BioEd℠

Ants in Space

TEACHER'S GUIDE

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Ants in Space

Experiments Aboard the International Space Station

by

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EXPERIMENTS IN SPACE: Curriculum Projects on ISS

BioEd Online archives science data from a series of investigations in microgravity focusing on ants, butterflies, plants and spiders. Future students can repeat these investigations by building new habitats and formulating their own research questions or hypotheses. Archived results from each flight can be downloaded and compared, day-by-day, with observations of classroom habitats, permitting students to experience the excitement of space-based life science research. Visit the URL below for more details.

http://www.bioedonline.org/lessons-and-more/resource-collections/experiments-in-space/

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www.colorado.edu/engineering/BioServe

Center for the Advancement of Science in Space
http://www.iss-casis.org

National Aeronautics and Space Administration
http://www.nasa.gov

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Introduction

Launch of the Antares rocket carrying the Cygnus spacecraft from Wallops Island Virginia on January 9, 2014, up to the International Space Station. Photo © Orbital Sciences Corporation. (www.orbital.com).

Ants in Space is an educational life science investigation on the International Space Station (ISS). Appropriate for students of all ages, the experiment builds on previous, similar ISS-based investigations, which examined spider web spinning, butterfly life cycles, and plant root growth in microgravity. Images and videos of organisms living aboard ISS are available, free of charge and in near real-time, for viewing and comparison with ground-based organisms maintained by student investigators. In this authentic research, students ask their own questions and collect data to answer them.

On January 9, 2014, the Ants in Space live investigation traveled to the ISS on the first operational flight of the new Cygnus Advanced Maneuvering Spacecraft. Cygnus was launched by an Antares rocket from the NASA Wallops Flight Facility in Virginia. Video and other data from the experiments are scheduled for release in early 2014.

TEACHER RESOURCES

Downloadable activities in PDF format, annotated slide sets for classroom use, and other resources are available free at www.bioedonline.org.

Students, teachers and the general public worldwide are invited to engage in the Ants in Space experiment. To do so, each participant (or group) simply must set up a "ground-based" chamber to observe and compare ants living in Earth's gravity to those living in microgravity aboard ISS. This investigator's manual describes the ant investigation and provides the necessary details for students and teachers to conduct their own data collection and analysis. The manual begins with a primer on ants, followed by details about the mission, instructions for building an inexpensive ant chamber, and ideas for investigation questions.

The Canadarm2 on the International Space Station moves toward the Cygnus commercial cargo spacecraft, January 12, 2014. Photo courtesy of NASA. (http://www.nasa.gov/)

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Fossil rock containing an ant, recovered from the Florissant Fossil Beds National Monument, Colorado. Photo courtesy of the US National Park Service (www.nps.gov).

Why Study Ants?

Ants are among the most abundant and diverse of all insects. In fact, it has been estimated that they comprise 10% of Earth's total biomass. Ants are social insects, thought to have evolved from wasp-like ancestors about 130 million years ago. They are members of the family Formicidae (for-mis-cid-ee) with an estimated 22,000 species, about half of which have been classified.

Ants are found on nearly every landmass on Earth. Some species live in structured nests below ground; others live in mounds above ground and some live in trees. Ants' ability to survive over millennia may be partly attributable to their social organization, which enables colonies to modify habitats to accommodate changing needs, obtain resources and defend themselves.

All ant species live in colonies, which operate without central control. A colony consists of one or more reproductive females, called queens, which have no authority, and serve strictly to lay eggs. The ants we see walking around are sterile, female workers that do not mate.

Ant colonies are distributed systems, in which collections of independent individuals or entities appear to act as single, coherent units. In fact, no individual ant directs the behavior of another. Instead, an ant's actions are influenced by cues it receives from other ants and the environment. The combined responses of single ants allow the colony to respond to changing conditions. By studying ant behavior, investigators are learning how to improve other distributed systems, such as the Internet, and are gaining insights into networks as complex as the human brain.

Large ant mound located west of Taos, New Mexico, as seen from a hot air balloon. Photo © Gregory L. Vogt, EdD.

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All About Ants

Female harvester ant. Harvester ants collect seeds which are stored in the nest in granaries. Photo © Joseph Berger (www.bugwood.org).

With elbowed antennae projecting from large, bulbous heads and slender waists, ants are easy to distinguish from other related insects, such as wasps. Ant heads contain many sensory organs. Most ant species do not see distinct objects, but their large compound eyes, consisting of many small lenses fused together, provide good motion detection. Ants also have three simple eyes, or ocelli, on top of the head to detect light. A few species of subterranean ants are completely blind.

TYPICAL ANT

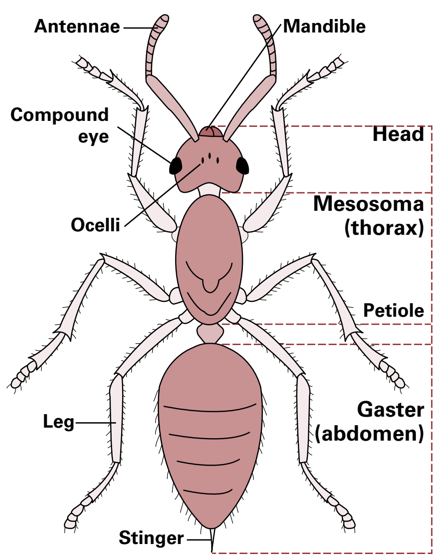

Illustration by G.L. Vogt, EdD.

The most important sense for ants is olfaction. Ants "smell" with their antennae, which detect chemicals, air currents and vibrations. Ants also communicate through antennae contact. When one ant touches another with its antennae, it can determine if the other ant is a nestmate by detecting the chemicals on the ant's body.

Ant heads feature two mandibles, used to carry food and other objects, such as material for constructing nests. Mandibles also are used to husk seeds and provide defense. An ant's gaster, or abdomen, contains reproductive and respiratory organs, and the excretory system. Many species have stingers to subdue prey and defend the nest. Like all insects, ants have six jointed legs. Small hooks at the ends of their legs enable ants to climb and hang on to things, perhaps even in microgravity.

Ant Colonies

Most ants within a colony, and the ones we usually see, are wingless female "workers." These ants never reproduce. Instead, they forage for food, care for the queen and the eggs, protect the nest if attacked, build mounds, and dig tunnels and chambers. In almost all ant species, males are produced only when "reproductives"—daughter queens and males from different colonies—meet to mate. Afterward, the males die and the newly mated queens found new colonies.

Ant colonies can last many decades, and they may have one or a few queens, whose only role is to lay eggs. Reproduction varies by species. Some queens reproduce asexually, while others mate with one or more males and store sperm to fertilize future eggs. A harvester ant queen, for example, can live for 30 years, using the sperm from a single mating session at the beginning of her life to produce new workers year after year. If an egg is fertilized, a female worker (diploid, with two sets of chromosomes) will develop. Males, which develop from unfertilized eggs, are haploid (only one set of chromosomes). Adult ants develop through complete metamorphosis: begin as eggs, become larvae and pupae, and emerge as adults.

Individual ants are not specialized for a particular job. Instead, tasks are allocated based on colony needs and environmental changes. For instance, a harvester ant colony performs four different kinds of tasks outside the nest: searching for, and returning with food (foraging); searching the mound and surrounding area to identify the best places for foraging (patrolling); carrying out dry soil from inside the nest (maintenance); and sorting and removing all kinds of waste (called midden gathering). A colony's oldest ants usually perform these tasks. Ants that work outside the nest sometimes will switch jobs, if more ants are required for a different job. Younger ants stay within the nest, where they feed and care for larvae, sort food, maintain the nest and attend to the queen. Workers in harvester ant colonies live for only a year.

Ant Communication

A basic question about ants is how their colonies function without central control. In fact, a colony's collective behavior is governed by interactions and brief antennal contact between individual ants. No single ant can assess the colony's needs or tell other ants what to do. Ants communicate through pheromones (excreted chemicals that trigger a response in other individuals) and cuticular hydrocarbons (chemicals present on the body surface), and by touch and vibration. Their antennae detect chemical odors, which differentiate the ants of one colony from those of another, and even among ants that perform different tasks within the same colony.

The Ants in Space experiment performed on ISS investigates how a colony works together to search for food, water, nest sites and other important resources, and also to identify potential threats. The investigation is described in detail in the next section.

Different ant species eat nectar, fungus, other insects, seeds and/or worms. In some species, an ant that finds food may deposit a pheromone "trail" on its way back to the nest. Foragers leaving the nest follow this trail to the food, and add more scent on the way back to reinforce the signal for others. When the food source is exhausted, no more scent is added to the trail, and the chemical signal dissipates (in some cases, very quickly).

However, not all ant species create trails. If the food tends to be scattered in small pieces, one ant can carry it back to the nest. For example, harvester ants eat seeds, which a single ant can transport. There is no point in leading more ants to the place where one ant found a single seed. In such cases, the ants do not lay pheromone trails.

Colonies sometimes regulate the number of ants foraging through interactions among ants. For example, a foraging harvester ant spends most of its time outside the nest searching for food. When food is more abundant—say a lot of seeds blew in with the wind the day before—foragers locate food easily and return more quickly. Outgoing foragers leave the nest at a rate commensurate with the flow of foragers returning with food. When food is abundant, foragers return more quickly, and more new foragers leave the nest.

Different ant species regulate their searches in various ways, but always through simple interactions. When observing ants, one can seek to answer questions such as: What gets the ants out of the nest? Is it the rate of antennal contact? Do ants seem to be responding to chemical trails on the surface?

Of course, ants do much more than forage. They build and maintain nests, and some species collect food to feed fungi, which serves as a food source. For further information about ant colony behavior, consult biologist Dr. Deborah M. Gordon's web page (http://www.stanford.edu/~dmgordon/), and the *Stanford News* article, "Evolution Shapes New Rules for Ant Behavior, Stanford Research Finds," (http://news.stanford.edu/news/2013/may/ants-forage-evolve-051413.html). ■

Notice the grooves on the head of this pavement ant. Photo © Joseph Berger (www.bugwood.org).

When an ant finds a food source, it my create a chemical trail. When many ants follow and reinforce the same signals, the pathways can become very large. Photo © Fir0002 (www.wikipedia.org).

Pavement ant returning to the nest with food. Photo © G.D. Alpert (www.antwiki.org).

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Pavement Ants: The "Ant-stronauts"

***Tetramorium caespitum*, also known as the pavemant ant, has a petiole with two segments (section is circled in red).** Photo © Joseph Berger (www.bugwood.org).

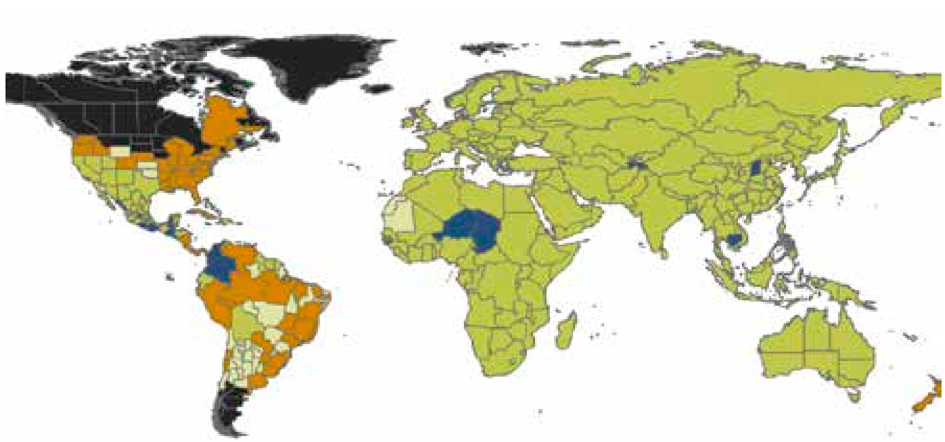
The experiment aboard the Space Station features *Tetramorium caespitum*, otherwise known as the pavement ant, which is dark brown to black, and about 2.5–4.0 mm long. This species was chosen because it is common in many parts of the US. The pavement ant is fairly easy to identify by the grooves on its head and thorax. Note the two segments that connect the thorax and abdomen. This structure, called the petiole, always has two segments in the ant subfamily Myrmicinae—to which Tetramorium belongs (see image, left).

Pavement ants are native to Europe, and probably first arrived in North America on trade ships during the 1700s. They now can be found from New England to the Midwest and southern U.S. They also are present in some parts of California and Washington. Pavement ants sometimes are considered pests because they form colonies near building foundations, under slabs and even inside walls, and they sometimes forage for food inside dwellings. The genus Tetramorium includes more than 400 species and subspecies of ants distributed around the world. The global distribution of Tetramorium is shown below.

A pavement ant nest typically has one queen and a few thousand to 10,000 of sterile female workers. The queen's sole purpose is to lay eggs. The female workers complete all other activities required for a colony to thrive. Some nests have more than one queen. With increased egg production, these colonies can grow quickly. A pavement ant usually will live a few weeks to several years; some queens survive up to 10 years. When a queen dies, the nest does not adopt or produce another, and the colony will survive only as long as the remaining workers do.

Pavement ants are quite adaptable. They can nest in urban areas, under

Global Distribution of Tetramorium



Genus status: **Present** **Likely present** **Uncertain** **Present as exotic** **Absent**

Map © Steve Shattuck (http://www.antwiki.org/wiki/Tetramorium).

Pavement ants will battle other pavement ants over resources. Photo © Joseph Berger (www.bugwood.org).

or near sidewalks, foundations and driveways—or in more rural locations, alongside wooded areas or under rocks, frequently by water. In the spring and summer, they can be found engaging in huge conflicts with neighboring ant colonies. If you have observed a large number of ants grouped together around the cracks or creases in a sidewalk or driveway, you may actually have been watching a pavement ant battle.

Pavement ants are scavengers that feed on sugar, nectar, fruits, dead insects and seeds. They are most attracted to foods with high fat or sugar content. Workers may forage for food as far as 30 meters from the colony, and they will establish pheromone trails to food sources.

You can learn more about pavement ants by visiting the websites below.

- **Animal Diversity Web** (http://animaldiversity.ummz.umich.edu/accounts/Tetramorium_caespitum/#f6be517405543262b8921d4e299f4d5b)
- **AntWiki** (http://www.antwiki.org/wiki/Tetramorium_caespitum
- **University of Nebraska-Lincoln** (http://lancaster.unl.edu/pest/ants/pavementant.shtml)
- **University of Pennsylvania College of Agricultural Science** (http://ento.psu.edu/extension/factsheets/pavement-ant)

PREVIOUS ANT MISSIONS

One of the first ant investigations in space was developed for the 1983 Space Shuttle Mission STS-7. Students in Camden, New Jersey, designed an experiment to determine if microgravity affects an ant colony's social structure. The investigation was flown in a trash can-sized container mounted to the wall of the Space Shuttle Challenger's payload bay. Unfortunately, the canister was purged with dry air during payload processing, dehydrating the ants before the flight. The students did not learn their ants had died until the Shuttle returned to Earth.

In 2003, a second ant investigation was flown on STS-107. The small colony of ants living in a gel material began tunneling while on the Space Shuttle. Students in Syracuse, New York, compared the activities of the flight ants with those in a control colony at their schools, observing that ants on the Shuttle were more active than their control ants. Video footage from this ant experiment may be viewed at http://spaceflight.nasa.gov/gallery/video/shuttle/sts-107/html/fd5.html/.

There are several reasons to fly ants into space. First, ants are tiny and a community of 80 ants does not take up much space, even within a supportive habitat. Second, because ants are very social insects, observing them in microgravity enables students to study both individual behaviors and interactions between ants. Finally, ants are easy to obtain, and it is simple for students and other investigators around the world to set up effective chambers for comparison in their classrooms.

We still have much to learn about how organisms behave in the seemingly weightless environment of Earth's orbit. For a description of microgravity and its effects on living organisms, visit the Experiments in Space section on BioEd Online.

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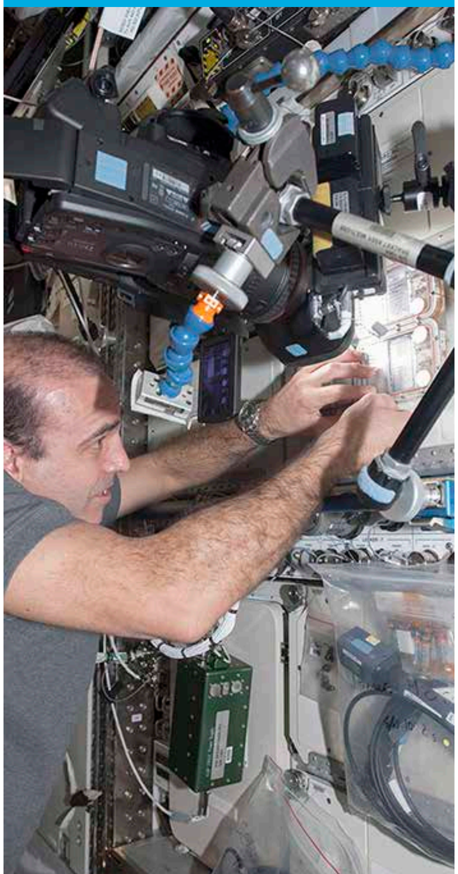
The Experiment in Microgravity



NASA astronaut Rick Mastracchio, Expedition 38 Flight Engineer, works with the Ant Forage Habitat in the Destiny laboratory aboard the ISS. Photo courtesy of NASA.

MISSION LAUNCH: ORB-1

To view the launch of the Antares rocket carrying the Ants in Space investigation, visit the URL below.

http://www.nasa.gov/mission_pages/station/structure/launch/orbital.html#.Us8F8vZZUi0

The Ants in Space investigation on the International Space Station (ISS) was conducted in January 2014. The experiments examined how pavement ants work together to search a novel space. Eight habitats, each containing approximately 80 ants, were transported to the ISS on the unmanned Cygnus resupply spacecraft, launched by an Antares rocket from NASA Wallops Flight Facility in Virginia.

All videos, images and other resources related to the Ants in Space mission are archived on BioEd Online, so your students can follow the ISS experiment and conduct their own ground-based ant investigations at any time.

Different species of ants solve search problems differently, depending on their ecology. Ants we find in our kitchens often are invasive species, able to thrive in many parts of the world because they are very effective at searching. Regardless of species, an ant colony must monitor its environment to find food, water and nest sites, and to detect potential threats, such as encroachment by ants of another colony. Because colonies work without central control, this monitoring must be done collectively. A colony's goal is to have an ant everywhere all the time, so that if something happens, or if food becomes available, an ant will be there to find it. Of course, no colony can do this perfectly. The experiment investigates how colonies adjust their searching strategies in changing conditions.

If you asked a group of people to find a needle in a haystack, they might devise a plan to divide the haystack and have each person search a small part of it. Ants can't do that because they have no way to figure out what the whole haystack is like. Instead, they must cover all the ground, so that if there is food anywhere in their domain, some ant eventually will encounter it.

There is a tradeoff between how thoroughly the ants search, and how much ground they can cover. A previous experiment by Deborah Gordon, PhD, done with Argentine ants, showed that ants adjust their search paths based on population density, which they assess by the rate at which they meet nest mates. If there are many ants in a small space, there will be frequent interactions and the colony can be very thorough. Each ant moves in a circular pattern to search a small area, and another ant will be available to search nearby. But when there are fewer ants, or when they are spread over a larger space, they will meet less frequently. In such cases, each ant will cover more ground by using a straighter, longer search path.

The Ants in Space experiment allows the observation of ant behavior at two different population densities in microgravity (aboard the ISS) and under normal Earth gravity conditions. It seeks to identify if ants in microgravity: (1) interact at a different rate, and/or (2) adjust the shape of their search paths differently than ants on Earth do.

Key Questions

1. When a group of ants is searching a new space, does the shape of each ant's path depend on the number of ants per unit area?

2. Do ants in a microgravity environment exhibit search behaviors and search patterns different from those observed among ants in Earth's normal gravity environment?

You and your students may come up with many other important questions about the exploratory behaviors of ants on Earth and in low-Earth orbit (microgravity).

The Investigation

Eight habitats, each containing approximately 80 ants, were transferred to the ISS on January 13, 2014. The Ants in Space flight habitat is a shallow rectangular box with a clear top through which to view the ants. It is just a few millimeters deep, but provides ample room for ants to move about freely. For ease of handling, the habitats were mounted on plates in sets of four (two plates, each with four habitats). For comparison, matching habitats holding similar numbers of ants were maintained on Earth. During transport to the ISS, and for three days before the experiment was conducted, the ants were kept in the small "nest" area of each habitat. The nests contained plaster of Paris infused with a nutrient solution to provide food and water.

Once loaded on the ISS, the eight ant habitats were secured in place, and two identical experiments were conducted on two different days. Each day, four ant habitats were set up in front of an HD video camera. The astronaut conducting the experiment lowered the barrier between the nest area and Search Area 1, thereby allowing the ants to explore approximately one-half of the total area of the habitat. The ants' movements in Search Area 1 were recorded on video for 25 minutes, after which time, the astronaut lowered the barrier to Search Area 2 in each habitat. Video recording continued for approximately more 30 minutes.

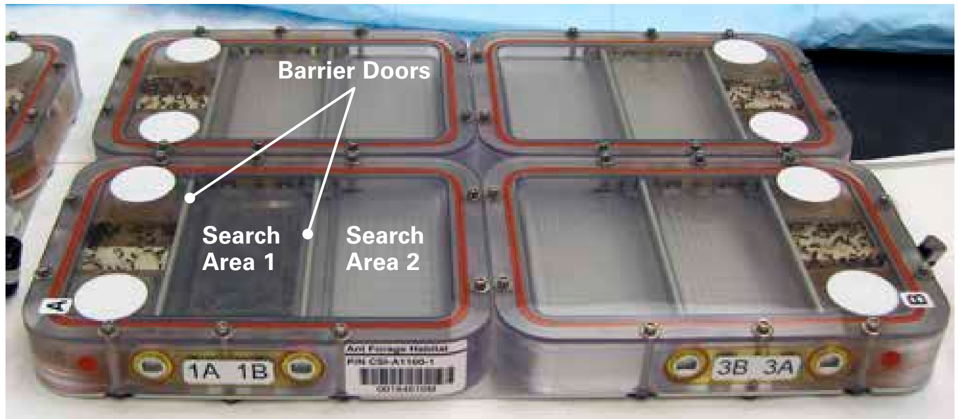
Video of the ants, transmitted to NASA, is available on BioEd Online (www.bioedonline.org). Investigators on Earth also are using a software program designed to track the ants' movement patterns and interaction rates. This information will be available later in 2014 on BioEd Online. Students and other investigators will be able to make direct comparisons of the "space" ants with their own ants living in habitats they construct from inexpensive materials. Instructions on how to build ant habitats with similar dimensions to those used on the ISS are provided later in this guide. (For the complete details of the experiment conducted in microgravity, see "ISS Protocol for *Tetramorium caespitum*," on page 9.) ■

Closeup of pavement ants in their habitat prior to release into Search Area 1 (see "ISS Protocol for *Tetramorium caespitum*," on page 9). Photo courtesy of NASA.

Pavement ant workers may forage for food as far as 30 meters from the colony, and establish pheromone trails to food sources. Photo © Babs Padelford, Fontenelle Forest (www.fontenelleforest.org).

ISS Protocol for *Tetramorium caespitum*

The steps described below summarize the experiment protocol followed by BioServe Space Technologies as they managed the transfer and loading of the ant habitats onto the Cygnus Advanced Maneuvering Spacecraft. The Cygnus Orbital-1 Mission carrying the experiment launched to the International Space Station (ISS) from Wallops, Virginia, United States on January 9, 2014.



View of four ant habitats, pre-loaded with *Tetramorium caespitum*. Photo courtesy of BioServe Space Technologies (www.colorado.edu/engineering/BioServe/).

Science objective. This investigation examines and compares collective search behavior among *Tetramorium caespitum* (pavement ants) in two different population densities, and in microgravity (on the ISS) and normal gravity conditions (on Earth).

Overview. Eight small ant habitats are mounted in sets of four on two mounting plates. Each habitat, loaded with approximately 80 worker ants from three different colonies (all females), are prepared for space-based experiments. Another set is prepared for ground control experiments.

- **9–11 days before launch.** The ant habitats are partially assembled and hand-carried to Wallops Island.

  A cotton wick is threaded from the liquid reservoir on the underside of the habitat, through a tiny hole that separates the liquid reservoir from the nest area. Plaster of Paris is mixed and poured into each ant nest area, leaving part of the wick exposed on top of the plaster and the remainder is positioned in the liquid reservoir. The plaster is allowed to set for 24 hours. A window is placed and secured on the top of each habitat.

  Note: The wick will transfer nutrient-rich moisture from the liquid reservoir into the plaster, enabling the ants to obtain the moisture and nutrients they need. The moistened plaster will keep the nest area humid, but not wet.

- **5–8 days before launch.** After arriving at Wallops Island, the ants are monitored for health and activity, then separated into appropriate groups in preparation for final assembly of the habitats.

  Minimal Essential Media (MEM) is the liquid used to provide moisture and nutrients for the ants. It has .03% v/v methylparaben added as an antifungal agent. The MEM is mixed and added to the reservoir in the ant habitat. At this point, the habitats must sit for at least 24 hours, so that the plaster and wick are saturated, but no standing liquid is observed within the nest area.

  Between 24 and 36 hours before transfer to NASA and Orbital Sciences, each of the eight flight habitats and eight ground control habitats are loaded with approximately 80 worker ants.

- **Four days before launch.** The flight and ground habitats are inspected for a final time to ensure the ants are healthy. The ant habitats are attached to mounting plates (four habitats per plate), packed in foam, placed in a soft stow bag, and handed over to NASA and Orbital Sciences. The payload is secured on the launch vehicle, where it remains in the dark at ambient temperature until it is transferred to the ISS. During this time, the ants have access to water supplemented with nutrients, ensuring that they remain as healthy as possible on their trip to space.

- **Launch and delivery.** After launch, the Cygnus vehicle takes two days to rendezvous and berth with the ISS. Given the limited lifespan of ants, the ant habitats are transferred to the ISS within one day of berthing.

- **Aboard the Space Station.** On the day the ant habitats are transferred to the ISS, they are activated within a relatively short time by the astronauts.

- **Activation.** All of the habitats are activated on the same day, two habitat sets at a time, in front of two different HD video cameras. The recordings are staggered between the two cameras by 30 minutes, with both habitat sets recorded at one time for a total of four recordings.

  The habitats are placed in a location with limited reflection and good visibility, focus and lighting. The cameras are positioned so that only two small ant habitats fill the viewfinder.

  The astronaut begins recording, then lowers the barrier between the nest area and Search Area 1 on the habitats. The ants' search and exploration within Search Area 1 is videotaped for the next 25 minutes. After 25 minutes, the astronaut lowers the barrier to Search Area 2 in the habitats. This allows observation of the same number of ants in a larger space, and thus at lower density. Video recording continues for 30 minutes, after which time, the experiment is completed.

  The ants live out their normal life spans on the ISS, living for an extended period of time on nutrient-rich moister in the habitats.

- **Measurements and observations.** Once the video is completed, astronauts transmit the video from ISS to NASA. Investigators on Earth use a software program specifically designed to track and document ants' search path patterns, the number of interactions between ants, and if/how interaction rates affect movement patterns.

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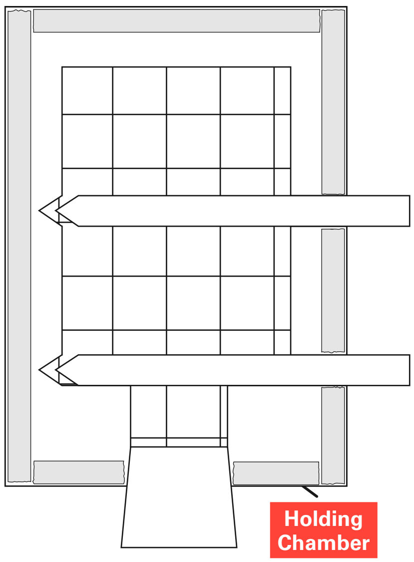
EARTH-BASED HABITAT



MATERIALS TO MAKE ONE HABITAT

- **12-in. x 18-in. sheet of craft foam, 5 mm in thickness (for example, Silly Winks foam sheets); available at craft stores or online**
- **Double-sided tape (clear)**
- **5-in. x 7-in. (13 cm x 18 cm) sheet of clear acrylic (plastic) for picture frame glazing; available at craft stores. (Transparency film may be substituted, but use care to seal it tightly to the habitat.)**
- **Copy of "Habitat Pattern" page**
- **Pair of scissors**
- **Ruler marked in centimeters**
- **Fine tip marker pen or ball point pen**

***Optional:* Glue stick, razor knife, straight edge, cutting board**

Illustration by G.L. Vogt, EdD, and M.S. Young.

How to Build the Earth-based Habitats

Students will be able to formulate and ask their own questions about ant behavior, or conduct experiments that match those on the International Space Station. The plans below describe how common materials can be used to construct an inexpensive, ground-based ant habitat similar in size and design to the ant chambers aboard ISS. To view a video showing how to build the habitat, visit the Ants in Space page on BioEd Online (http://www.bioedonline.org/lessons-and-more/resource-collections/experiments-in-space/ants-in-space/).

A crucial feature of both space- and Earth-based habitats is the capacity to increase the size of the foraging area. Initially, the ants are placed in a small holding chamber. In stage one of the investigation, the first of two sliding partitions (doors) is opened, allowing the ants to enter Search Area 1. Students will observe how ants behave in this relatively confined space. In stage two, the door to Search Area 2 is opened, effectively doubling the space available to the ants. Students again will observe the ants, now at lower population density as they spread out to explore this larger area. Students will be able to compare ants' search/exploration behavior during stage two to the behavior exhibited in the higher population-density environment of stage 1.

Procedure

1. Cut a 5-in. by 7-in. (127-cm x 178-mm) rectangle from the sheet of craft foam. This rectangle will serve as the base of the chamber. With the ruler and marker, draw a 2-cm grid on one side of the sheet. If you teach older students or will be observing very small ants, use a 1-cm grid instead.
2. Use the remaining sheet of craft foam for cutting out the frame and doors of the habitat (see "Habitat Pattern," p. 11). Place the pattern over the remaining foam, and secure it in place with tape (or a light coating of glue from a glue stick). Using scissors or a razor knife and straight edge, carefully cut out each piece, discarding the "gray" areas on the pattern. Alternatively, cut out the pattern and trace it on the sheet of foam before cutting out the pieces.
3. Position the base with the grid side up. Reassemble each pattern piece over the base. Using double-sided tape, fasten the three frame pieces to the base of the habitat (see "Habitat Base and Frame," p. 12).

   Important: Do not glue or tape pieces 4, 5 and 6; they must be able to slide. Also, do not distort the frame as you press it into place. It must fit snugly around the three sliding doors, with no gaps through which ants might escape.
4. Use double-sided tape to fasten the glaze or transparency sheet firmly over the top of the assembled foam. Do not tape doors (see "Completed Habitat," p. 13). ■

Habitat Pattern

1. Make precise cuts on the solid lines to ensure a snug fit for habitat doors.
2. Discard pieces marked in gray. The frame will have notched areas corresponding to the shape of the sliding doors.

To ensure that the pattern prints at the correct size from a PDF, follow the steps below.

1. Select: Print

2. Find: Page Sizing and Handling

3. Select: Actual Size

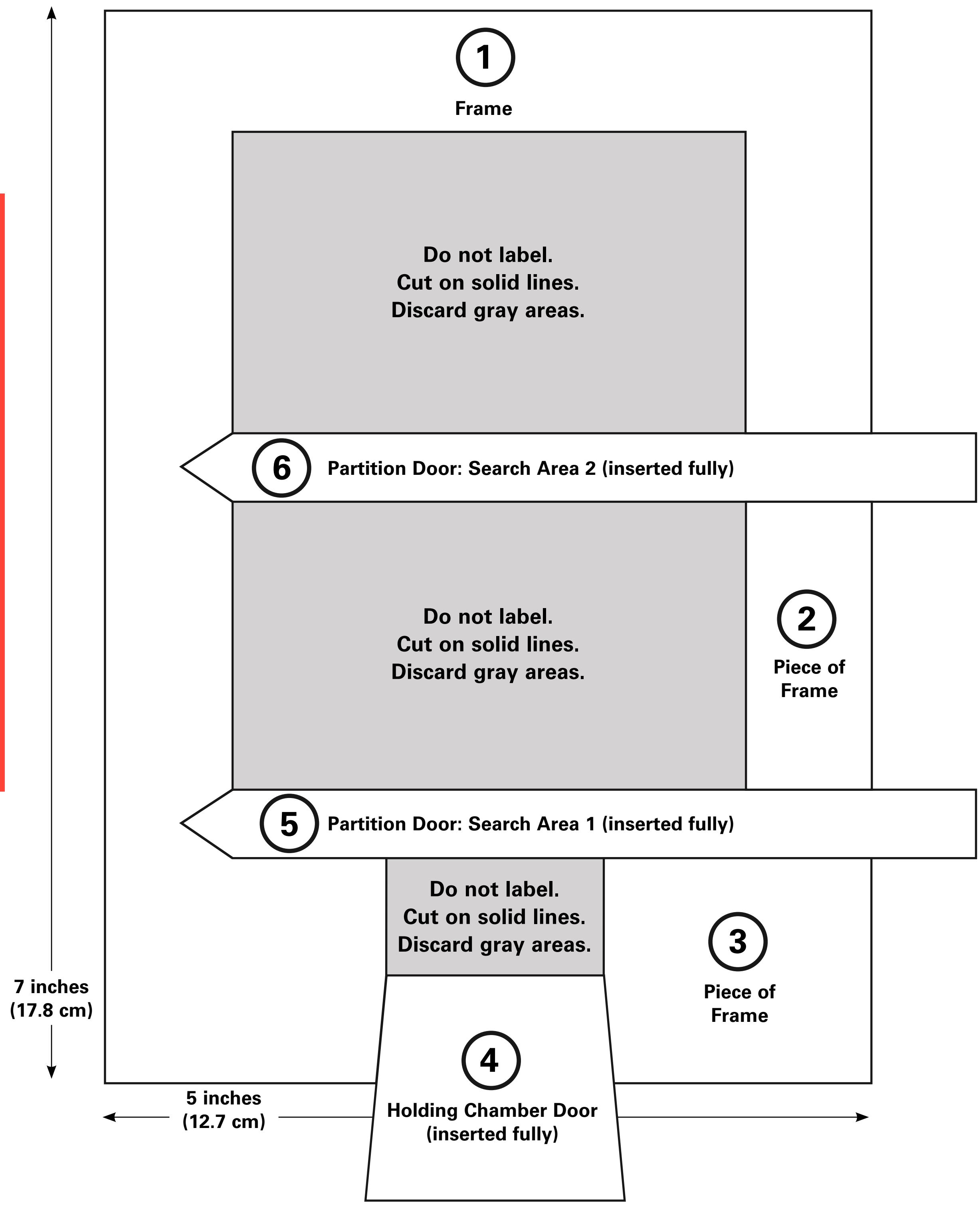


Illustration by G.L. Vogt, EdD, and M.S. Young.

Habitat Base and Frame

1. Reassemble each pattern piece over the base (doors removed to show taping areas).
2. Place double-side tape between the frame (pieces 1, 2 and 3) and the base, without placing tape beneath door areas. Press the pieces firmly into place without distorting the frame. Once in place, the sliding doors must fit snugly into the frame with no gaps through which ants might escape.

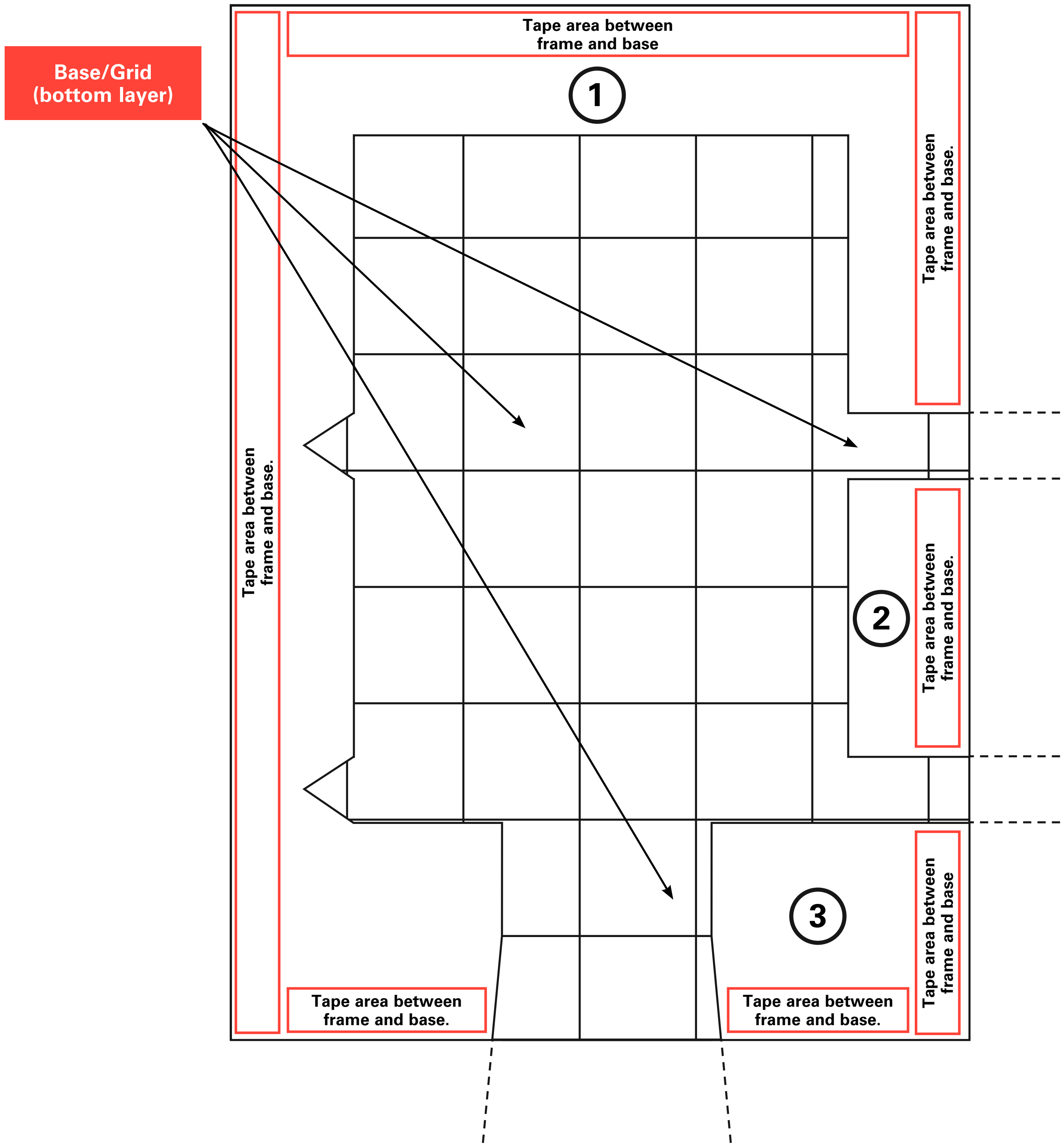


Illustration by G.L. Vogt, EdD, and M.S. Young.

Completed Habitat

1. Use double-sided tape (shown in gray below) to fasten the sheet of clear acrylic plastic (or transparency film) firmly over the top of the assembled habitat. Do not place tape over the sliding doors (pieces 4, 5 and 6).
2. Slide both partition doors firmly into place prior to loading ants into the habitat.

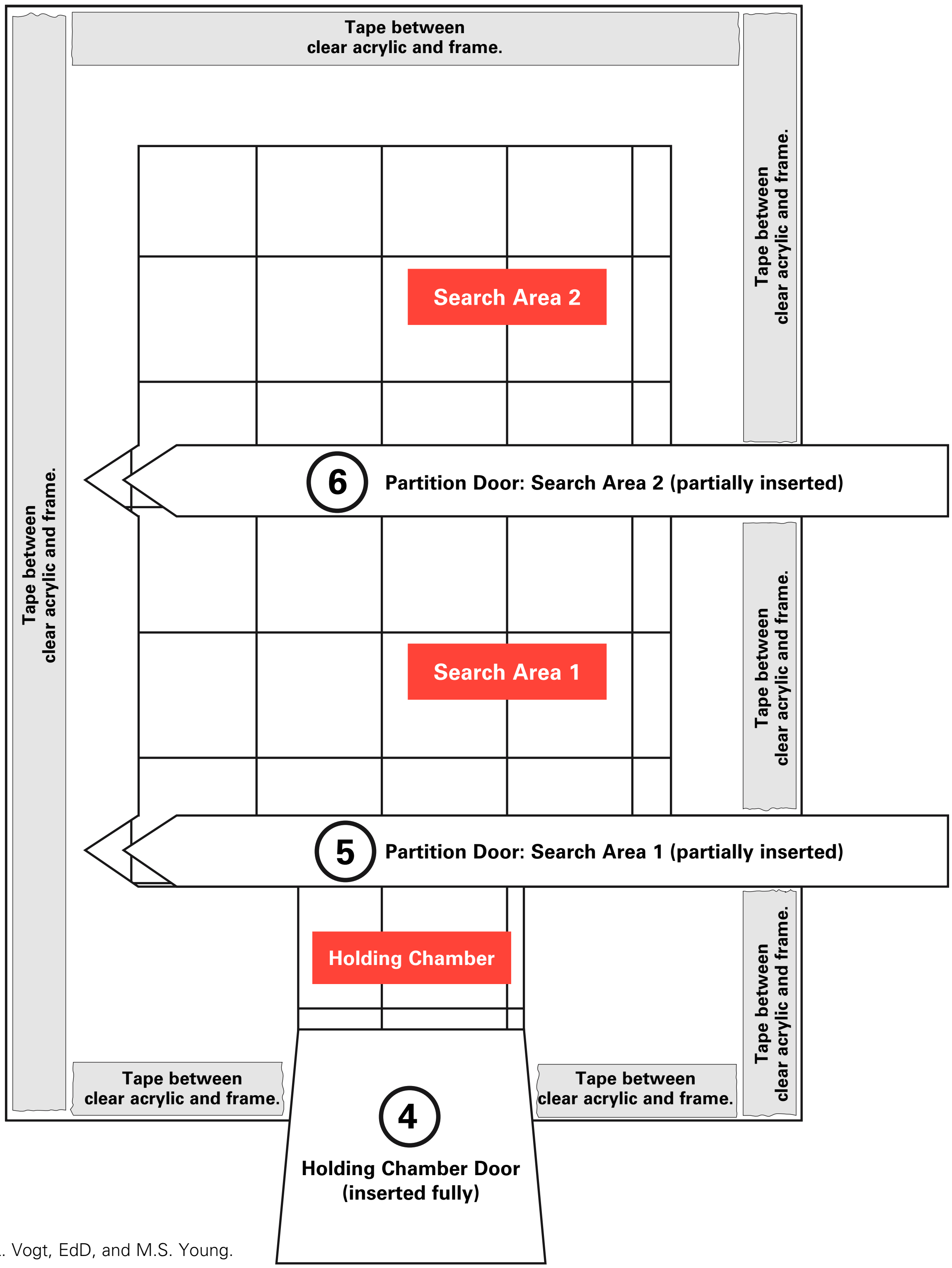


Illustration by G.L. Vogt, EdD, and M.S. Young.

7

Collecting and Adding Ants to the Habitat

Even pavement ants, especially in large colonies, can bite or sting when handled without care. Photo © Joseph Berger (www.bugwood.org).

Although ants seem to be everywhere (including places you do not want them), it can be a challenge to find and safely capture them for an investigation or to stock a colony. Only worker ants are needed for this investigation, so no excavation of ant nests is necessary. Arizona State University provides a useful, downloadable booklet about ants and how to collect them (http://askabiologist.asu.edu/collecting-worker-ants).

Pavement ants often establish colonies under objects, such as bricks or boards, or on the surface of the soil, or near the building foundations. If pavement ants do not live in your region, Argentine ants (*Linepithema humile*) are a suitable substitute. Originally from northern Argentina, these ants are common pests in the southern United States and Hawaii, and in Mediterranean-type climates in other countries, including New Zealand and Japan. Argentine ants are small—only 1/8-inch long. They live in shallow mounds under wood, slabs or debris.

Students should be encouraged to collect their own ants. There are more than 12,000 species of ants in every conceivable habitat on Earth. They use different resources, and employ different search strategies. Thus, different ant species may behave differently in this experiment. Any species is acceptable, but ants found in or near human buildings are likely to be invasive species that are effective at searching. Those species are especially good candidates for this investigation, certainly better than species like harvester ants, which forage for single seeds and do not have a very effective process for group search. If students living in multiple states and countries conduct the Ants in Space experiment with a variety of ant species, we may be able to compile the results into a guide to global ant search behaviors.

Ants often can be found under debris, under rocks or along the edges of buildings or sidewalks. Sometimes it is necessary to watch a small area for a few minutes before ants become visible. Individual ants often can be picked up with the bristles of a moistened watercolor paintbrush. The Science Tool Box website provides instructions for making an insect aspirator, which uses suction to collect ants (http://www.sciencetoolbox.com/articles/article_06-16-04.html).

Aspirators also can be ordered online, including from the vendors listed below.

- **BioQuip Products** (http://www.bioquip.com)
- **Carolina Biological Supply** (http://www.carolina.com)
- **Ben Meadows** (http://www.benmeadows.com)
- **Forestry Suppliers** (http://www.forestry-suppliers.com)

If ants are being collected on sand or soft soil, use a trowel (hand shovel) to scoop up several ants at a time, along with small amounts of soil. Bait, such as peanut butter or pecan cookies (“sandies”), also will attract some species of ants. Place the bait on a sheet of paper or index card, and wait for the ants to arrive. Use a zip-top bag or plastic container with a lid to transport the soil or bait and ants back to the classroom.

SAFETY ISSUES AND TYPE OF ANTS NEEDED

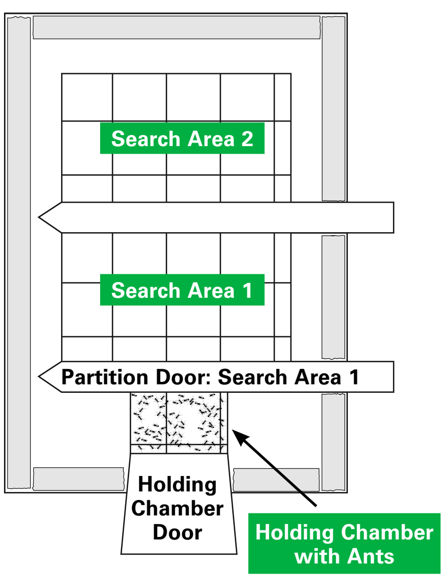
Warn students that some ants, even pavement ants, may bite or sting. Red imported fire ants, common in the southern United States, form large mounds containing colonies with as many as 500,000 workers and multiple queens. These ants are extremely aggressive and will swarm out of their nests to attack in large numbers. They are not appropriate for this investigation.

Harvester ants are found primarily in drier regions of western and southern North America. They have a painful sting, but harvester ants are commonly supplied with commercial "ant farms" used in classrooms or student experiments. These ants are not suitable for the Ants in Space investigation, because they search individually and do not perform the coordinated group search activities being studied.

At certain times of the year, it may not be possible to collect ants. Since ants cannot regulate their body temperature, they cannot move when it is cold, and they remain inside their nests. You would have to dig deeply to reach them. Do not bore into an ant colony, as this can be very destructive.

Transferring Ants to the Habitat

Build and assemble the ant habitat before attempting to collect and transfer ants.



You will begin by placing your ants in the habitat's holding chamber. It may be easier to transfer the ants from their original container to the habitat if you refrigerate them for a few minutes first. But be sure to place them in the refrigerator, not the freezer. Ants become very sluggish when chilled, and easy to manipulate. Work quickly because the ants will start to scatter when they warm up. A soft bristle watercolor paintbrush can help to corral errant ants, and a small paper funnel will help the ants slide into the holding chamber.

Once the ants are in the holding chamber, quickly block the entrance by sliding the loading door (piece number 4) into position. Be careful not to injure any ants when sliding the door shut. The loading door should fit snugly, so the ants cannot escape. As an additional precaution, use a bit of tape to hold the door in place.

The most important step for keeping your ants alive is to give them water. Unless ants have larvae to feed (yours will not), they don't require much food. Any carbohydrate, like apple slices or pecan cookie crumbs ("sandies") will meet their needs. Most ants can't drink water directly, but can extract it from moistened cotton or paper towel. Place a small folded square of paper towel soaked with water in the holding chamber. If you collect ants in the wild and they seem to be dying, it is probably from lack of water.

Students may be concerned about the lifespan of their ants. Ants sold commercially and transported across state lines are older harvester ant foragers, nearing the end of their lives. These ants do not thrive in captivity and usually die quickly. Ants that you collect from the wild (your nearby sidewalk) will do better in captivity, because they are coming directly from their natural environment. The ants may be fed pecan cookie ("sandies") crumbs. At the conclusion of their observations, students may release outside any wild ants they trapped themselves. ■

RESOURCES FOR IDENTIFYING ANTS

There are about 12,000 known species of ants, but only about 50 that have been studied in detail. The ant family, Formicidae, has 15 subfamilies, of which Myrmicinae and Formicinae are the two largest. It is easy to distinguish between these two subfamilies by examining the structure, known as the petiole, which connects the thorax and abdomen. Among ants of the Myrmicinae subfamily, the petiole has two segments; the petiole in ants of the Formicinae subfamily, has only one segment. Pavement ants are in the Myrmicinae subfamily.

Many websites offer information that can help you to identify ants. Listed below are just a few examples.

- **AntKey provides resources for identifying more than 100 invasive, introduced and commonly observed ants from around the world. (www.antkey.org)**
- **AntWiki lists all ant identification keys currently available worldwide. It also provides detailed descriptions of ant morphology and the terms commonly used in ant identification keys. (www.antwiki.org/wiki/Category:Identification_key)**
- ***Bayer Ant Identification Guide* has information about to the most common ants and ant pests in the U.S. (www.backedbybayer.com/system/product_guide/.../Ant-ID-Guide.pdf)**
- **The Mueller Lab at The University of Texas has developed an online key to identify ant species. The site also has a glossary and additional links. (www.sbs.utexas.edu/muelleru/AntOutreach)**

Pavement ants even will form symbiotic relationships with other organisms. In the image above, ants eat honeydew produced by magnolia scale insects. Photo © Sarah Vanek (www.bugwood.org).

8

Planning and Guiding the Investigations

The ant habitats for the ISS and the classroom are designed to enable students to compare ant behaviors—particularly searching behavior—in differently sized spaces. Each habitat on the ISS began with approximately 80 ants. For classroom observations, approximately 40 ants per habitat will be sufficient.

Ants carry out complex search behaviors without central control: no single ant directs the movements of other ants. Instead, each ant adjusts its search strategy based on its interactions with other ants. In combination, this communication among individual ants produces the search and exploration strategy of the entire colony.

The pattern in which many ant species search depends on the number of interactions each ant has with other ants. When an ant encounters many other nest mates, it is prompted to search a small area thoroughly by making many random turns. Conversely, exploring ants that do not interact with many other ants tend to walk a straighter path—a pattern that enables fewer ants to survey a larger area. Thus, population density is one factor that determines the exploratory pathways .

The Ants in Space experiment will investigate how thoroughly the ants search and how much ground they cover in a higher and lower population-density environment. To evaluate the thoroughness of the ants' search, we must observe how convoluted or circuitous their paths are in the smaller and larger search areas. To gauge the ground covered by the ants, we will measure how much of each search area they visit or the lengths of their pathways. In combination, this information will enable us to determine if the ants' path shape and ground coverage differed in the high population-density, smaller search area and the low population-density, larger space.

One way to determine the thoroughness of the ants' search is to trace their paths. Place a sheet of transparent plastic (e.g., an overhead transparency) over the habitat, and follow some ants with a transparency marker. To get a value for how random a path is, divide the ant's route into steps of equal length, and measure the angle between successive paths. The more the angle changes (i.e., the higher its variance), the more random the path. Shorter step lengths will produce more precise measurements.

To measure the amount of ground the ants cover, use a sheet of transparent plastic to make a grid matching the habitat search space (the finer the grid, the more precise the measurement). Place a dot in every square that an ant enters. The more squares marked with dots, the greater the ground covered. The finer the grid, the more precisely this approach measures the amount of ground covered.

Finally, to determine whether—and how much—the ants' behavior changed between the higher- and lower-density search areas, compare the values for path shape or ground covered. If the values are different, then the ants altered their search behaviors according to density. The list below describes ways in which student can observe, record and compare ant pathways.

- **Informal observations.** Allow students sufficient time to watch the ants and make their own observations about the ants' behaviors, before or after conducting an experiment to document search behaviors. Naturalist journals are an excellent tool with which students can record their impressions. A template for *Naturalist Journals* is available on BioEd Online.

Usually, ants will not be active unless something new has occurred in their environment (e.g., when the door from the nest area is opened, and when the partitions between Search Area 1 and Search Area 2 are removed). Ants also will become more active if food is introduced into the habitat.

- **Ant-to-ant interactions.** Cut a 5-in. x 7-in. piece of overhead transparency film and tape it lightly over the ant habitat. Have students record each time two ants come together, using overhead markers to place a dot in the square in which the interaction occurred. If there are many ants in the chamber, have students observe a subset of squares (for example, two or four) and record the numbers of interactions in the smaller area.
- **Dot Density.** Cut a 5-in. x 7-in. piece of overhead transparency film and tape it lightly over the classroom habitat. Have students document each square entered by an ant by placing a dot in that square. For example, if an ant enters one square, crosses into a different square, and returns to the first square, students would place two dots in the first square, and one dot in the second. Students should use a different color overhead marker pen for each ant they are observing. Teams of two or more students may work together to make observations in different sections of the habitat grid.
- **Tracing Pathways.** Cut a 5-in. x 7-in. piece of overhead transparency film and tape it lightly over the ant habitat. Have students use overhead marker pens to trace the movements of individual ants for short periods of time (30–60 seconds). Each student should locate an ant, position his or her pen over the ant, and trace the ant's search pathway on the transparency film.

When an observation is complete, students should mark the search starting point with an X. Have students use a different color marker for each observation. To analyze the pathways, direct students to divide an ant's route into steps of equal length, and measure the angle between successive paths. The more the angle changes (i.e., the higher its variance), the more random the path. This technique will enable students to compare the straightness and length of ant pathways.

- **Video Tracing.** Position a video camera over the habitat to create one or multiple videos of ant movements. Use one of several free tracking programs to map the ants' pathways. These programs, such as Bio-Tracking, require certain computer configurations and the installation of several different free software products or apps.

Planning the Investigation

Students should design their investigations before obtaining ants. In all cases, the principal experimental variable will be the effects of gravity. Ants on the ISS will be living in a microgravity environment, while ants in students' investigations will experience the effects of Earth's gravity. ("Microgravity" is the term scientists use to describe the sensation of weightlessness that occurs in an orbiting space vehicle. For details on this effect, please refer to the "Microgravity" article at www.bioedonline.org.)

When the investigation begins onboard the ISS, ant images will be transmitted to Earth and made available on BioEd Online, free of charge, for anyone to use. What will your students study? What questions will they seek to answer? What behaviors or characteristics will they compare between their Earth-based ants and those living on the ISS?

Sometimes, students must spend a couple days observing several variables to devise an interesting question or pattern to investigate. The table above provides a sampling of ideas. ■

POTENTIAL INVESTIGATIONS

Behavior/Variable	Possible Questions
Movement	Does compartment size impact ants' navigation pathways? Are the search pathways similar on the ISS and on Earth? If not, how do they differ? Are the pathways circular or straight?
	Do the ants remain on the floor of the compartment, or on the "ceiling," or both?
	How fast do the ants move? Do they spend long periods without walking? What is the ratio between the amount of time walking and the amount of time at rest?
Location	Do the ants congregate in any particular area of the first compartment? Track a particular ant using the grid.
	What happened when the second compartment was opened? How did the ants distribute themselves between the two compartments?
Social interaction	Do the ants make antenna-to-antenna contact? How often?
	Do any ants avoid contact?
Survival rate	Have any ants died? How long did particular ants survive? (**Note:** The ants you collect will be older worker ants, nearing the end of their life spans. Attrition is to be expected.)

CASIS Education: *Where Gravity Won't Hold You Back*

The Center for the Advancement of Science in Space (CASIS) provided financial support for the Ants in Space experiments and educational activities. CASIS is tasked by Congress and appointed by NASA to manage, promote and broker research on board the International Space Station (ISS). Additionally, CASIS strongly believes in maintaining a robust education program intended to spark the creative and scientific minds of our nation's youth. CASIS Education seeks to 1) increase science, technology, engineering and mathematics (STEM) literacy for all students; 2) support teachers in improving STEM education; 3) advocate the ISS as a STEM learning platform; and 4) excite K-12 students about STEM-related careers.

CASIS is in a unique position to reach out to all U.S. students and convey the excitement of the ISS by stimulating students to engage in subject areas related to space science and its potential value to humankind and for commercialization opportunities. From funding actual student research flight projects to creating interactive new mediums capable of inspiring students on the wonderment of space and science, CASIS is a catalyst for utilizing the ISS for the benefit of education-related activities.

Why is there such an emphasis on education from CASIS? Since the 1980s, children in the U.S. have been falling behind other nations in their understanding of science and mathematics. As youth get older, they report significantly less interest and self-confidence in their science ability. Children ages 6–12 report a high level of interest and belief in their science abilities; by age 14, interest and self-confidence related to science drops off. For our nation to recapture global leadership in research and development, we must invest in educating the next generation of Americans in STEM areas, to prepare a future workforce capable of competing in the international market. That is why CASIS has taken such a proactive approach to taking advantage of the unique environment of the ISS.

CASIS Education Initiatives

- CASIS is a sponsor of the BioServe Ants in Space Mission. This experiment analyzes the interrelationship between the interaction rate of a group of ants and the density of the group in normal gravity conditions versus micro-gravity. This and related experiments are designed to engage the K-12 community on Earth in near real-time ISS science.
- CASIS Academy.org is an interactive learning website created to educate middle school students about the ISS, and to pique their interest through multimedia videos and features. The website incorporates breakthroughs resulting from ISS research, a tour of the space station and suggestions for using the CASIS Academy.org in the classroom.
- CASIS is developing the National Design Challenge, a national education campaign that provides educators and their students the opportunity to design and implement an authentic research experiment on the ISS, with standards-based curriculum that will model STEM best practices, and feature science and engineering practices as developed in the new Next Generation Science Standards.
- CASIS Academy Live brings middle and high school students to NASA's Kennedy Space Center Visitor Complex and the Space Life Sciences Lab. This all-day event allows students to interact with a NASA astronaut and a research scientist selected by CASIS to send their experiment to the ISS.
- Story Time From Space combines STEM literacy with simple science demonstrations. The project includes videotapes of astronauts reading selected stories from the cupola of the ISS and conducting simple physics demonstrations that complement the science concepts in the books.
- CASIS is a sponsor of the Student Spaceflight Experiments Program, which gives students across a community the ability to design and propose real experiments to fly in low Earth orbit on the ISS.
- CASIS is a sponsor of the SPHERES Zero Robotics Competition, a fun and flexible STEM curriculum for middle school students. Over the five-week program, teams of students work with program staff, MIT mentors and prominent scientists to learn about programming, robotics and space engineering. The best designs are selected for the competition to operate the SPHERES (Synchronized Position Hold, Engage, Reorient, Experimental Satellites) satellites on the ISS.
- CASIS is a sponsor of the NASA HUNCH Program, a partnership between high schools and NASA where students design, build and implement experiments in micro-gravity aboard the ISS.

For more information about CASIS Education, visit our website at http://iss-casis.org/Education.aspx.