Drawing as a Way of Looking at the Natural World

The best way to study an arthropod or plant is to draw it. That is the opinion of Barrett Klein, who combines his training in both art and entomology in his work as a preparator and display maker in the Exhibition Department at the American Museum of Natural History.

"I think the best way for any scientist to understand his or her science is through visualization," Barrett told us. "Close observation is the first step in any scientific inquiry, and to my mind, there is no better way to observe than to try to draw what you are looking at."

Barrett described an experience in college to explain what he means. "One of my favorite studies is morphology—the shape of a creature. A college course in insect morphology perfectly fused science and art for me. We each were assigned to choose an organism—mine was a species of longhorn beetle—and to do everything we could to understand its anatomy, its morphology, its external and internal structures. That meant we had to do a lot of collecting, dissecting, and viewing under a 3-D microscope." For Barrett, the process was one of discovery. "What I saw when I looked at these beetles under a 'scope, or even when I held them in my hands, was so beautiful. But it was even better when I began to draw. Even if you are a poor artist, when you take pencil to paper and just draw the line—not even the shading—you begin to appreciate each structure and understand it better."

Barrett regards drawing as an important tool for learning. "I will memorize anything better if I write it down or, better yet, if I draw it. A single sketch is more important to me than a page of notes. Even if it's just a scribble, when I look at it later, what I was seeing at the time will click back into my mind three dimensionally." Try it and see if the same thing happens for you, he suggests.

Sally Goodman, who does highly detailed and realistic drawings of arthropods as part of her job as a curatorial assistant in the Entomology Department at AMNH, agrees with Barrett on the importance of observation.

"The basic materials of scientific illustration are paper and pencil," she said, "but a good eye is the most important tool of all. Some people think that drawing is just about using your hands, but it is really about using your eyes. You need to look and you need to really see. Sometimes people who have trouble drawing are not really seeing things that are there."

We asked Sally how to solve that problem. "The best way is to learn what to notice, to learn about the thing you are drawing—a plant, an arthropod, whatever it is—so you know what you should be looking for and what, when you see it, you are looking at. For example, the organism could have legs in a very particular place. Learning the parts of the organism and how it is put together is the first step. If you know that, you'll look for it, and if you see it, you'll be able to draw it."

Aside from studying the organisms you are most likely to encounter, Sally thinks it is a good idea to study the drawings other people have made. "One of the best ways I know to learn how to do something is to observe how others have done it." Art students study the work of other artists; students who want to illustrate plants and arthropods should do the same.

Sally also suggests taking the time to observe. "In the beginning, pay a lot of attention. Don't even draw until you have observed and thought about the details of what you are studying."

Both Sally and Barrett recommend beginning simply with paper and pencil. Barrett uses various leads, ranging from hard to very soft. Pen and ink, and even colored pencils and watercolors, can be added later, but many beautiful and informative scientific illustrations are all in black and white. A stereomicroscope (which has two viewing lenses and offers a three-dimensional view of the specimen) is a wonderful tool for drawing, they said, but if you do not have access to one, a strong magnifying glass and a bright light are helpful.

They both agree that a good and useful drawing can be done even if you do not think you have the talent or skill. "I think people get hung up on their fears," Sally said. "I believe everyone can draw, and that it's really a matter of patience and practice. Begin that practice by rendering what you see as best you can."

Barrett suggests starting with the form of the organism, a quick line drawing of the outline. "Pay attention to proportion," he advised. "If you want to represent something accurately, the size of the various parts in relation to each other is important."

Sometimes drawings are done of specimens viewed under a microscope; sometimes they are done in the field. Some stereomicroscopes have a grid in one lens. "When you look with both eyes, the images fuse so you see the grid over the organism, and then you can draw the specimen square by square," Barrett explained. When drawing in the field, he suggested using your thumb as a portable measuring stick: "Hold up your thumb and sight along it with one eye to the thing you are looking at. Say the bee resting on that flower is as long as the tip of your thumb to the knuckle, and the wings are about the size of your thumbnail. You can translate those proportions to your sketch pad."

"The basic materials of scientific illustration are paper and pencil, but a good eye is the most important tool of all."

When drawing a preserved specimen viewed under the microscope, you have time and the opportunity to focus on the tiniest details. In the field, the best approach depends on the circumstances, Barrett said. "Is your subject stationary, or is it in motion? If you're looking at something that will be there for a while—a flower in the middle of the field, for example—I'd take some time. First do a quick overall sketch, then firm up the outline, and then fill it in. You can add color, if you want, and the finer details later, when you get back inside." If there happened to a bee on the flower, Barrett noted, "I'd quickly draw its position, or any other thing that represented its behavior, so I could fill in that detail later, too."

If conditions in the field are changing—if the sun is setting or an ant is rushing past, for example—you need to be fast. "Just do a quick sketch—it might be little more than a scribble—and make a note about color in terms you will understand later. Say it was a sort of a burnt umber or an egg yolk color," Barrett said.

Speaking of the setting sun, Barrett told us that it is customary in scientific illustration to draw specimens as though the source of light is coming from the upper left. "If you use shadows or techniques such as stippling to give your specimen a three-dimensional look, be sure to imagine light coming from that direction so everyone will understand what he or she is seeing," Barrett advised.

Taking a photograph in the field often helps, especially if your subject is fleeting, but Barrett says it is no substitute for a detailed drawing. "Photographs have a very narrow depth of field, especially with small objects," he explained. "One plane will have high resolution—you'll get clear details—but the rest will be a blur." The best thing is to have both a sketch and a photograph to take back with you.

In Barrett's opinion, "Illustration beats photography because you can pick out important details and make all the key points visible." These points can be emphasized in many ways: with darker or bolder lines, with arrows, or even with circles to highlight important features.

Barrett gave us a fascinating example of how a drawing can show a plant-insect interaction in a way that a photograph never could.

"There is a species of fly that lays a single egg inside the stem of the goldenrod. As the larva develops, it starts eating the stem. But instead of weakening and dying, the plant has a defense. It creates a huge stable structure called a gall, a bulbous swelling on the stem. The gall strengthens the stem, but it also serves as a protective home and food source for the insect until it pops out as an adult.

"Now, there is no way you could show that effectively with a single photograph, but in an illustration you could draw a composite that shows what the plant looks like on both the outside and the inside. You would draw a ragged edge to divide the illustration, with a cross section revealing the insect larva inside the gall."

Drawings like that offer a unique experience: a way to look at, and into, the natural world.

Keeping a Field Journal 1

All scientists who work in the field keep a field journal. In it they record everything they find, observe, and collect. No matter what kind of science they are doing—whether they are studying plants or arthropods, mammals or fish, individual organisms or interactions between organisms—their journals contain the evidence on which all of their work is based. The journals scientists keep become the property of the museum or other institution for which the study was done. They are kept so other investigators can use them as references, sometimes many years later.

You will be asked to keep a field journal. It is not quite like a personal diary you might write in at home, or even as an exercise at school, but it is not busy-work either. It will contain your evidence, and perhaps it will become part of the class or school library, to be used as a reference by others.

To find out how, and why, to keep a field journal, we asked an expert: Eleanor Sterling, an anthropologist who has done fieldwork and kept field journals in Africa, from the rain forests of Madagascar to the savannas of Tanzania.

"Field journals are incredibly important," she told us. "Basically you can't do science without them." We asked her to elaborate.

"When I first went out into the field, I thought it wasn't very important to take notes, because I wasn't collecting data, I was just looking for a site. I wrote down things occasionally but not rigorously. Besides, the things I was seeing were so amazing that I was convinced that I would remember them for the rest of my life. But the truth is that so many things crowded my brain that I couldn't remember them all, and some of what I couldn't remember turned out to be very important. For example, when I got home, I couldn't remember whether a little baby animal we had seen had his eyes open or closed. Now that makes a huge difference if you want to figure out when the baby was born. Later, when I was working on other research, suddenly that little piece of information would have been very valuable . . . but I didn't write it down!" She laughed. So the moral is: No matter how trivial an observation or piece of information seems, write it down.

But how can you write down everything? we asked.

"You can't write down everything, it's true," Eleanor told us. You have to figure out what basic things are important and then, through trial and error, you begin to know what kinds of information you need for your project. "You will probably find that you've left out some important data that you really could use. Chalk it up to experience, and take more complete notes next time," she advised.

Here are some tips from Eleanor on keeping a field journal:

1. Use a well-sharpened pencil.

2. Begin each field session by writing down these basics:
   - site name/location
   - plot name/number
   - group name
   - date
   - time of day
   - temperature
   - weather conditions: for example, is it cloudy, sunny, windy, raining?
   - wind conditions
   - soil conditions: for example, is it moist or dry?

3. Record your observations. Some things to consider recording are:
   - if there are fruits or flowers on individual trees or plants in your site
   - if you observe any kinds of interactions among insects, like mating or fighting, or between insects and plants, like feeding and pollinating
   - if you see any changes from the last time you were there

4. If things are happening so quickly that you do not have time to get everything down, try developing a coding system—what scientists call an ethogram—to help you make notes quickly. For example, Eleanor assigns a number to each of a range of typical behaviors, and when she observes one of those, she just writes down the number. It makes taking notes on the run much easier. You can make up your own ethogram to suit your site and the kinds of things you want to observe and record. Just be sure to make, and keep, a key so anyone who reads the journals knows what the numbers stand for!

   Some typical arthropod behaviors you might observe are:
   - feeding
   - fighting, including aggression and defense
   - building
   - reproduction
   - caring for young

5. When you get back to class or, later, when you get home, read over your notes and underline or use a highlighter to mark the really important things. You might want to color-code them so observations or data in the same category are all one color.

6. Do not lose your field journal. Put your name and class number, and the name, address, and phone number of your school on your notebook.

Losing a field journal is every scientist's nightmare, Eleanor said. "You just can't reconstruct all the data, so it's really a disaster when it happens." She told us some stories about journals lost and found.

She once found another scientist's journal in a marketplace in Madagascar, where paper is very scarce and very valuable. It was being sold page by page, and fortunately, the merchant had started ripping out pages from the back, where they were still blank. Eleanor recognized the journal and knew to whom it belonged, so she bought the entire book and mailed it back to its owner. "I have a friend for life," she said.

Then there was the time she was in Tanzania, studying baboons. "The little baboons would come up to me all the time, and anything I put down beside me would be gone. They'd snatch whatever it was, as if to say, "Oh, this is cool,' and head off with it into the forest. What I ended up doing was putting a string through the spine of the notebook and attaching it to my belt, sort of like a leash, so if an animal made off with it, eventually it would stop." She also wore her pen or pencil on a string around her neck. That way, if she needed her hands free in a hurry, she could drop everything and not worry about losing it.

A strategy like that might have saved another scientist Eleanor knows from some unpleasant mucking around. She had her notebook in her pants pocket when she made a visit to the outhouse. To her dismay, the book fell out of her pocket and into the hole. Knowing what you know about the importance of field notes, you will not be surprised to learn that the scientist retrieved the notebook, but, as Eleanor said, "It wasn't a pretty sight!"

How you record data is a mixture of formal requirements and your own needs and skills.

Field journals end up being very personal. It may take some trial and error before you come up with the way that works best for you.

A formal field journal, the type Eleanor Sterling and other Museum scientists keep, has three parts:

- A diary-like account
- A field catalog consisting of a list of specimens, with a number assigned to each one. Specimens found in the field are tagged and numbered to correspond to the catalog
- A species list, which includes all specimens by number, along with the site and date of collection, the name of the collector, and any remarks

The field catalog and species list are compiled back in the lab, often in separate notebooks. For your project, they will be entered into the computer and posted on-line.

Some scientists write everything—measurements, data, observations, specimens collected—on the same page; others record some of this information—specimens collected, for example—in a list at the back of the journal. Eleanor divides her page vertically, with the main part reserved for recording data and a narrower area running down the side for scribbling questions, ideas, sketches, hypotheses, and things to look up back at school or in the library. Some scientists make sketches or drawings; some do diagrams or graphs or flowcharts.

Keeping a Field Journal 2

If you sit in Brian Boom's office at the New York Botanical Garden, you will see a shelf of field journals, their spines labeled with the year and the specimen numbers each includes. When he pulls out a dried and mounted specimen from his collection, it is an easy matter to find the exact page of the specific field journal with the notes he made when he originally found the specimen. The specimen number is written in the left-hand margin, and it is the same number as can be found on the mounted specimen's label. In fact, all of the information on the label can be found in the journal entry.

"That's where the label data come from," Brian explained. "Everything on the label is in the journal, but everything in the journal does not necessarily make it to the label." The field journal is a continuous record of everything collected, arranged in numerical order.

Brian recommends recording everything you observe, both the standard things—such as date, elevation, location, and so on—and the fleeting things—such as the color and smell of the plant along with any plant-animal or plant-insect interactions you observe. Although he advises students to take only specimens from whole, living plants for study, he says that notes about any fragments you find—acorns, pinecones, seeds, and other plant parts—should be included in the journal.

Brian makes rough sketches of such things as his site in his field journal, and he takes photographs of living specimens. "I don't have the skills to draw specimens—that's why I use a camera—but there are botanists who do beautiful drawings, and all the rest of us are jealous of them," he admitted.

"The field journals are permanent records," he said. "They are one of the great resources of museums and institutions like the New York Botanical Garden." Brian keeps his in his office, but they will eventually end up in the NYBG archives, where other botanists will be able to consult them.

Selecting a Site

How do working scientists pick a site for study? We asked a number of scientists what they think about when looking for a site. Here's what they all said: It depends what you want to know. Everyone we talked to emphasized that all research starts with questions. What those questions are helps determine where you look for answers.

For example, Eric Quinter, Senior Scientific Assistant in the Entomology Department at the American Museum of Natural History, told us: "I have to know what my project is, what question I'm trying to answer. Am I looking for a particular insect, or am I studying a habitat? If I'm looking for a particular insect, I have to know what it eats, and then I go looking for that plant. Recently, though, I've decided to change the way I look for a site. Instead of trying to track down an insect that we know about by going where someone has seen it before, I'm going to look at a niche and see what's there. For starters, I'm going to select some of the large native grasses that seem like potential hosts. I'm going to begin with an assumption that something eats them, and then I'm going to look and see what it is."

Don't be afraid to ask questions.

"If I don't know where a particular habitat is," Eric told us, "I just ask local people: 'Hey, where's a good place to see a nice pine savanna that has some marshland on the perimeter?' or whatever. If I'm looking for a particular plant that I know my target insect eats and I don't know where to find it, I'll go talk to some botanists and ask them."

Choose a place you can get to for long enough or often enough to get the information you need.

That is a good idea in general, even though some of the scientists we talked to chose sites that were in faraway and challenging places. Eleanor Sterling, Program Director for the Museum's Center for Biodiversity and Conservation, wanted to study the aye-aye, so she had to go to Madagascar, the only place where the tiny primate is found. She spent two years on a small, steep-sloped island off the east coast of Africa and learned more about this endangered animal than anyone had ever known before. But, she said, it was hard.

"Aye-ayes come out only at night, so no one had been silly enough to plan a two-year trip to study them. Reasonable people had told me that it was too difficult a project. I remember sitting myself down about four months into the project and thinking about what I was going through. I thought to myself that if somebody had explained to me before I started what this was going to be like, I might never have done it. But there was something about all those people telling me, 'You can't do it,' that made me just say, 'I'm going to do it,' and I did, and I'm glad."

Brian Boom, Vice President of Botanical Science and the Pfizer Curator of Botany at the New York Botanical Garden, studied trees in the Bolivian rain forest, but convenience was a factor in his choice of a site. “I decided that, for what I was trying to do—which was to get a sampling of plants in an intact forest—I would choose a site within a thirty-minute walk along the trail from the village.” He came up with the thirty-minute figure because it was close enough to the village that he could get to it easily but far enough away from the kind of human activity that would alter the forest. “Thirty minutes seemed about right, and I didn't think I could get a better answer if I walked for two hours,” he said.

Eric Quinter said, “You don’t have to trek to a far-off jungle to find a good site. Discoveries can be made in a backyard or a field or the wooded area of a local park. I have found new things here in North America all over the place, and it’s not that I have X-ray vision. I’m just looking in places that no one has looked before for that purpose. They’ve been there to look at the birds; they've been there to look at the plants; they just haven’t looked at the bugs.”

Make sure you have permission to use the area as a site.

Brian Boom said it is important to look at the practical side of site selection. “The reality is that you’re probably going to have to select a site that’s in a park or a nature preserve or even on private property, and then you have to deal with the owner or whoever is in charge of the place. That person may limit where you can set up your project and may say, ‘You can work in this area here, but just don’t step over here and don’t step on that.’ So in reality your site selection is made for you.”

Get a feel for the area before you make your choice.

Brian told us about a walk he took before picking his site. “I walked around for a few days near one particular village, just following the trails, until I sort of got a feel for how the forest looked and felt. It was very subjective stuff. A lot of science is subjective, and this is one example.”

Choose a site you like.

Helen Hays, Chair of the Great Gull Island Committee, an American Museum of Natural History research station, has studied ruddy ducks in a remote marsh in Canada and seabirds a subway ride away from home. She suggests “thinking about what kind of site you like: whether you like to look at things around water, or in water, or in a dry field, or if you like to look at trees in a forest or if you like to walk through woods, maybe that’s the kind of site you should choose. You could take the forest floor or the edge of the forest and then you could see what species are in the various parts of that: on the earth, under the leaves, in the shrubs, in the trees. If your site is in the water, of course you’d have lots of water insects. Or in a marsh—marshes have wonderful life in the water and in the marsh itself. If I were going to do a study like that, I think I might decide to go where I like to go. If I liked lakes, I would go to a lake. Or maybe I would just go into my backyard, because that’s so easy. You can just go out and look and see what’s there. I think that would be fun.”

Collecting Plants

Brian Boom has been collecting plant specimens since 1978. If that sounds like a long time to you, you'll be amazed to learn that the New York Botanical Garden, where he works as a curator, has specimens that date back to the Lewis and Clark expedition of 1804–1806.

A plant specimen that has been properly pressed, dried, mounted on acid-free paper, and protected from moisture and insects can last for hundreds of years, Brian told us. Specimens can be stored in stacks on shelves or in cabinets, and they require very little care. The trick is to prepare them carefully and label them according to scientific conventions. If you do that, you can assemble a museum-quality botanical collection that your class, and future classes, can study and learn from.

Brian has collected botanical specimens in such exotic places as the rain forests of Bolivia, but he had a lot of valuable tips for student collectors closer to home.

Collecting Tools

In addition to the identification tools (hand lens, binoculars, metric ruler, metric tape measure, altimeter, compass, and plant identification keys), Brian Boom recommended the following:

- digging tools: spade, trowel
- pruning shears
- plastic bags: various sizes to accommodate different-size specimens
- plant press, with corrugates and felt sheets
- old newspapers: for pressing specimens
- wax pencil or crayons: for marking newspapers
- field journal
- lead pencil or pen with permanent waterproof ink
- camera (optional)
- sketching materials (optional)

This is the basic kit, according to Brian Boom, though he told us about some specialized tools he uses when collecting specimens in the tropics. Typically, trees in the rain forest are very tall and do not have branches near the ground. Their foliage grows in a crown way beyond reach. Scientists use clippers on long poles, but if tree climbing is called for, they strap fearsome-looking curved spikes to their shoes or use an ingenious contraption called a tree bicycle.

Even though it is possible to put specimens in plastic bags and mount them when you get back to school, Brian recommends pressing them in the field. "Plastic bagging is okay if it's raining or if you can't press for any other reason, but it's definitely second-best. You want to press and dry your specimens as soon as possible to keep the leaves from falling off and the whole thing from rotting," he said. "You'll get the best-quality specimens by pressing in the field in newspaper and then drying with heat as soon as possible. That way the specimen is damaged less and you end up with fewer pieces of plants, which may be hard to identify. Equally important, though, you are forced to look at your specimen right then and there, instead of just tossing it into a bag to examine later. If you do that, you might think of things you should be observing while you're out in the field that you might otherwise forget about."

Numbering Specimens

When Brian Boom collected his first plant specimen in 1978, he designated it specimen 1. He still has the specimen, and he still has the field journal in which he made notes the day he collected that specimen. Now, 20 years later, he has collected more than 11,000 specimens, all numbered in the order he began with specimen 1. "These are my personal numbers, from 1 until infinity. Everything I collect will be part of that system," he explained. "I recommend that anyone who collects plant specimens start with number 1." Brian told us there are more complex numbering systems. Some people, for example, begin again at the number 1 each year, so their specimen numbers run 98.1, 98.2, and so on, with 98 standing for 1998, followed by a decimal point and the specimen number. "But I think most of the fancy systems are unnecessarily difficult to figure out," he said. "The specimen number is very important because forever, until the end of the world, that number will refer to that specimen. And as 16 or more generations of scientists study it, they will know it by that number," Brian said.

Brian added that one of the first and most important lessons field scientists learn is: "You can't always go back. If you don't notice certain things in the field—like odors or colors—and get them down in your field journal, you're in trouble." It is also vital to record measurements and observations about the habitat from which the specimen was taken.

"When you press and dry a specimen, you are reducing it to a two-dimensional structure, which is why observation in the field is so important," Brian said. Some scientists also take photographs or, if they have the skills, make detailed drawings of the living specimen.

Each specimen should be arranged between sheets of old newspaper. It should then be assigned a specimen number, and that number should be written in wax pencil or crayon on the newspaper as well as in the field journal. "All notes about the specimen go in the journal, but these data are useless without a corresponding number on the pressed specimen," Brian reminded us. (If you do not press in the field, put the number on the plastic bag or, if you have more than one specimen per bag, attach a label to the specimen itself.)

A plant press can be bought from a scientific supply house or made with easy-to-obtain materials. Once in the press, specimens must be dried quickly. Brian suggested rigging up a wooden box with lightbulbs at the bottom; the press or presses can be laid on top for a few days while the rising hot air does the job of drying. Alternatively, the press can be put on top of a radiator, but care must be taken to avoid fires. A microwave or conventional oven will not work since hot air must be allowed to circulate, carrying the moisture up and away from the specimens, he said. "You want to dry them, not cook them."

Once the specimens are dried, they should be mounted on acid-free paper and carefully labeled. They can be attached to the paper with sewing thread or white glue. Any pieces that have fallen off—fragments of leaf, bark, flowers, fruit, seeds—should be placed in a small envelope folded from another piece of acid-free paper and attached to the mounting sheet in such a way that the envelope can be opened and the fragments removed for examination.

The label should include the following data, all of which you should be able to find in your field journal:

- name of your school
- name of your project
- specimen number
- specimen identification
- collection site: including city or town (if any), state, exact location (latitude and longitude), elevation, and a brief description of habitat
- description of plant from which specimen was taken: including size, color, odor, and any other pertinent observations
- whether photos or drawings are available
- name of collector or collectors
- date specimen was collected

Plant Identification

Identifying plant specimens is the most important job in botany, according to Brian Boom, Vice President of Botanical Science and the Pfizer Curator of Botany at the New York Botanical Garden. “There’s an old Chinese proverb that goes something like, ‘The beginning of knowledge is knowing the names of things.’ That's how scientists communicate,” he said.

As a professional botanist and an amateur entomologist, Brian told us that it is much easier to identify plants than arthropods. “There are fewer plants than arthropods, for one thing, and they’re mostly bigger. And in this part of the world, they have been studied more thoroughly.” That would not be true in the rain forest, where Brian has worked identifying trees, but the native plants of North America are generally well known.

All the same, there is a discipline and a challenge involved in the identification of plant species. “Identifying involves a comparison between a known and an unknown, so you have to have a guide or a field manual or a key of some sort (the known) to compare with your specimen (the unknown),” he said. Regional field guides are available in libraries and bookstores; other sources are local museums, botanical gardens, wildlife and conservation agencies, and college and university departments of botany.

“Identification begins with observation,” Brian said. “You have to observe the qualities of the unknown, but to do that accurately—so you know what to look for when you are using a key—you need to know some plant basics: the difference between perennial and annual plants, for example, and some general information about plant parts—flowers, leaves, roots, seeds, and fruit.”

Brian described a typical dichotomous key for plant identification, which presents a series of choices to narrow down the search. “Is the specimen woody or non-woody? If it is woody, is it a tree, a shrub, or a woody vine? If it is a tree, is the leaf arrangement opposite or alternate? Are the leaves compound or simple? Do the leaves have entire margins, or are they serrated? And so on.”

Brian warned that a plant detective can make a lot of progress with this line of questioning up to a point, “but a botanist’s life starts getting difficult at the species level, because you have to use flowers and fruit to distinguish between species. The vegetative features (leaves, needles) of plants are not very characteristic at higher levels of classification. There will always be difficult specimens, especially if they are sterile,” that is, without flowers and fruits. “Fruits and flowers are what systematic botanists use to get to the word ‘go,’ “ he told us. “That is the basis of the whole classification system, so if you don’t have them, you have to rely on experience or guesswork to try to find out what something is.” Brian recommended asking a local expert for help if you are stumped.

Identification Tool Kit

The tools of identification are relatively few and simple. The following tools are part of the field kit, which also includes tools and equipment for specimen collection.

- field guide with keys to plants of the region
- hand lens, to examine plants at close range
- binoculars, to look at things high up in a tree, for example
- metric ruler, to measure leaves and other small features
- metric tape measure, to measure the diameter of tree trunks
- altimeter, to measure the altitude of your site
- compass, to determine the location of your site

Brian Boom suggests wearing the lens and ruler on strings around your neck. Another idea is to tape an actual ruler or a photocopy of a ruler to the inside cover of your field journal.

Even experts sometimes make mistakes when identifying plants. Brian showed us an example from his own work, and because of the careful way he kept his records, we could follow the history of the mistake and its correction by looking at his field journal and specimen sheet. He collected a specimen consisting of a twig with a few leaves in Bolivia in 1984. While still in the field, he identified it as being a member of the Euphorbiaceae, a large family commonly called the spurges, with more than 5,000 species. Most are tropical plants, but the decorative poinsettia is one family member we know in North America. "In all fairness, the plant was sterile," he said. In other words, he had no flowers, seeds, or fruit to help him identify the plant.

"But when I got back to the lab I was able to examine it more thoroughly without a lot of mosquitoes buzzing in my ears, and I changed my identification to a species of Moraceae," a family that includes mulberries, figs, and Indian rubber trees. Then, in 1992, the world Moraceae expert took a look at Brian's specimen and said it belonged to a different genus of Moraceae. "At least I had it in the right family," Brian said.

The specimen label Brian showed us gave the full history, including the name of the person who made each identification. Each time a correction was made, the incorrect name was crossed out. "Never erase anything," advised Brian. "Simply cross things out so others can trace the history. Sometimes when I've made a real whopper of a mistake, I might scratch it out heavily, but that's not the same as erasing," he joked.

"Seriously, though, making mistakes is part of the process, and it's nothing to be embarrassed about. What's important is to document everything so you can go back and determine when the mistake occurred, which is why you never erase anything from a field journal either."

Plant Inventory

Is doing a plant inventory like looking at the trees, not the forest? Is it a matter of counting blades of grass? Or is it more like looking for a needle in a haystack? How, when it comes down to it, do working scientists actually inventory a site? We asked a botanist who specializes in rain forest trees and an ecologist whose work often involves looking at entire habitats how they go about the task.

Brian Boom, the tree specialist, who is now Vice President for Botanical Science and the Pfizer Curator of Botany at the New York Botanical Garden, told us, "I usually study trees in tropical lowland forest areas, but most of the principles apply anywhere." Brian works in hectares—10,000-square-meter units—and you will be working in 4-square-meter units, but in either case, the first step is to mark out the plot. "Your plot can be an absolute square or a longer, narrower shape," he said. The shape of the plot might be determined by what the scientist wants to find out or by what the terrain requires. For example, Brian said, "You will pick up more diversity with a long, narrow plot because you are going through more microhabitats." On the other hand, in some areas, such as a mountain summit, "I'd fall off the edge if I didn't measure my plot with an eye toward the topography."

After you have measured the plot, mark the perimeter with colored flagging. You can write on the flags with permanent marker. Brian said that biodegradable flagging is available from forestry supply houses. If you use flagging that is not biodegradable, be sure to remove it when your study is over. "Then I start systematically going through the site, dividing it into subplots and working my way through, measuring, collecting, and taking observations of each plant that meets my size class criteria."

Dividing a plot into smaller subplots is an excellent strategy, especially if the plants you are inventorying are smaller than trees. Liz Johnson, Manager of Metropolitan Biodiversity Programs at the American Museum of Natural History's Center for Biodiversity and Conservation, typically inventories 300-acre plots, so subdividing is absolutely necessary.

She told us about trying to count individual plants of a species of ground cover that grew in a twisted mat throughout a site. "It was so dense and had so many offshoots that it was really impossible to do a count. Instead, we made a grid within the plot and tried to count the number of individual plants within a single square." She suggested getting down on your hands and knees and looking for the place where the plant comes out of the ground. Then multiply the number of plants within a single square by the number of squares in the entire plot that are filled by the plant. "Another way is to estimate percent of coverage. This works for grasses, some ferns, and other ground cover plants."

The grid also helps you move through your plot in a systematic way, Liz said. "You just have to start at a particular point and count." Each team member could take one or several subplots, or each team member could take certain types of plant or plants of a particular height, and work through the entire plot counting only those plants. "Concentrate on what you're doing and try not to lose track," she advised.

Liz agrees that counting plants can seem impossible, particularly if you have limited time. The best thing, she said, is to break the job into parts and then set priorities. "Think about how much time you have for each session and how frequently you can come back, and then decide what to do first, second, and so on. You may have to work very fast if you have only one or two sessions, or if the season is changing and you have to do the inventory before certain things disappear." Otherwise, start with the most important things and then, if you have time or can make another visit, do as much of the rest as you can manage.

Responsible Collecting

When it comes to plants and arthropods, should specimens be taken from their habitats and kept in collections? Nearly every scientist we talked to agreed that collecting and keeping specimens are essential to the work they do. Botanist Brian Boom from the New York Botanical Garden said, "In systematic botany, if you don't have a specimen, you don't know what you're talking about. The voucher specimen—the evidence that you have found what you say you have found—is of absolute importance."

Arachnologist Kefyn Catley of the American Museum of Natural History said, "You can't do this kind of work without collecting. I can't persuade people that I have a new species of spider by sending them a picture of it; *they want to see the specimen*." Another AMNH entomologist, Eric Quinter, referred to his collection as his "library," the place he goes to find important information about what he is studying. Still other scientists spoke of "responsible collecting."

To find out what responsible collecting means and how to go about it, we talked to Liz Johnson, Manager of Metropolitan Biodiversity Programs at the American Museum of Natural History's Center for Biodiversity and Conservation. "Responsible collecting is really a series of behaviors and attitudes," she told us, adding that it makes no difference if you are a scientist working in a museum or research institution or a student at a university or middle school. Here are the behaviors and attitudes Liz thinks are most important.

Know your purpose.

"No matter who you are or what level you are working on, before you go out to do collecting, you have to have a plan." Speaking directly to students, Liz said, "You need to think about what the purpose of your study is, what exactly you want to accomplish, what the questions are that you want to answer."

We asked her to give us some examples of purposes and to tell us what would be responsible collecting for each.

"If, as a scientist, your purpose was to go to a brand-new place somewhere in the tropics that no one had ever studied before and you wanted to know what was living and growing there, then you'd want to collect samples of everything, since nothing was known about the habitat.

"In a school science class, collecting as a way to learn about studying plants is also a valid purpose," Liz said. In both of these cases, collecting specimens of everything would be appropriate.

"There are times when selective collecting is what is responsible. Say someone was studying only one or two species," Liz continued. "He or she would target only those particular things for collecting." Everything else in the habitat would be left alone. "If a scientist is studying a site in an area where the plants and arthropods are well known, there may be no need to collect at all. The scientist would go out and identify things in the field but would not collect them." There would be exceptions, Liz said. "It would make sense to collect a specimen that could not be identified without further study, such as some moth species that are so similar looking that you really need to take them in and look at them more closely under a microscope."

Liz summarized: "It all comes back to what is your question, what do you really need to get your answer?"

Find out what other scientists already know.

Once you decide what you want to find out, do some research. Often scientists go to a museum or botanical garden to talk to people and look through their collections to find out what has already been collected from the site. Liz thinks it is a good idea for students to do this, too. "It's a lot easier to know what you can expect to see out in the field if you've done this background research. Also, you can get a historical perspective: You see what has been found there, and then you can go out and see if it's still there. You see what was common and what was rare, and then you go out and see how those populations are doing now."

Never take rare or endangered specimens.

"It is the collector's responsibility to find out if anything is rare or endangered," Liz warned. She said that there are both state and federal lists of protected, rare, or endangered species, and in many states it is possible to obtain lists on a county-by-county basis. In some localities, there may be laws against damaging or removing certain species from their habitats. Liz advises consulting with a local expert to find out what is rare in your area and what rules apply. "A responsible collector knows to be on the lookout for what is very special and knows never to collect any species that is rare or declining," she said.

Do not overcollect.

"Don't go crazy," Liz advised. "Don't take more than you need. And don't take something of which there are not very many." Even an arthropod or plant population that is not rare can be damaged by overcollection, she warned.

"Some butterfly species have a flight period of only one or two weeks over the whole course of a year, and where they live is so localized that a collector in that particular place could easily wipe out the entire population," Liz told us.

"A plant might not be rare in general, but it might be rare in that location. Some botanists will not take a specimen unless there are at least 100 individual plants within one quarter mile of the site." For a small plot, Liz suggests asking a local expert what is a reasonable minimum number.

Take a good specimen.

Make the most of the specimens you do take by taking ones that are in good condition and are representative. That is, they should show what you need them to show for purposes of identification.

"For arthropods, one specimen may not be enough. The male and female might look different, so it would make sense to have one of each, if you can find them," Liz explained. "Or if you find different stages in the life cycle of the same insect, you'd want to take an example of each. And since many arthropods are fragile, it's not a bad idea to take more than one in case one gets broken as you're preparing it."

For herbaceous plants, Liz advises taking the entire plant, including the roots. If the plant is too big to take the whole thing—a shrub or tree, for example—take a twig with leaves and, if possible, flowers, fruit, and seeds. "And take lots of notes," Liz added.

Collect good data along with good specimens.

"Your field notes should include everything you cannot collect or that is fleeting: observations about insect behaviors and sound (many insects make sounds), and about color, fragrance, how a plant is growing—is it clumped or solitary, is it entwined around something else, or is it a creeping ground cover? What is its relationship to other plants or insects or other living and nonliving things on the site?" Liz emphasized that all of these observations belong in a field journal, and "they must be keyed to that particular specimen, by number."

Find out what the laws are and obey them.

"A responsible collector needs to abide by all legal issues that exist," Liz insisted. "Who owns the property you're going to? Is it private property, a national or state forest, or nature preserve? Do you need permission to go there? Do you need permission to do the sort of work you plan to do? What are the limitations of any permits you may obtain?"

Analyze your resources.

It is easy enough to take specimens in the field, but responsible collectors know what they will do with their specimens afterward. If you cannot prepare and maintain a collection, you have no business taking specimens, Liz believes. "It's a good idea to find out what is involved in making and maintaining a collection so you can match how much you collect with the time, space, ability, and interest you have in preserving and keeping your specimens in good condition," she said.

Collecting Arthropod Specimens

As a National Science Foundation Research Fellow in the Entomology Department at the American Museum of Natural History, Kefyn Catley has had a lot of experience collecting specimens. We asked him what he thought were the best ways to catch arthropods in the field.

"It depends on what you are trying to find out. If you want to know what insects are living on this particular plant or this particular site, you have to be quite thorough in your methods. You can't just go in there and see what you can catch. You have to choose collection methods that are suited to the vegetation on your site and that target the sorts of bugs that live there," he told us.

He recommended visiting the site before you begin collecting. "Get a handle on what's there before you begin so you can bring the right equipment when it's time to collect."

He listed six of the main collection methods and explained what sort of terrain and specimens they were best suited to.

1. Aerial netting: An aerial net with a long tapered tail is made of a lightweight mesh. It is used to collect organisms on the top of flower heads and other vegetation. "It tends to catch aerial insects, lots of flies particularly. You don't really hit the vegetation," Kefyn explained. "You just very quickly sweep over it, and insects feeding or resting on the vegetation will fly up into the net. You need to flick your wrist at the end of each sweep to close the mouth of the net."

2. Sweep netting: According to Kefyn, this is one of the best ways to catch a lot of organisms. "The classic habitat for using a sweep net is a meadow," he told us.

A sweep net is heavier and shallower than the aerial net and has a wider mouth. "It's usually made of sailcloth or canvas, rugged enough not to be torn by the leaves and other vegetation that usually wind up in it, along with the bugs," Kefyn said. "It's good for catching heavier arthropods: beetles, spiders, true bugs, and such. You sweep the vegetation itself and end up catching arthropods that actually live in and on the plants."

With either type of net, sweep as many times as necessary to get a good sample. "In some habitats, you might have to sweep 20 or 30 times. In others, you do four sweeps, and your net is full of organisms," Kefyn explained.

3. Beating: This method is good for sturdier vegetation, such as trees and shrubs. "You tap the plant with a stick and catch whatever falls off in a large tray, a sheet, or an upturned umbrella. You can also do it with flowers—tap gently—if you don't want to harm them by using the sweep net," Kefyn suggested.

4. Hand collecting: "With some very delicate plants and flowers—milkweed, for example—you don't want to go sweep netting or tapping them, or you'll destroy the plant. But if you want to collect bugs living on them, the aerial net won't do." That is when hand collecting is a good choice, Kefyn said. A soft paintbrush or cotton swab could be used to gently knock the specimen into a collecting vial, or it could be carefully picked off by hand.

Turning over stones and logs exposes many arthropods—beetles, spiders, centipedes, sowbugs—and hand collecting is the method of choice. "The best strategy is to take turns with two people since there are often too many specimens for one person to catch, and you have to be fast before they run and hide," Kefyn advised. "Also check any webbing for spiders hiding there," he added.

"You can't study arthropods in any meaningful way without collecting them."

5. Pitfall trapping: "This is a wonderful method for catching ground-living arthropods. You'll catch things with this method that you won't catch in any other way," Kefyn said.

Make your pitfalls by digging round holes with a bulb planter or trowel and sinking a plastic cup in each. The hole should be deep enough so the rim of the cup is level with the ground. Pour about an inch of water with a drop of liquid laundry detergent into each cup. Check the cups every few days and remove the specimens that have fallen into your traps. The water will evaporate and the specimens will rot if you leave them more than two or three days.

6. Berlese funnel: If your site is at the edge of a wood or is in a wood itself, leaf litter will yield a rich harvest, according to Kefyn. "That's where the greatest diversity is, period. Typically, in a woodland, you'll get several thousand individual organisms out of a square-meter site."

Kefyn defines leaf litter as fallen leaves and anything else that has accumulated in a wooded area for several years.

You can rig up a Berlese funnel device using a large coffee can with a plastic funnel inside and a metal grid over the top. Put the litter on top of the grid and cover it with another coffee can with a light in it. After a few days, the heat and the dryness will force the arthropods down the funnel and into your collection container.

“Most of what you collect will be very small—soil mites, springtails, that sort of thing,” Kefyn said. He advises using a paintbrush to remove the tiniest arthropods from the collection container. “You will need a stereomicroscope with a good top light to sort this material,” he advised.

No matter which method you choose, Kefyn said it is important to decide ahead of time what you plan to do with your specimens. “There’s no point catching the things if you don’t know what to do next.”

When it comes to the debate on whether to collect or not, Kefyn votes for killing specimens, then identifying, labeling, and preserving them in a collection.

“You can’t study arthropods in any meaningful way without collecting them,” he argues. “Whereas drawings and photographs done in the field are very useful aids for memory and a great help in close observation, they have limited usefulness in taxonomy. Experts can’t identify them without the specimen. I can’t persuade somebody that I have a new species of spider, for example, by sending a picture of it. He or she wants to see the specimen.”

Maintaining an Arthropod Collection

Christine Johnson helps maintain the collections in the Department of Entomology at the American Museum of Natural History. She inspects the specimen cases to be sure that none of the delicate parts of the brittle specimens have broken off, that all labels are in place, and that moisture and living insects have not damaged any of the preserved specimens. She also adds newly prepared and identified specimens to existing collections, making sure they are in the right place, according to order, family, genus, and species. It is a big job and one that requires meticulous care and extensive knowledge, but then the Museum's collection includes millions of arthropods, some more than 100 years old.

We asked Chris what advice she had for students setting up and maintaining an arthropod collection on a smaller scale. The first thing she told us is that it is a big job, no matter how small the collection is. "Before going out to take specimens in the field, students should be aware of what's involved in keeping a collection: from killing, preserving, and identifying specimens to pinning and labeling them. And then it all has to be stored properly and checked periodically to ensure that everything stays in good condition. It can be a lot of fun, but it's also a lot of work," she said.

Although entomologists use some dangerous chemicals to kill and preserve specimens, Chris had some good ideas for safe alternatives. "With just a few exceptions, most of what you catch can be put immediately into a jar filled with ordinary ethyl alcohol. This will both kill the specimens and keep them from becoming damaged until you are ready to dry and pin them for exhibit," she advised.

Some specimens—butterflies, moths, and dragonflies—would be damaged by being put in alcohol even briefly. Dragonflies need special treatment to preserve their iridescence (see sidebar, "Preserving Color," below). Chris recommends killing butterflies and moths by carefully placing them between two sheets of tissue paper or paper towel, then into a small box or plastic food container. Finally, put them in a freezer for a few hours.

"You can kill any other specimens this way if you don't like the idea of putting them in alcohol," Chris said. But she cautioned that beetles may take longer to die. “You might even want to leave them in the freezer overnight,” she said. You should also be careful about putting different kinds of living arthropods in the same container, she warned, since some types will eat other types, “and then you’ve lost your specimen.”

Some specimens are not suited to drying and pinning and should instead remain in alcohol. These include soft-bodied arthropods like spiders, termites, and caterpillars and other larvae. For these specimens, use forceps to carefully transfer each one to its own small vial. Fill the vial with alcohol and close it tightly. You can tape the label to the outside of the vial or, if it is small enough and written in pencil, put it into the vial along with the specimen. “Don’t use ink,” Chris warned, “because the alcohol will quickly blur what you have written.”

For specimens that will be pinned, the next step is drying, “except for specimens that are frozen, in which case you need to rehydrate them before you pin them.” Chris noted that this is the only time dampness is not the collector’s enemy. “Otherwise, they are more likely to break when you try to arrange the wings while pinning them.”

Chris told us that *Peterson Field Guides: Insects*, edited by Donald J. Borror and Richard E. White, gives detailed instructions for pinning most common types of arthropods.

Chris recommends using forceps rather than your fingers whenever you handle specimens. “Most specimens are very small and quite fragile. Handling them gently with forceps will help prevent damage. If a leg or wing or antenna does break off, don’t despair,” she said. “Just cut a small piece of card stock, put a drop of white glue on it, pick up the piece with your forceps, and place it on the glue. Then you can put the card right on the pin, just under the specimen. That way, all parts of the specimen can be found in one place and you haven’t lost an important piece of your collection.” Chris told us that the same thing is done in museum collections.

The next step is labeling. Chris told us there is a standard format for labeling that is used in museum collections worldwide:

- scientific name of specimen
- country, county, town or city; latitude and longitude where it was found
- name of collector
- habitat where it was found: for example, under a leaf, in a log, in the air
- date when it was found

“A properly prepared and maintained arthropod specimen could last for hundreds of years,” Chris told us. “I’ve seen specimens in the Museum’s collections dating back to the late 1800s, and there are probably others older than that.” It is unlikely your specimens will stay around that long, but it still makes sense to adopt some of the techniques Chris uses to protect the Museum specimens.

Keep the collection dry. "Try to keep it out of a damp environment, such as a basement, but if moisture is a problem where you are, tape a packet of desiccant, available from scientific supply houses, to the inside of each specimen box."

Be on watch for Dermestidae. These little beetles—commonly called carpet beetles—can be found just about anywhere. "Even when a specimen box is closed, they get in, lay eggs, and then the larvae literally eat the specimens from the inside out," Chris warned. A telltale sign is a fine dust called frass, which looks almost like sawdust. Chris inspects the collections carefully and regularly—she suggests doing it once every three or four months. At the first sign of frass, she puts the entire specimen box in a freezer for two days. "If I see a dermestid beetle crawling in the specimen box, I'll take it out, but freezing will kill dermestidae larvae and prevent further damage to infested specimens," she explained.

In the past, museum collections were protected from these beetles with mothballs and other fumigants, but Chris said that the American Museum of Natural History no longer uses these harmful chemicals. "We just keep a careful watch on things and freeze anything that looks suspicious," she said.

Basic Equipment

- fine forceps
- hand lens
- vials or small bottles with screw-on tops or rubber stoppers
- alcohol (70–80%)
- Styrofoam (cut to fit into specimen boxes)
- insect pins (available from scientific supply houses) or tailors' straight pins (stainless steel and at least 2 inches long)
- water-based white glue
- card stock (for labels)
- specimen boxes—these can be as fancy as glass-topped Cornell drawers, which come with individual unit trays, or Schmitt boxes, which have to be opened for display (both are available from scientific supply houses), or as humble as cardboard shoe boxes; with a piece of glass or Plexiglas fitted into the top, you will be able to see the specimens without opening the box.

Pinning Specimens

Specimens in Alcohol

Pour contents of vial onto a plate. Using forceps, carefully pick out individual specimens and place them on paper towel for 10 to 20 minutes. When they are almost dry but still soft, pin them. For flies and other insects with veined wings, gently arrange wings to show venation.

By the time pinning is completed, the specimen will be dry enough so the box can be closed.

Frozen Specimens

Put about an inch of water in a large plastic food storage container. Place a sheet of paper towel in the bottom of a smaller container and place frozen specimens on the towel. Put the smaller container into the larger one, taking care not to splash water onto the specimens. Leave the smaller container open, but close the larger one tightly and leave in a secure place (where it will not get bumped) for 24 hours.

Remove specimens and pin them, gently arranging the wings. Leave the specimen box open for about an hour after pinning to allow everything to dry completely.

Preserving Color

Many arthropods have beautiful colors that are worth preserving if possible. The metallic sheen of a beetle, the rich velvety wings of a butterfly, the iridescent lacy wings of a dragonfly are among the fascinations of a well-prepared collection. Some of these colors will fade in bright light, so Chris Johnson advises keeping specimen cases with glass or Plexiglas tops in cabinets except when they are on display. “Being in daylight or incandescent light for several hours at a time won’t hurt them, but I’d keep them out of direct sunlight if possible,” she said.

The wings of dragonflies tend to lose their iridescence soon after they are killed. Hazardous chemicals such as acetone are sometimes used to “fix” the colors before they fade, but Chris suggested a safe alternative.

“When you’re collecting in the field, fold back the wings and put the live dragonfly in an envelope so that you don’t destroy the wings. Then tape the envelope shut and put it in a shoe box. You can put more than one dragonfly in the shoe box, as long as there’s only one in each envelope. Later, freeze the specimen and rehydrate the dragonfly the next day. When it is soft enough to spread the wings, pin it.”

Sorting Arthropods for Identification

When we asked Kefyn Catley how he thinks students should go about identifying their arthropod specimens, he said, “That’s the 64,000-dollar question.”

Identifying arthropods is a challenge, even to Kefyn, who spends his days identifying Australian ground spiders at the American Museum of Natural History. He also writes identification keys, which are used to classify specimens down to the species level. This sort of work is called systematics.

“Systematics deals with species,” Kefyn explained. “The unit we study is the species, not populations or individual organisms.” But identifying an organism to species can be very difficult, he said, even for experienced scientists. Kefyn thinks it is more realistic for students to group arthropods by order and try to identify them further by families.

Kefyn recommends putting everything that has been collected into alcohol, except butterflies and moths. Most will be dried and pinned later on, but soft-bodied specimens, such as spiders and caterpillars, must be kept in alcohol, he told us. Then the sorting can begin.

Identification involves a series of steps, Kefyn explained. “Systematists begin with the largest classification—the phylum Arthropoda—and keep narrowing it down—through subphylum, class, order, family, genus, until they get to species. You may not get as far, but the procedure is the same,” he said.

“Start by making a very gross first cut: separating things with wings from things without wings. Next divide those into very basic groups: beetles, ants, flies, wasps, for example,” he said. Do not be surprised if you have a lot of beetles, Kefyn mentioned as an aside, since beetles are the largest group of organisms on the planet.

He advised using a picture key such as is found in many field guides or asking a local museum or naturalist to recommend a key to arthropods most likely to be found in your area. When you use such a key, you will be sorting according to appearance, or morphospecies.

“Basically, you’re eyeballing your specimens, looking at the differences and similarities. Sort your specimens according to shape, color, number of legs, and any other differences you can discover, and see how many groupings (what scientists call taxa) you come up with and how far you can take it,” he suggested.

“If you are able, for example, sort all the things that appear to be beetles. Next separate the long, narrow beetles from the round beetles. Then take a closer look at the long, narrow beetles and see characteristics that some share, like the same type of antennae or the shape of their wing covers. This is the type of process of elimination that scientists use all the time to group organisms. In doing so, you may be sorting beetles into families, or even genera, without knowing it. This first step can take place by just using your powers of observation—you don't even need a key," he said.

"Some students may want to specialize in a particular group," Kefyn suggested. "Some might want to tackle the bees, others might take on the ants. That way you'll end up with experts in the class who can share their knowledge with others, which is what entomologists do all the time."

Investigating Plant-Arthropod Interactions

Amy Berkov has carved out a special niche for herself as a way of keeping things interesting during the long years it takes to get a Ph.D. "I study the association between a group of neotropical longicorn beetles and their host plants, a family of tropical trees that include the Brazil nut," she told us. (Neotropical refers to the tropical regions of the Americas, as opposed to those in Africa, the Indian subcontinent, and Asia. Longicorn beetles are sometimes called long-horned beetles, nicknamed for their very long antennae, or timber beetles, because the larvae tunnel into wood.)

Her research is extremely complex, requiring knowledge of arthropods and plants and the interaction between the two groups of organisms. "I intentionally selected a project that had a lot of components because I thought it would be more stimulating. When you're working toward a doctorate, you spend a lot of time with your subject, so I looked for something that would offer me variety."

She certainly got it.

Amy's arthropods are members of the Cerambycidae, a family of beetles that come in many shapes and sizes. "I spent a whole semester in the entomology collection at the American Museum of Natural History, drawing my way

Can Beetles Smell?

If *Couratari stellata* is unpopular with cerambycids, does that mean these beetles can smell? "Yes, indeed," said Amy Berkov. "Insects are incredibly sensitive to smell compared to humans. They find their appropriate host by smell, and they don't make very many mistakes."

But what do they smell with, since they don't have noses? "They smell with their antennae, which are highly sensitive sensory structures, especially for smell but also for touch. Volatile chemicals waft through the air, and the beetles pick them up with their antennae and follow the smell, just like you might follow the smell of freshly baked cookies. Once they actually land on a tree they make sure they made the right selection by tasting the bark with their mouthparts. Some insects, including butterflies, moths, and flies, have taste receptors on their tarsi so they can actually taste with their feet."

How Do Cerambycidae and Lecythidaceae Interact?

Plants give off volatile chemical compounds that can be sensed in the air by insects. A few cerambycid species are specialists that are attracted to the particular compounds coming from Lecythidaceae. “The adult beetles meet and mate right on the tree, and then the female lays her eggs there,” Amy Berkov told us. “When the eggs hatch, the larvae tunnel down into the wood.”

Some cerambycids lay their eggs on rotting wood; others select intact, living trees. The particular cerambycids Amy studied favor freshly cut wood. “They are among the first insects to attack freshly killed wood. They spend the next four to five months in the larval state, chewing the wood and creating a system of tunnels and galleries inside the branch. Then other insects and microorganisms enter into the wood and speed up the process of decomposition.”

through the cerambycids.” If the best way to understand an organism is through close observation, many investigators believe the best way to begin is by drawing. “It’s a huge family, with 35,000 described species, and I was just trying to get the lay of the land. By the time I did that I was hooked, because they are so spectacular,” she said.

Next, she went out into the field. “I spent a year in Central French Guiana doing rearing experiments. I knew there was a group of cerambycids that laid their eggs only on trees belonging to the Brazil nut family (Lecythidaceae). Organisms that are picky like that are referred to as specialists. And I knew that this tree family was avoided by the generalists, insects that lay their eggs on many different plants. I wanted to find out how these beetles were using this resource, so I had to look more closely at the relationship between the beetles and the trees.”

Amy designed her study to include a number of variables in the hope that at least some of her questions would be answered. “I worked with five different tree species. My beetles are wood-borers, so we had to provide them with freshly cut wood. I had the assistance of a professional tree climber who climbed up into 25 huge rain forest trees. The tallest one was about 47 meters (more than 150 feet) high. I wanted to see if different beetles prefer different-size branches, so in each tree I asked him to cut a skinny branch and a thick branch. He left a section of each branch up in the canopy (treetop) and brought down a section so I could see

Are There Really *30 Million Arthropod Species?*

Part of what inspired Amy’s research was a theory put forth by Terry Erwin in the early 1980s. Erwin suggested that there might be 30 million species of arthropods, implying that for every one that has already been described there are 29 that are unknown, unnamed, and unclassified.

Erwin’s statement was based on the assumptions that many arthropods are very picky about where they live and lay their eggs (this is called host specificity) and that there are twice as many arthropods that live only at treetop level as there are that live on the ground. It was a provocative statement that scientists have been debating ever since. But, as Amy pointed out, “We need people to go out and make wild speculations because it focuses research on areas that have been ignored. Erwin made everybody realize that we don’t know much about the host specificity of tropical arthropods, and we don’t know whether the canopy and ground faunas are distinct, and we don’t have any idea how many species exist. In fact, there is almost no data that allow us even to begin to evaluate those figures.”

if there are different beetles at canopy level and at ground level. We did this two times: first in the dry season and then in the rainy season.

"I looked at five different tree species, two different branch diameters, two different strata (levels) of the forest, and two seasons." That is a lot of variables. "My question was: Were the beetles dividing up the resource? That is, did some prefer certain trees? Could some be found only in the canopy, while others could be found only on ground level?"

Each branch was left in the forest for three and a half months, to allow the beetles time to lay their eggs. Then Amy took them back to where she was staying, put each branch in a plastic cage, and waited to see what emerged.

"I couldn't afford to hire the climber more than twice, so when he climbed up to do the rainy season cuts, he brought down the branches that had been left up in the canopy during the dry season. And then we rigged up pulleys so when the time came to collect branches after the rainy season, I just pulled them down," Amy told us.

"Part of what I was trying to find out was whether there was host specificity, that is, how picky are these particular insects? I was also trying to identify plant compounds involved in the host selection process. What was it about the trees I was studying that attracted my beetles but not other beetles?"

Here are some of the things Amy found out: Not all of the tree species were equally popular. "I had two popular tree species, one that was kind of so-so, and two that were really unpopular." As it turns out, the least popular tree—*Couratari stellata*—has a truly foul odor.

So What Is the Answer?

"I wasn't trying to prove or disprove what Erwin said," Amy explained. "What I wanted to do was take a small piece—sort of like a snapshot or a single piece of a complex jigsaw puzzle–and examine it closely."

Still, looking at the snapshot, Amy's experiments with cerambycids did not support some of the assumptions on which Erwin based his statement.

"Erwin guessed that about two-thirds of the arthropods would be found only at canopy level and one-third only at ground level," she said. In the case of the beetles she was studying, only 17 percent were found at canopy level and 28 percent at ground level. More than half (55 percent) could be found at both levels.

Erwin thought there were at least 29 undescribed arthropods for every one that has been described, but only about one-third of the beetles in Amy's study are not yet described. "That is still a lot," Amy said, "but it's not even close to Erwin's projection. Of course, cerambycids are very large beetles—the megafauna of the insect world. In most cases, the big, conspicuous, and dramatic-looking organisms are much better studied than ones that are tiny or for other reasons more easily overlooked. I might have gotten a much higher ratio of undescribed species if I had been studying fungus gnats or something else small and humble."

"It was so stinky you could smell it before you saw it when you were walking through the forest. I found very few species of beetles and very few individuals of each species in the branches from that tree. A second tree species also had the odor, but it was not nearly as strong. A lot of species reproduced in that one, but there were still not many individuals of any species." Amy has a hypothesis to explain this finding. "I know my beetles are capable of reproducing in those trees because I did get a few, but I think they don't like the smell any more than I do, so they avoid it if they can."

One thing that surprised Amy was that during the rainy season more beetles reproduced at canopy level, where it is drier and windier, than at ground level. "I'm not sure why," she said, "but I do have a hypothesis." She thinks that during the rainy season the air at ground level is so full of moisture that the volatile chemicals that attract the beetles are unable to travel very far. "I think the beetles just couldn't find the branches at ground level," she said.

Amy found answers to quite a few of her questions, but what she mostly came up with were more questions.

"I ended up building a lot of new questions on my original questions." We asked her if she found it frustrating to come up with more questions than answers. "I don't think it's frustrating," she said. "I think it's fun. I really like coming up with possible explanations for what I observe, and I like generating ideas. To me, the best part of discovery is following a trail of questions."

Saving El Imposible: A Biodiversity Puzzler

How do people decide to set aside a piece of land for conservation? What kinds of things have to be considered? Can biodiversity be protected at the same time as the land is used for research, recreation, and growing food? When there is a conflict between nature and people, how is it resolved? Can compromises be made?

These are among the questions faced by Salvanatura, a nongovernmental organization that manages a large national park on behalf of the government in El Salvador. Because the same questions might be asked about site preservation anywhere in the world, we asked Carlos Ramirez-Sosa, who served on a committee that advised Salvanatura, to tell us about the decision-making process.

In 1979, the government of El Salvador created a new national park called El Imposible—The Impossible One—covering 5,000 hectares in the department of Ahuachapan, which borders on Guatemala. (A hectare equals 10,000 square meters, or a little less than 2.5 acres.) "This park is on the Pacific coast of Central America, an area that has basically been destroyed," Carlos explained. "A lot more people live there than on the Atlantic coast, where the lowland rain forest is found. This area is dry forest, which means it's easier to burn and manage than rain forest. Over the years most of the forest has been cleared for coffee, sugarcane, and cotton plantations. What little remains has been called the Jewel of Central America, because outside of Mexico it is probably the largest remaining old-growth forest," he said.

The land inside the national park combines the last bit of old-growth forest with abandoned coffee plantations and cattle ranches taken over by the government nearly 20 years ago. "It has been estimated that there are 400 species of trees there, a very high diversity for that type of land in El Salvador. Even in the time since the plantations and ranches were abandoned, the forest is recovering, and many of the original tree species are coming back."

But why is it called El Imposible, we asked. "The name was given because the terrain is so broken, with very steep mountains, that you cannot drive through it. You have to go on horseback or foot to traverse the entire forest," Carlos explained.

In the early 1990s, an advisory committee was formed to study the park and make recommendations for how it should be managed. “I was hired to look at how diverse the flora (plant life) is. Another scientist looked at the fauna (animal life). There was also an archaeologist because there are 18 archaeological sites within the park, and a sociologist to study the people who make the park their home.” Carlos explained that when the park was established, 65 families of agricultural workers were permitted to remain on the land. “They had been born there and they had nowhere else to go, no jobs, no way of earning a livelihood. There was an oral agreement that they could remain there, but no one else could move in and they couldn’t build new houses or grow more crops than they needed for their own use.” Over the years, the population has shrunk to 35 families, and Salvanatura was considering evicting them.

El Imposible: The Inventory

The area designated as a national park contains the following:

- 5,000 hectares of land.
- 35 families, some of whom have been there all of their lives. They farm small plots to grow food for their own use and cut wood in the forest to use as fuel.
- 18 archaeological sites that may be 3,000 years old and contain evidence of ancient Maya civilization.
- 8 different vegetation types, including old-growth forest, new forest, and land cleared for agriculture.
- 6 separate rivers and many small streams. It is one of the most important nonpolluted watersheds in the country.
- 400 species of trees, including *Guapira witsbergeri*, a tree that is found nowhere else in the world.
- An undetermined number of species of herbaceous plants and shrubs, including orchids and plants with healing properties.
- 31 species of fish, 263 species of birds, 31 species of mammals (not counting bats or rodents), 25 species of snakes, and 10 species of amphibians. Many migrant birds from North America winter there.

Each specialist studied one aspect, and then everyone met to decide on recommendations. There were disagreements, of course, but Carlos said that a compromise was finally reached. “Some people thought it was most important to protect the old-growth forest, which is only a very small area of the park. Others, including me, felt that biodiversity includes everything that is there, even newer plants, which are still part of the ecosystem.”

In Carlos’s opinion, the reason for the very high level of biodiversity of both plants and animals is that there has been a lot of change, creating what Carlos calls “succession levels” over the years. “Some forested areas are 100 years old, some are only 30 or 40. You find different species at different succession levels.” For example, he said, “In the early stages of forest recovery, there will be more butterflies and birds because the open lands and the type of plants that grow in those areas attract them. In old-growth forest, it’s too dark and there are more predators, so there won’t be as many butterflies and birds.

“If we want to keep biodiversity as it exists today, we have to maintain those systems.” The way to do that, he believes, is by selectively pruning, cutting, or burning trees. As surprising as it may sound, Carlos says that “If we let the forest continue to grow, biodiversity will decrease.”

Dividing the Park

Up until now, El Imposible has not been open to the public, but park administrators soon plan to open some areas for day visitors and overnight campers, while reserving other areas for special use.

"The park will be divided into three main zones," Carlos Ramirez-Sosa told us. "One will be open to anyone who wants to go there. A second section will be more restricted; visitors will have to go with a guide provided by the park. Then there will be portions of the park that are open only to scientists who are doing research. These are areas where the terrain is very fragile and could be easily damaged by foot traffic or where there are archaeological sites that might be looted."

Picnic and camping areas will be located where the abandoned plantations once stood. "Since this land has already been cleared, putting parking lots and other visitor facilities here will cause the least amount of disturbance to the environment," Carlos explained.

One of the biggest questions was whether the park inhabitants have a negative or positive impact on the land. "Our conclusions were ambiguous," Carlos said. "It really is a many-sided question." On one hand, the small-scale farming they do still includes the use of pesticides and fertilizers, some of which is applied by young children and all of which is harmful to the ecosystem. Furthermore, it was assumed that the wood they cut for fuel would alter the forest in negative ways. However, Carlos discovered that the types of trees the inhabitants cut resprout, so there is no danger of depletion. He also suggested encouraging adoption of farming methods that would reduce pesticide and fertilizer use, such as planting species that repel insects and others that add nitrogen, an important fertilizer ingredient, to the soil. "Legumes—peas, beans, and peanuts—are nitrogen-fixers. And there are many tropical plants that naturally repel insects, similar to the marigold here in the United States," he said.

Recommendations

Here are highlights of what the advisory committee recommended.

- Inventory the biodiversity of the park.
- Protect old-growth forest from fires and human intervention.
- Monitor species populations, especially those such as butterflies that are targets of poachers.
- Open selected areas of the park to the public.
- Monitor the effect of public use of the park.
- Promote scientific research in the park, including the establishment of a biological research station.

Carlos also believes that the human inhabitants of the area are an important resource. "They know the forest in a way that no one else does. They could work as guides in the park and assist in the biodiversity inventory. Furthermore, they are part of our cultural heritage. Some of their houses are of a type found nowhere else in El Salvador, and their way of life, which is the way people have lived in El Salvador for hundreds of years, has totally disappeared everywhere else in the country. If we kick them out, all of that will be lost."

Carlos sees a lesson in the archaeological sites found in the park. “They tell us that people have been there for centuries. And I believe that the park is the way it is because people, as well as natural forces, have played a major role. There have been fires, there have been hurricanes, just as there have been plantations and settlements, but the forest regenerates itself if we let it.”

How to Design an Exhibit with Passion

Niles Eldredge is passionate about his science. An evolutionary biologist and research paleontologist who is a Curator in the Department of Invertebrates at the American Museum of Natural History, he has been focusing some of that passion toward the Museum's new Hall of Biodiversity. He is the chief curator of the Hall, so he struck us as a good person to ask for advice about putting together an exhibit on biodiversity.

Obviously, a school exhibit will be smaller and less complex than a permanent exhibit hall in one of the biggest natural history museums in the world. "That does not mean there aren't a lot of possibilities," Niles said. In some ways, they may be even greater. For example, with a permanent exhibit in a museum, he told us, the ideal thing is to have a single vision and a single voice. "But a school exhibit could be designed to speak in the many different voices of the student scientists."

Those many voices could be presented as a way of showing the diversity of thoughts and opinions about the subject of biodiversity. "In a project like this, different students will see different things in the same place and will have different responses to it," Niles said.

"If each individual talks about what he or she likes about what was observed and why he or she thinks the rest of us should care about it, the result could be a very rich and personal tour of the ecosystem." It makes it possible to understand and appreciate the value of biodiversity from many points of view.

Aside from words, Niles recommends communicating with images. Collecting specimens is fine, to the extent that it is possible, he said. "But I am a paleontologist, so I don't go out and collect living specimens. I am also a bird-watcher, a hobby I took up because I am interested in ecosystems and it is a great and fun way of going out and studying different habitats. In that activity, I do my collecting with my eyes." Binoculars and cameras (both video and still) are important collecting tools, he said, and so are sketch pads, pencils, and paints. Niles also suggests collecting sounds and playing tape recordings as part of the exhibit.

Parts of the exhibit could be organized according to themes. "Following up on a theme—such as interactions between organisms in an ecosystem—can be very rewarding. Who's eating whom? What happens when one thing changes? How does that affect everything else in the ecosystem? That sort of thing."

Niles said curating an exhibit is, in many ways, like putting on a show. It is important to engage the audience, keep people interested, and make them care. "In the Hall of Biodiversity, we want visitors to walk in and be overwhelmed by the beauty of life. The exhibit is layered, so it can be experienced in different ways depending on people's age and interest and how much time they have. And we expect that many people will come back and look at it more than once. But on that first visit, we want them to have a gut-level response—an emotional experience—that they can get without reading a word, or maybe just a couple of words."

Those words, Niles said, have to be clear but also interesting, and they must speak to the audience on an understandable level. Identifying the audience and the appropriate level is one of the biggest challenges the team of curators is facing.

"We need to know to whom we are speaking and figure out how best to speak to them. It's all about communicating: We want to be sure the message is getting across, but we don't want to short-change the science. The writing has to be punchy, but we also need to give information that is often complex. It's a very tricky balancing act," he said. Niles has been showing the text he has written to a number of people and asking for opinions. "I take their comments very seriously when I think about changes to make in the text."

It all comes back to passion, Niles thinks. If the curators can communicate their passion, the audience is sure to pick it up. His advice to student curators? "I believe it's important to figure out what really turns you on as an individual, what you like about science or whatever it is you're doing or learning."

Planning an Exhibit

In May 1998, the Hall of Biodiversity opened at the American Museum of Natural History. It covers approximately 11,000 square feet on the first floor of the Museum and joins the 33 other permanent exhibit halls that have been built over the course of the Museum's 129-year history. The Hall is devoted to the theme of biodiversity—what it is, why it is important, why it is threatened, and what this and future generations can do to preserve it. It contains more than 1,200 specimens, dozens of models, and a multitude of media displays, including 20 video monitors, 20 interactive computer stations, and assorted special effects. The centerpiece is a 2,000-square-foot diorama—one of the largest in the world—depicting the plant and animal life in a Central African Republic rain forest.

Designing and building the Hall was a four-year effort, requiring the participation of hundreds of people, from architects and designers, museum administrators and curators, to carpenters, electricians, model makers, and volunteers from the community.

To find out how such an enormous task was accomplished, we talked to a cross section of these people, beginning with Willard Whitson, former Associate Director and Senior Exhibition Developer in the Museum's Exhibition Department and the Museum's Project Manager for the Hall, and Melanie Ide, an architect who is the Project Director from the firm of Ralph Appelbaum Associates, which designed the Hall.

We asked Willard how he begins planning an exhibit, whether it is as ambitious as the Hall of Biodiversity or something considerably smaller.

"Step one is to think about what the parameters are: What is the topic? How much money is there to spend? How much space is there? How much time do we have before it opens, and how much of that time can we spend working on the project? What are our resources: What kind of help, materials, and equipment do we need and can we get?"

Each one of those questions leads to a series of other questions, and the answers are all important elements in the planning.

Developing the exhibit script is step two, and it grows out of many of the questions asked in step one, especially, "What is the topic, or the 'big idea'?" For example, Willard said the big idea of the Hall of Biodiversity is: The diversity of life is necessary for the survival of all living things; diversity is under threat primarily by human beings living in the environment, but things can be done and are being done to help." He added, "There it is in one sentence, even though it's a compound one!"

The Script

Willard Whitson explained that the script is the central planning document of an exhibit. It is not a script in the sense of a play or film script, and few if any of the words in it will be seen, heard, or read by visitors to the exhibit. Nonetheless, it states what the exhibit is about and helps the exhibit planners decide how to tell the story of the exhibit.

"The script is a narrative description of the exhibit, a way of verbally stating the big idea of the exhibit," Willard said. "You should be able to state the big idea in one sentence, though it could be a complex sentence. Once you have that, you can begin developing the script.

"The script might begin something like this: This exhibit will be about this subject. It will occupy this number of square feet. It will cost this much money to put together. It will use a combination of live and mounted specimens, with photographs, video, hands-on exhibits, interactive computer stations, and so on, whatever media seem appropriate to tell the story.

"In the beginning, we just plug in the details we know, and then, as we go along, we fill in the blanks and add flesh to the skeleton. A script is a constantly evolving document," Willard explained.

Melanie stressed the importance of knowing the audience and designing the exhibit to speak to that audience. That can be a complicated matter, however. "If the audience is going to be all different sorts of people, of different ages and levels of interest, the information should be layered in as many different levels as possible. It's a good idea to have at least three main levels of getting through the exhibit," she said. For example, some people want to go through very quickly and just get the general idea. Others want to spend more time in certain areas and explore things more deeply. Some people like to participate in interactive exhibits or activities related to the big idea. Some people know something about the subject; others have little or no information at all. Some visitors are young children, others are adults.

Willard also works with students of exhibit design at the Fashion Institute of Technology, a design school in New York City. At the end of each year there is an exhibit of student work for the whole school. The exhibit design students are in charge of the "theme" and "look" of the exhibit. "Groups of students present proposals for the exhibit design, and a panel reviews them to pick the best one. What usually happens, though, is that no single proposal wins. Instead, we end up finding that we like one basic concept best, but we like a piece from another proposal and maybe a few ideas from another one or two, and so on. Ultimately, the final concept represents a combination of the best ideas of many proposals," Willard said.

With the skeleton constructed, how do exhibition designers go about putting the flesh on the bones? Melanie approaches it this way: "Begin by outlining the information you want to communicate, listing all of the topics. Then assign each topic a level of importance. Decide which media technique will most effectively communicate each piece of information. For example, will this work best as a specimen exhibit or as a talk by a knowledgeable person? Should this be a video or a diorama? Could this be shown with photographs or drawings? Would sound or smell or touch be a good way to communicate this?"

Deciding how the exhibit will be laid out in the space allowed comes next. Willard described a technique he uses early in the process. "We start off with bubble diagrams. These can be very informal, little more than doodles or sketches. Without thinking of actual layout, they just say, 'This information should come first, this should go here, this is related but less important.' The bubbles show how information is spatially related.

"Then we start moving bubbles around as we think about what things have to be in a certain place—for example, if we have a huge stuffed elephant, there may be only one place where it will fit. Or whether something is the hook, the dramatic thing that will grab the audience and should, therefore, come at the beginning. Or whether it is the climax and should come near the end of the story. Or whether it's a place where people can stop and rest and get some information at the same time as they're getting some time out—a small theater where videos would be shown, for example. Or whether something is absolutely vital so we have to be sure everyone sees it, or whether it is supplemental and could be off to the side."

Willard said that there are many ways to lay out an exhibit. "If you are telling a straightforward story, you might want to lay out the exhibit sequentially. If visitors need to know certain things before they can understand other things, you have to make sure first things come first."

One interesting layout he described resembles the spokes of a wheel. "You put your main focus in the center and then have other elements extend outward like rays or spokes. What visitors find on each path has similar weight and importance, so they can sort of pinball out from the center, following a particular path, and then bounce over to another. This works if you don't have to learn about things in a particular order," he explained. "Actually, any structure is fine as long as it serves the theme of exhibit."

Access for All

Museums and other public places are required by law to provide access to people with disabilities. Exhibit designers have to keep in mind that visitors may use wheelchairs or crutches to move through the exhibit. They may be visually impaired or unable to hear.

Rather than feeling limited by the legal requirements, Willard Whitson regards this as an opportunity to enhance the experience for all visitors, regardless of their abilities.

"There are so many strategies available to us. Sounds, smells, things to touch, hands-on materials, large-scale models of plants and insects, and more. It goes beyond having aisles wide enough for wheelchairs and places for people to sit down, though those are important too. Every bit of research I know says that when you design an exhibit to maximize the learning opportunities for people with disabilities, you also automatically maximize the learning opportunities for nondisabled visitors. What you are doing is enriching the experience, and everyone wins."

Willard recommends a tour through an existing exhibit space in a wheelchair, with a blindfold, and with earplugs, so that the planners can come as close as possible to the experience of a person with various disabilities. The information gained will be helpful in designing a new exhibit.

Decisions, Decisions

Melanie Ide said that the curators wanted to be sure that visitors to the Hall of Biodiversity would really be “grabbed” by the exhibit. The job of the designers was to figure out how to accomplish that.

“We decided that using the Museum’s collections was a good way to show biodiversity, and that showing different habitats would make it real to people.”

There was debate about whether to have nine dioramas, each representing a different biome, or just one diorama to focus on a single biome. “At one point we were going to have four dioramas, then two (a forest and a coral reef). In the end, a decision was made to have only one, but it would be a huge and very dramatic one, and it would put the spotlight on the biome where both diversity and the threat to it are greatest, the tropical rain forest,” Melanie said.

“We then decided to use videos to cover the eight other biomes and to locate a resource center off the main track. It is designed to be a quiet place where people can spend more time getting more detailed information.”

Both Melanie and Willard recommend doing a mock-up of the exhibit to see the layout in three dimensions. “You want to be able to look at it spatially so you can be sure it’s not a deadly march through a boring space,” Mel-anie advised. “There needs to be a focus and it needs to be a compelling one.” For example, the rain forest diorama in the Hall of Biodiversity is a dramatic demonstration of a richly diverse habitat that is at risk.

Willard cautioned against throwing in everything but the kitchen sink. “That’s hard, but you do have to be selective. At the Museum, curators choose those objects that best interpret the idea of the exhibit.” The Hall of Biodiversity is a very rich exhibit, filled with sights and sounds and smells and things to think about, but as Melanie said, “It is not heavily loaded with detailed information, because the issues are really very complex. We have tried to give the basic message, some essential information, and some examples. The idea is to provoke the visitor to want to know more.”

Once there is a basic layout, it is necessary to analyze all the components. “Everything should have a reason for being in the exhibit, and for being where it is and how big it is,” Willard said. “Everything should be in support of or relate to or be a reflection of that big idea. If it isn’t, you must seriously ask yourself why it is in the exhibit. If it doesn’t fit the big idea, then it doesn’t belong in the exhibit.”

Organizing an Exhibit: It's All About Teamwork

Can you imagine getting hundreds of people divided into dozens of teams to work together to do a job in half the time it usually takes? Suppose that job includes building a rain forest with nearly 200 trees, more than 1,500 shrubs and smaller plants, and 20,000 feet of vines, all inside a 129-year-old building in the middle of New York City. And suppose the work has to be done at the same time as 3,000,000 visitors a year traipse through the building and 1,000 other people are working in offices above, below, and immediately adjacent to the work site.

That is what Phil Fraley did for nearly two years. We asked him how he managed it.

"The first and most important thing is knowing how to get along with others. You have to be able to communicate your ideas, and to understand that everyone else has his and her own ideas. You have to be willing and able to find a way to compromise to make a project like this work.

"I have to deal on a daily basis with museum administrators, architects and designers, construction managers, scientists and curatorial staff, and my own staff. I believe it's the interpersonal relationships on all levels that make a job difficult or make it easier."

How does Phil build those relationships? "When I interview people for a job, I may look to see if they have specific skills or training in certain areas, but what I'm looking at more than anything is their personality: how they are able to relate to other people and work with other people. That's probably more important than anything else, because if someone is personable and willing, that person can always learn what needs to be done," Phil said.

"After I've had an opportunity to get to know each one a little better, I try to match the jobs to the people. I evaluate who they are and the skills they have and assign them to positions that allow them to use those skills. What I really want is for the people who work for me to be successful; I do not want them to fail. When people are successful at the tasks they do, they find enjoyment in it. And when they enjoy their work, they work harder at it. If you give people tasks that are too difficult and they continually fail, they won't want to come to work every day and do a good job."

Phil may be the boss, but he tries not to be bossy. "When I assign a task, I let the person do the task in whatever way he or she thinks is best. I may do something one way, but that doesn't mean it's the only or even the best way to do it. If I have a serious question about the way someone wants to do a task, I'll ask him or her to put together a plan. If it's well thought out, he or she should be able to explain to me why it is going to work. If he or she can't explain it, that's an indication that it needs to be thought about some more, or maybe we'll be able to work together to solve the problem," Phil said.

It's a two-way street, though, according to Phil. "The people who work for me have the opportunity to question what I say, and I should be able to explain to them what my reasons are. If I can't do that, then I need to go back and reconsider it also."

We asked Phil how he keeps track of the many tasks that need to be done. "I outline all of the tasks and then categorize them according to level of importance. If any tasks need to be done before others can be done, I arrange them in sequence. Based on past experience, I try to figure out about how long each task will take. Then I go to the people who are working with me and ask them to use my information to come up with their own schedule for accomplishing their part of the project."

Phil thinks it works best to ask people to make their own schedule rather than telling them what it should be. This is especially important when there is a lot of work to do and not very much time to do it. "My experience is that allowing people to tell me how much time they think they need means they accept responsibility for their jobs and feel committed to the project as a whole. Then they are more likely to meet their own schedule—and they even often finish ahead of time."

A Teamwork Tip

Willard Whitson, formerly the Senior Exhibition Developer and Associate Director of the Exhibition Department at the American Museum of Natural History, also thinks people do best when they do what they like and like what they do.

"Different people have different skills and interests," Willard observed. "Some people enjoy doing two-dimensional design while others are good at making models. Some people like to build things and others are good at writing or photography or producing audio/video material. I think there's probably a natural falling out of people into these various disciplines so that, with a little bit of attention, each person can be working in roles that suit him or her."

Willard recommends that students working on an exhibit define the teams and their roles and decide how big each team will be. Depending on when different tasks need to be done and how much time they take, some people might join more than one team.

No matter how systematic he is, Phil knows that sometimes things do not go according to plan. He told us about one of the first challenges he faced with this project.

"I had to organize a collecting trip to the Central African Republic. That involved working with doctors to make sure that everyone who was going got the necessary shots, and arranging for transportation for 15 tons of equipment and 20 people. While we were there civil war broke out and we had to be evacuated. And then I had to get all the equipment and the material we collected back to the United States. I found it pretty difficult to ask where a bunch of trees and leaves were while other people were dying. It felt heartless and cold during such trying times for the people who live there."

Phil got back to New York in December 1996, and it was March 1997 before all of the material was recovered. Then he oversaw the fabrication of 35 huge canopy and 150 small to medium trees. In addition, models were made of 61 species of smaller plants and vines and numerous insects and herptiles (reptiles and amphibians). All were then installed in the rain forest diorama, which opened in June 1988.

“There are sounds, smells, videos, and special effects, bringing the art of diorama making into the twenty-first century,” Phil told us proudly.

Making an Exhibit

Exhibits at the American Museum of Natural History sometimes tell their story through specimens, artifacts, and other material from the scientific collections. More often, though, lifelike models, dioramas, and other replicas are used. In addition, photographs, videotapes, and computer interactive and multimedia displays provide information and interest. A large group of people, most of them specialists in different media and techniques, work behind the scenes to make the exhibits that are seen by the public.

We asked Barrett Klein, a preparator and display maker in the Museum's Exhibition Department, why so many of the displays use replicas.

"Many people have asked me why we make the fake things. Is it a game, a test, a challenge to viewers? Why not use the actual specimens?

"There are a number of reasons. First, if we put a real specimen in a display, whether in a glass-enclosed case or a diorama, dermestid beetles will chomp away at it. They go for any organic material. They slip into the tiniest crevices and lay their eggs, and then their larvae destroy the specimen.

"Second, replicas can be made of durable materials, but dried specimens are not at all durable. A butterfly would fade and get dusty. If someone tried to brush off the dust, the delicate wings would be damaged and eventually might disintegrate. Aside from butterflies, many other specimens lose color through fading. For example, the hourglass marking on a black widow spider tends to fade when exposed to light, and soft-bodied specimens shrivel up."

But don't specimens in collections suffer the same problems? Barrett said that these specimens can be stored and preserved in ways that keep them suitable for scientific study but that would not be satisfactory for public display.

"Specimens in collections for study don't need to look as though they are alive. A systematic collection of arthropods, for example, consists of cabinet after cabinet of specimen boxes filled with carcasses with stakes driven through them. The legs are in various unnatural positions and the wings pinned out so everything is visible for study. The bodies may be shriveled. Sometimes the organisms are floating in jars full of preserving solution. Birds and mammals are usually preserved in collections as study skins and separate skeletons. And plants are preserved as pressed and dried herbarium specimens, which do not look at all lifelike. All of that is fine for scientific study. For public display, however, the illusion of life is important," Barrett explained.

Barrett said that an exhibit of specimen cases can be effective in some circumstances, but displays of organisms in their habitat are an especially good way to educate the public. "For that, dioramas filled with replicated plants and animals are the way to go. If these types of exhibits are successful, people will assume they're real. What we're aiming for is not to make the visitor say, 'Oh, wow!' but to say, 'Oh, well.' The goal is not to make visitors feel awe at the creation of illusion but to fool their senses so they think what they're seeing is real."

He showed us the many steps involved in making an arthropod replica, which begins with a real dried specimen. He removes the legs, antennae, and other delicate structures (such as wings from flies or butterflies) that would not survive the mold-making process. He makes a two-part silicone mold, which he uses to make a plastic cast of the body. It is a time-consuming process using materials Barrett and others have developed or modified to suit the desired result.

"That's what I love most about this job," Barrett said. "Most of these things have never been done before. A good chunk of my job is experimenting with methods and materials. For example, I am currently working on three new methods of representing not only insect wings but also legs, antennae, and mouthparts.

"I experimented with wire of different thicknesses," Barrett told us. He also tried making separate molds and casts for the legs. "As for the wings, there are a couple of different methods. The one I chose depended on the type of wing and, to a degree, how far the model is from the visitor. If I'm aiming for a convincing effect of, say, butterflies off in the distance, I can take actual wings and make color photocopies of both sides. Then I score along the veins so they pop out a bit, glue the two sides together, and then paint them. The color on the photocopy is really just a guide, since the process creates a surface that is too shiny and might fade with time.

"There's a method I like better for butterflies and moths, but especially for insects with transparent or translucent wings, like grasshoppers, mantids, cicadas, wasps, bees, and flies. I make them with a vacuum-form machine, the same way leaf cookies are made into leaf replicas. You get great resolution that way, with every bit of veining coming through."

Making Models for the Rain Forest

Barrett worked with two other preparators to create models of all of the arthropods and herptiles (reptiles and amphibians) in the Central African Republic rain forest diorama, which is the centerpiece of the Museum's new Hall of Biodiversity. "The mammals and birds are all taxidermy mounts—stuffed skins, basically—but we did all the fake animals," he told us. In addition, there is a wall of 700–800 life-size models to represent the awesome range of biodiversity in the world today.

"We made molds of spiders and myriapods (many-legged creatures, such as millipedes and centipedes) and, of course insects, including true bugs, beetles, hymenoptera, butterflies, and more. In all, there are models of between 300 and 400 arthropods, representing more than 60 different species, and more than 60 models of herptiles representing at least 14 species," Barrett said.

Baking Cookies, Museum Style

Vacuum forming is a technique used to make many copies of something—leaves, for example, or insect wings—from a plaster mold. Alec Madoff explained how leaves are made by this method.

"After the original leaf has been painted with many thin layers of plaster, the plaster mold resembles a cookie with a leaf impression on one side. These 'cookies' are embedded in a plaster block, and hundreds of small holes are drilled through the plaster around each leaf. The mold is then placed in a vacuum-forming machine. A sheet of clear acetate is placed over the block and is softened using a heating element. When the acetate starts to sag, you push a button that creates a vacuum by sucking the air down through the tiny holes. That pulls the acetate against the mold. It hardens in seconds, and then you pop off the sheet." The result is a sheet of perfect replicas of the original leaves.

Hundreds of thousands of leaves were made this way for the Central African Republic rain forest diorama, requiring teams of volunteers to spend untold hours carefully cutting them out of the sheets.

"It's very labor intensive," Alec said. "Every jagged edge and every curve has to be preserved." The edges are then sanded, and wires are attached to the rib lines of the leaves. "Then the leaves are individually painted on both sides with an airbrush, and then someone else goes over the leaves to burn in insect holes and make other imperfections so the leaves look natural. Leaves that are too perfect just don't look real," Alec said.

Insect wings also need to be cut out carefully. Then they are painted in colors and patterns that accurately mimic those found in nature. Finally, they are attached to the replicated body.

Barrett is a fanatic about accuracy, and that carries over to how replicas are placed in the diorama. An entomologist as well as an artist, he researched all of the organisms he has replicated to be certain their place in the habitat is true to nature.

"Some need very specific positions," he told us. "For example, beetle grubs have to be in something that has recently been dug up by a mammal, a rotten log, perhaps. Dung beetles have to be on elephant dung. I have butterflies lapping up water from puddles." He pointed to model in the diorama. "That parasitic fly is about to suck the blood of one of the ungulates. Very little of it is visible since it is be buried in the fur of the mammal." After all that work to make it look real? As far as Barrett is concerned, it is well worth the effort.

Two other preparators who swear by accuracy are Joyce Cloughly and Marco Hernandez. They built dioramas for the Museum's *Endangered!* exhibit and also worked on the rain forest diorama for the Hall of Biodiversity. We asked them how work on a diorama begins.

"The first thing to do is make a detailed scale model," Joyce said. "After collecting, that's probably the most important thing to do. If you make it to scale, you really get an idea of the problems you may encounter in a full-size diorama. You work out those problems in the model so when it comes to doing the real thing, there's no guesswork and no unpleasant surprises. The last thing you want is have to redesign things at that late point."

According to Marco, the model is like a blueprint of the diorama, and a lot of time is spent making it. "You get answers to all your questions about positioning of objects, how many of each thing you need, and where the light is coming from. If you're still asking questions about sun and shadows when you're installing the life-size diorama, forget about it. You might as well stop right there and do a model to work those things out."

Marco advises model makers: "Make it well and make it durable, because exhibits come and go, and the model may be the only record of how the exhibit looked."

Aside from replicas of plants and taxidermy mounts of animals, dioramas contain landforms such as hills and cliffs, rivers and ponds, rocks and possibly even features made by people. The backgrounds are painted on curved walls to give depth to the diorama so viewers feel as if they are looking out on a landscape through a window.

The formula and technique for achieving convincing perspective on a curved background wall are very complicated, Joyce said, but basically the artist needs intentionally to distort the painting so that it looks correct from the position of the viewer. A bison on the side of a diorama, for example, must be painted much wider than it actually is so that it doesn't look too narrow when viewed from the outside. If the viewer could climb inside the diorama, however, and look at the bison straight on, it would look unnaturally bloated.

Marco's talent and his art school training came in handy when he made the panda diorama for the *Endangered!* exhibit. "I made the landforms with a wire framework and wood, which was covered with burlap and then plaster. I had to do that first, before I began painting the background. I started out with a charcoal sketch of the landscape on the canvas. I composed it so the three-dimensional landforms in the diorama ran right up to where the canvas began. It was a real challenge to get it right."

Model Materials

Joyce Cloughly told us about some of the materials they use at the Museum for making diorama models:

- nonhardening clay
- Styrofoam
- papier-mâché
- wax
- epoxy putty
- two-part epoxy: when it hardens it makes very convincing-looking water
- wire for armatures
- twigs: these can make nice-looking trees
- chopped up leaves: for leaves
- human hair, bristles from brushes: for grass
- paint: acrylics, or casein for a less shiny surface

Another kind of display used in exhibits at AMNH relies on mounts holding objects inside a display case. Alec Madoff is a master mount maker, and we talked to him about his work.

"A mount is really just a piece of material—usually metal—that holds an object or artifact. The idea is to hold it securely in a position that shows what should be shown without damaging the object or drawing attention to the mount."

Alec has made mounts for objects as diverse as Peruvian pottery, Northwest Coast Indian masks, and, most recently, precious gems and priceless jewelry for the *Nature of Diamonds* exhibit at the Museum.

"We usually use brass, which can easily be bent to shape, and then cover it with plastic tubing or paint so that oxidation of the metal does not mar the surface of the object it is holding.

"Mount making begins with a talk with the exhibit designer about where a particular object will go on display. We also talk with the curator about what part or parts of the object should be visible. Then we talk to someone in the Conservation Department to determine how to protect the piece from damage. We work very closely with conservators, the people who are either repairing or restoring or just making sure all of the objects in the Museum are handled properly."

According to Alec, "The ideal mount is one that is invisible so the object looks as if it is just floating there. We try to use the thinnest possible piece of brass that will still hold it securely. The mount should come around from the back and extend just beyond the halfway point. We taper the end that shows in front so you don't see a hard edge."

Some Mounting Tricks and a Tricky Mount

Alec Madoff told us about some special mounting strategies he has worked out in the past.

- To show the back side of something, place a mirror in the case so the back or bottom of the object can be seen as well as the front.
- If some part of the message or design or some other detail is too small or hard to see for some other reason, have an artist make a drawing of it and add that to the display.
- Kwakiutl transformation masks are a special challenge. These show one face on the outside, and then they open up and show another face. "We wanted to show both, so we had to construct a multipart mount that held the mask open," Alec said.

Geralyn Abinader makes videos for the Museum. We asked her how she works with the other people who design the exhibit.

"The curator comes up with the idea for an exhibit, then the designer comes up with the different elements, including specimens, models, and videos. After they decide on a concept for the video, I meet with the designer, to find out how he or she envisions the video fitting in with the whole design, and the curator, to define the content, what the point is, what its purpose will be.

"There are several different types of videos. There's the story video, which can be experienced on its own and has a beginning, a middle, and an end. There are loops that just show examples of something over and over, and the viewer can catch the show at any point. Often it is something the visitor can't see in any other way: how a particular machine works, a peek into the microbial world, living animals beside a skeleton of an ancestor, things like that. Then there are

> ### *Making Words Work*
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> Captions, labels, posters, video narration, and other verbal information have a place in an exhibit. It is often necessary to tell as well as show. Exhibition Developer Willard Whitson gave us some tips on how to use words effectively.
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> "Keep it short; use the fewest words possible," he said. "You have to recognize that visitors breeze through an exhibit. They are not there to read; they are there to look and experience. So your exhibit text should be as eloquent and amusing and engaging and succinct as it can be. It should be jargon free; it should have a minimum of terminology that requires a visit to the encyclopedia and dictionary to get through it. That doesn't mean you can't use words that people aren't familiar with, but if you're going to use them you have to define them. And if you find you're defining every other word, then you're doing something wrong.
>
> "With labels, the main point you want to get across is: 'You are looking at a . . .' Make sure what you're writing is not redundant. That is, if the object is a blue vase, you do not have to say it is blue, but you should say where it comes from and how old it is and what it is made of. If you're showing three beetles, you don't have to say there are three of them, but you should identify them by genus and species."

interviews, which bring people into the exhibit to talk to the visitor about some subject related to the exhibit."

Besides the type of video, what does Geralyn have to think about?

"You have to choose a style that suits what you are trying to accomplish with the video. For example, for the *Amber* exhibit, we focused on artists in Russia who had spent their lives learning how to carve amber in a traditional way that has almost been lost. We interviewed them and showed them doing their work as a way of respecting their art and bringing it to life. In contrast, we took a much more dynamic approach for *Endangered!* We were trying to evoke emotions in our viewers, so there were a lot of graphics, special effects, jazzy music, quick cutting—all as a way of getting people involved."

Another important consideration is where in the exhibit the video will be shown. "The location often influences how long the video can be. Surveys have been done in museums to see how long people will stick around and pay attention in various locations. If it's in a main traffic area, people will come by, stop for a few minutes, and then move on. It doesn't matter how interesting it is. So if there's nowhere to sit, it's a good idea to keep your piece down to about three minutes because people don't last longer than that. If it's in a separate sit-down area, the piece can be longer, maybe eight to ten minutes," she said.

"You also have to take into account the type of display and the lighting around it. For example, if the video will be projected on a wall, the image will bleach out unless the area around it is dark. If it's on a video monitor, lights around it may cause glare. LCD screens have to be watched from directly in front, or the image turns negative. It may be necessary to try different locations and different display techniques to get it right," she suggested.