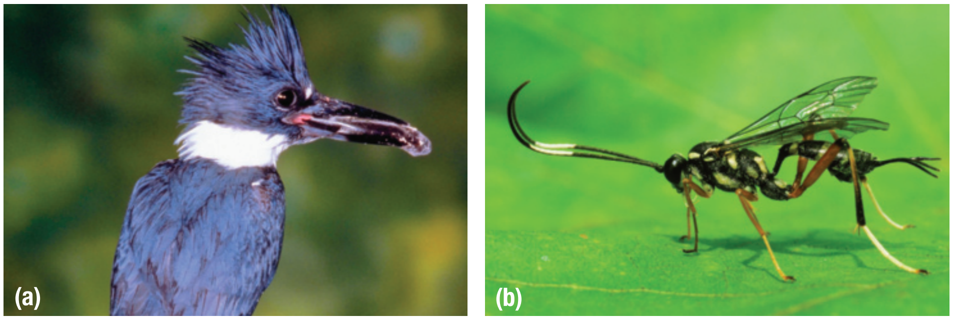


Figure 10 (a) The average bird family taxon contains approximately 50 species. The belted kingfisher is one of only nine species in the family Cerylidae. (b) This wasp is one of more than 60 000 species in the family Ichneumonidae.

As you will learn in the next section, most modern taxonomists no longer use similarity as the basis for grouping organisms. Instead they use the principle of relatedness, which is based on the evolutionary history of a species. This new approach has significant advantages, but many biologists still use the traditional and familiar classification system.

Investigation 1.2.1

Using and Constructing a Dichotomous Key (page 32)
Now that you have read about dichotomous keys, you can complete Investigation 1.2.1.

In this observational study, you will use a dichotomous key to classify fish, and you will create a dichotomous key that can be used to classify insects.

1.2 Summary

- Classification systems are useful, but extremely variable.
- The science of classifying living things is called taxonomy.
- All species are given a unique binomial (two-word) species name.
- Traditional taxonomy groups species together according to shared characteristics.
- Scientists often disagree about the criteria used to group species.
- Traditional taxonomy groups species into a number of major levels, or taxa.
- Dichotomous keys are often used to help identify species.

1.2 Questions

1. Describe four classification systems you have used in the past week. How did they help you? K/U A
2. What is taxonomy? Explain how taxa are arranged in a hierarchy. K/U
3. Use a graphic organizer of your choice to describe the key contributions of Linnaeus to the science of naming and classifying species. Include the term “binomial nomenclature.” K/U C
4. Describe the philosophy behind the *scala naturae*. K/U
5. Use the information in **Table 3** to answer the following questions: K/U T/I
   (a) Which two species would you expect to share the greatest number of features?
   (b) Which species would you expect to be least similar to all others?
   (c) What evidence is there that otters share more features with mink than dogs do with cats?
   (d) Predict some probable characteristics of *Alopex lagopus*.

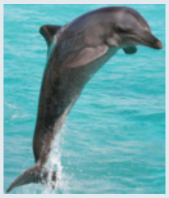
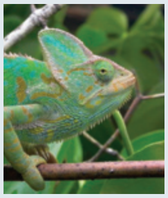
Table 3

Common Name	Order	Family	Scientific Name
orca	Cetacea	Delphinidae	*Orcinus orca*
river otter	Carnivora	Mustelidae	*Lontra canadensis*
mink	Carnivora	Mustelidae	*Neovison vison*
Siamese cat	Carnivora	Felidae	*Felis domesticus*
Labrador retriever	Carnivora	Canidae	*Canis lupus*
	Carnivora	Canidae	*Alopex lagopus*

6. Conduct online research to find out the common name of *Alopex lagopus*. Were your predictions correct? T/I
7. Research the following taxa and answer the questions below.
   (i) Cestoda
   (ii) Cervidae
   (iii) Euphorbia T/I C A
   (a) What is the taxonomic level of the group (phylum, class)?
   (b) What are their key distinguishing features—what criteria are used to define the group?
   (c) How many species are in the group? Provide a few examples.
   (d) Describe the ecological role of the group and any specific relationships to humans.
8. Traditional biological classification systems group species according to shared characteristics. K/U T/I C
   (a) Consider some of the important and obvious characteristics of the species in **Table 4**. Describe some of the problems you might encounter when trying to decide which characteristics to use for grouping.
   (b) Which characteristics would you use for classifying these species? Why?
   (c) Based on your choices, construct a dichotomous key for these species.

GO TO NELSON SCIENCE

Table 4

					
• warm-blooded • hairless, smooth skin • four-chambered heart • swims using flippers and tail flukes • live birth	• warm-blooded • some hair • four-chambered heart • walks on two legs • live birth • no tail	• warm-blooded • feathers • four-chambered heart • walks on two legs • flies • lays eggs • short tail	• cold-blooded • scales • three-chambered heart • walks on four legs • lays eggs • swims using its tail	• cold-blooded • scales • three-chambered heart • walks on four legs • prehensile tail • lays eggs	• warm-blooded • covered in hair • four-chambered heart • no tail • live birth • four limbs used on land and in water