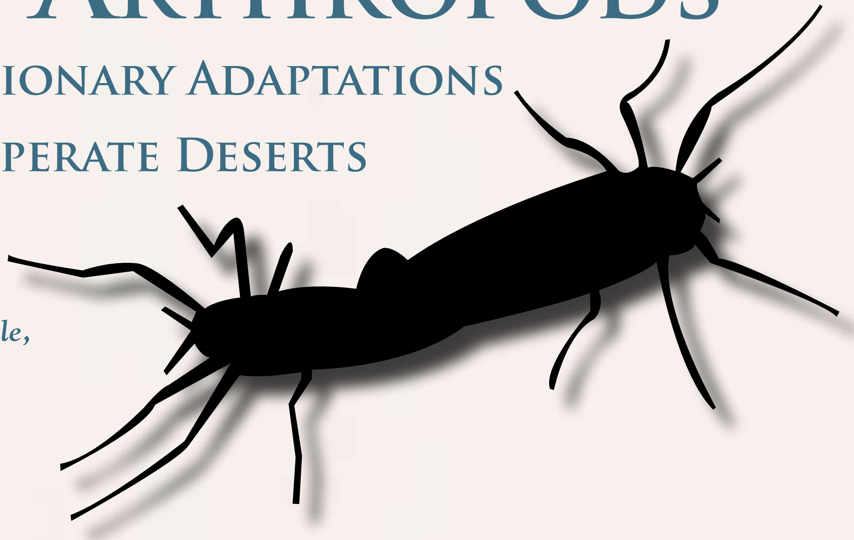
EXTREME ARTHROPODS

EXPLORING EVOLUTIONARY ADAPTATIONS TO POLAR AND TEMPERATE DESERTS



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In this activity, Namib and Antarctic arthropods are used to illustrate several important biological principles. Among these are the key ideas that form follows function and that the environment drives evolution. In addition, students will discover that the climates of the Namib Desert and the Antarctic Peninsula are similar in several ways, and that these arthropods have evolved some analogous adaptations. This investigation is a good introduction to the phylum Arthropoda, the most successful group of animals on Earth, and spotlights the group's ability to occupy some of the most challenging niches on the planet (National Science Content Standard C; NRC 1996).

Student Page 1

Part I. Extreme arthropod from scratch

Your job in this activity is to pick one extreme environment, and then build your own extreme arthropod. It must

1. be an arthropod, with a hard exoskeleton and jointed legs;	5 pts.
2. have at least one adaptation to help it survive each of your environmental conditions; and	10 pts.
3. show your effort, creativity, and understanding of the environment.	10 pts.

Extreme arthropod environments

1. The Antarctic Peninsula
- Extreme cold in the winter, -20°C (-4°F) and below
- Extreme temperature variability—summer temperatures up to 7°C (45°F), with rock and moss surface temperatures of up to 21°C (70°F)
- Very short period each year in which small arthropods are able to gather food, due to low temperatures and frozen conditions
- High winds on small islands—it's easy to be blown into the ocean
- Extreme dryness—Antarctica's freshwater is almost all frozen! Ice also tends to steal moisture from small arthropods
- Exposure to acidity and lack of oxygen, due to immersion in penguin guano (waste) during summer breeding season
- Possible immersion in both salt and freshwater due to snowmelt and waves/tides in the summer

2. The dunes of the Namib Desert, Africa
- Extreme heat on sand surface during the daytime
- Very little food, mostly detritus (dead plants and animals) blown into piles on the dunes by the wind
- High winds that blow small animals off dunes and cause water loss from animals
- Extreme dryness—the Namib is the driest temperate desert. Fog that occurs an average of 60 days each year is its only reliable water supply
- Sand—the sand of the dunes is easily heated by the Sun and blown by the wind, but also provides shelter for animals that can get below its surface

On the first day of this lesson, individual students design imaginary arthropods able to survive in either Antarctica or the Namib Desert. On the second day, student groups use evolutionary "toolboxes" to pick out appropriate adaptations for actual Namib Desert and Antarctic arthropods using a menu of authentic names, adaptations, and photos. This activity involves students in evolutionary thought and allows them to collaborate on assembling adaptations using aspects of technological design to overcome specific environmental problems (Content Standards A and E; NRC 1996).

Extreme arthropod lessons

In popular auto-racing video games, one can choose special tires, shock absorbers, and engine modifications to suit a particular racing environment. The activities presented here get at the idea that an organism is an accumulation of modifications, evolved over thousands or millions of years in response to the environment. While engaging students with the idea of designing the perfectly adapted arthropod, the lesson allows them to discover the extraordinary designs of real arthropods, which survive in varied and extreme conditions. The activities presented here guide students to think of arthropods as having a "toolbox" of evolutionary adaptations. This lesson would fit nicely as a transition between the end of a biome unit and the beginning of an evolution unit. While studying biomes, student groups can choose to investigate either the Namib Desert or Antarctic Peninsula using library and internet resources prior to this lesson. Because this activity requires little prior evolution knowledge, it stimulates student interest in learning more about the evolutionary mechanisms that have caused such amazing adaptations.

First, students are asked to create an arthropod from scratch, inventing adaptations that will help it to survive either Antarctica or the Namib Desert. Second, students

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Student Page 2

Part 2. Build a real extreme arthropod

Paste extreme arthropod description here.

Paste adaptations in these squares (up to nine for each arthropod)—use “Extreme arthropod toolbox” and the description you pasted above to select adaptations.		

When your instructor gives you an extreme arthropod photo, attach it to this page.

construct an arthropod by choosing from a menu of adaptations that will enable the arthropod to survive.

Materials

Day 1

- Art supplies, such as colored markers, colored pencils, or paints
- One per student: Student Page 1

Day 2

- Glue, scissors
- One per group: Student Pages 2 and 3
- One per group: Student Pages 4 and 5

Procedures

Day 1: Extreme arthropod from scratch (Student Page 1)

1. Engage students with a video-game analogy, if possible; many students will understand analogies to a car-racing game, in which players choose the best shock absorbers, engine modifications, and tires to fit the chosen racetrack. Also, in many role-playing video games of the Dungeons and Dragons-type, players allocate points to different character abilities like strength, intelligence, and speed, as well as choosing skills to learn, all to suit their character to the game environment.
2. Explain to students that the Antarctic Peninsula and the Namib Desert present unique challenges to all life forms. Students will focus on the terrestrial arthropods that inhabit these environments.
3. Distribute Student Page 1. Ask students to read through the list of extreme conditions in the Namib Desert and the Antarctic Peninsula. Discuss ways organisms might survive these conditions. Students will likely be thinking of larger animal adaptations, like those of camels, penguins, and so on. Encourage them to think like a smaller creature that is not endothermic (warm-blooded)—imagining how high winds, sand, and ice might affect them differently as small ectotherms (cold-blooded).
4. In this phase of the activity, students will work individually. Explain that they will design an arthropod that can survive in one of these two environments, and that it must possess at least one adaptation for each of their chosen environment's extreme conditions.
5. Students should creatively draw and present their arthropod to the class, explaining how each adaptation addresses each extreme. The rubric on Student Page 1 can be used for assessment.

Day 2: Building a real extreme arthropod

1. In a large group, have students name adaptations they gave to the arthropods that they created on day 1. Note student-generated adaptations that are the same as or similar to real adaptations. Ask "If a population evolves a good adaptation for its environment, does it stop evolving?" Lead students to the idea that with millions of years of evolution by natural selection, populations of arthropods have been able to accumulate a toolbox of enough successful adaptations like this to survive conditions that would kill other organisms.

2. Break students into groups of two or three. Distribute one copy per group of Student Pages 2 and 3 from the Activity Sheet. Explain that these include adaptations from the actual toolboxes mentioned above, and will be available to them as they design another extreme arthropod, this time trying to come as close to a real-life organism as possible by cutting and pasting adaptations.

3. Distribute one copy per group of Student Page 4. Assign each group one of the four arthropods. Explain that in their groups, they will each be asked to construct the arthropod, using their toolbox.

4. Instruct students to complete the questions on Student Page 4, and then cut and paste the arthropod description and toolbox adaptations appropriate to each arthropod directly onto Student Page 2.

5. Pass out Student Page 5 and ask students to paste the correct photo onto Student Page 2. Alternative 1: Cover the photo captions and ask students to choose the correct photo based on the adaptations they've decided their organism has. Alternative 2: Students may draw their version of their arthropod before seeing the photograph.

6. Assessment: The key below can be used to determine "correctness" of chosen adaptations, but this is not essential as long as pasted adaptations are reasonable and follow all rules. Each group can be evaluated on how well they teach the rest of the class about their particular arthropod; questions provided on Student Page 4 can be assessed.

Key—arthropod genus matched to adaptation card number.

Arthropod genus	Adaptation card number
Onymacris	1, 2 or 3, 4, 6, 7, 9, 12, 13, 14
Lepidochora	3, 5, 6, 7, 9, 12, 13, 14, 15
Belgica	3, 6, 8, 11, 12
Cryptopygus	3, 6, 8, 10, 12, 16

Student Page 3

Extreme arthropod toolbox

Adaptation 1 Long legs—“stilting” behavior, which raises body safely above surfaces that are too hot (Cannot be paired with trench-digging) __Ant. __Nam. __Both	Adaptation 2 White coloration (Cannot be paired with dark coloration) (Cannot be paired with trench-digging) __Ant. __Nam. __Both	Adaptation 3 Dark coloration (Cannot be paired with white coloration) __Ant. __Nam. __Both	Adaptation 4 “Fog basking”—“headstand” to condense fog droplets on body, which run down grooves to their mouths (Cannot be paired with trench-digging) __Ant. __Nam. __Both
Adaptation 5 “Trench-digging”—able to dig long trenches in the sand, which collect condensed fog—then drink water from trench (Cannot be paired with fog-basking) __Ant. __Nam. __Both	Adaptation 6 Wingless—wings either absent or fused together __Ant. __Nam. __Both	Adaptation 7 Wax “blooms” that cover exoskeleton, sealing it tightly, preventing water loss and reflecting sunlight to keep cool __Ant. __Nam. __Both	Adaptation 8 Cryoprotectants like glycerol and sorbitol, which protect animals when temperatures become dangerously low __Ant. __Nam. __Both
Adaptation 9 Ability to survive high body temperatures of up to 49°C (120°F) (An arthropod can have only one of adaptations 9–11) __Ant. __Nam. __Both	Adaptation 10 Ability to supercool to as low as -20°C (-4°F) without freezing (An arthropod can have only one of adaptations 9–11) __Ant. __Nam. __Both	Adaptation 11 Freeze-tolerance— ability to freeze without damage (An arthropod can have only one of adaptations 9–11) __Ant. __Nam. __Both	Adaptation 12 Long lifespan (two to five years)—allows more time to gather scarce nutrients, storing enough energy to mature and reproduce __Ant. __Nam. __Both
Adaptation 13 Ability to burrow into sand __Ant. __Nam. __Both	Adaptation 14 Specialized kidney-like organs that get rid of waste with almost no water loss, and can even reabsorb water from the air (Namib Desert only)	Adaptation 15 Sensitivity to wind speed—able to “hear” when wind is strong enough to blow food particles from under sand (Requires trench-digging adaptation) __Ant. __Nam. __Both	Adaptation 16 Hydrophobic exoskeleton—float on water surface to avoid being encased in ice, also clump together in large “rafts” (Only one arthropod has this) __Ant. __Nam. __Both

Student Page 4

Extreme arthropod descriptions

SCILINKS THE WORLD'S A CLICK AWAY
Investigate arthropods
at *www.scilinks.org*
Enter code: SS070702

Genus *Lepidochora*—Namib Desert flying-saucer beetle
These members of the family Tenebrionidae live on dunes in the Namib Desert.

Genus *Onymacris*—Namib Desert fog-basking beetle
These members of the family Tenebrionidae live on dunes in the Namib Desert.

Genus *Cryptopygus*—Antarctic Peninsula springtail
These insect-like hexapods must survive cold Antarctic winters. In summer, they are often found floating in clumps in pools of melted ice water.

Genus *Belgica*—Antarctic Peninsula midge
Belgica are larvae for most of their lives, gathering food and energy for the 10 days they'll have as adults, when they need to mate. Larvae must survive Antarctic winters, are frequently encased in ice, and may freeze. During summer they live in mud, algae, and sometimes penguin guano—which can expose them to acidic and low-oxygen conditions.

Extreme arthropod questions

- What conditions do the Antarctic Peninsula and Namib Desert share?
- What adaptations do Antarctic and Namib arthropods have in common?
- What are major differences in adaptations to the two environments?
- What advantage would each of the following adaptations give an insect: White coloration? Dark coloration? Winglessness? Burrowing in sand?

Extensions

a. Assign student groups to research another animal or plant that is adapted to the same environment as their arthropod, then compare and contrast.

b. Allow students to collect real arthropods. Tenebrionid beetles, midges, and springtails similar to *Onymacris*, *Belgica*, and *Cryptopygus* are easily found in most climates; students can compare and contrast the representatives they find in their own climate with the extreme arthropods they've studied.

c. Once students have some understanding of natural selection mechanisms, ask them to propose ways in which each of their arthropods' adaptations might have evolved.

Note: As part of an evolution unit, this lesson should be followed with further investigation of evolutionary adaptation; teachers should emphasize that populations, not individual organisms, adapt. For example, many of the simulations found at the Evolution and the Nature of Science Institutes (Flammer) website (*www.indiana.edu/~ensiweb*) would be appropriate activities to follow this one.

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Student Page 5

Extreme arthropod photos

Belgica antarctica larvae

COURTESY OF THE AUTHORS

Cryptopygus antarcticus

COURTESY OF THE AUTHORS

Belgica antarctica adult

COURTESY OF THE AUTHORS

Onymacris unguicularis

COURTESY OF GOBABEB TRAINING AND RESEARCH CENTRE

Lepidochora discoidalis

COURTESY OF DR. EK DEL VAL DE GORTARI

Background information

The Central Namib Desert

The Namib Desert, on the west coast of Africa (roughly 25°S, 15°E), receives about 23 mm of rainfall per year (Hachfeld and Jurgens 2000) and contains sand dunes of every known type, including some of the world's largest dunes. Almost all of the moisture available to the organisms that live here is in the form of fog, which comes about 60 nights each year. Wind is also a major part of the dune environment; in addition to moving the fog, wind shapes the dunes and causes plant and animal detritus to collect on the dune slip-faces. Though relatively sparse, this nonliving organic matter is an important part of the dune food web (Cloudsley-Thompson 1990). Finally, temperatures in the Namib can be extremely high, reaching 45°C at the sand's surface.

Tenebrionid beetles of the Central Namib Desert

Numerous species of beetles in the family Tenebrionidae—a group that includes mealworms—exhibit remarkable adaptations to the conditions of the Central Namib. Namib tenebrionids have the highest body temperatures measured in any ectothermic animal, and come nearer their upper-lethal temperature limit than most other ectotherms. To avoid the sand's extremely high temperatures, they bury themselves under its surface, emerging periodically each day (Seely, Roberts, and Mitchell 1988). To conserve water, their Malpighian tubules (insect kidneys) produce nearly dry waste in adults, and larvae can actually absorb moisture from the air. Many tenebrionids also secrete a layer of wax that coats the exoskeleton, reflecting some of the Sun's radiation and protecting beetles from water loss, abrasion, and microorganisms (Chown and Nicolson 2004). Most of these species have extended lifespans of up to six years, allowing them time to gather the energy they need to reproduce (M. Seely, pers. comm.). These beetles are flightless, having evolved fused wing covers; this may or may not function as an adaptation for water conservation (Duncan 2003), but makes sense for an insect that frequently buries itself in a windswept environment.

A few adaptations of individual tenebrionid species are particularly striking. *Onymacris unguicularis,* the fog-basking beetle, stands on its head, collecting droplets of fog on its body that run down grooves into its mouth (Hamilton and Seely 1976). *Onymacris bicolor* has a partially white exoskeleton, reducing the amount of heat it absorbs from visible light. Both these beetles have evolved especially long legs; when they are overheated, they can temporarily elevate their bodies above the dune surface, through a process known as "stilting." In specific wind conditions, a few millimeters of elevation can significantly reduce their body temperature (Chown and Nicolson 2004). The flying-saucer trench beetle, *Lepidochora discoidalis,* exploits the fog by digging long trenches in the sand perpendicular to advancing fog, from which it drinks condensed water droplets (Seely and Hamilton 1976). It is also able to "listen" to the wind while it is buried beneath the surface, only emerging when it senses that wind speed is high enough to blow the detritus on which it feeds free of the sand (Hanrahan and Kirchner 1997).

The Antarctic Peninsula

The Antarctic Peninsula extends north from continental Antarctica toward the southern tip of South America. The islands associated with the Peninsula have three environmental characteristics in common with the Central Namib Desert: extreme wind, extreme temperature, and extreme aridity. Of course, in contrast to the Namib, the Antarctic Peninsula is cold, not hot: Winter temperatures are well below freezing (-20°C and lower) for several months of the year. In many places, however, the Peninsula is very much a desert. Most of the precipitation is either locked up in ice or rapidly drains away because there is no soil to hold it in place. Summer thaws frequently make fresh meltwater available on the Peninsula. In addition, salty ocean water is splashed on organisms near island edges, so organisms living on these islands experience considerable fluctuation in the availability of fresh water (Block 1997; Convey 1997).

Antarctic arthropods

The wingless fly *Belgica antarctica* and a springtail called *Cryptopygus antarcticus* are two arthropods found on islands surrounding the U.S. research base Palmer Station (64°46'S, 64°03'W). For the most part, these arthropods are considered to be preadapted to the conditions in Antarctica—that is, the adaptations they possess were not evolved specifically in response to the Antarctic environment, but are commonly found in many closely related species on other continents (Block 1997; Convey 1997).

Background information (cont.)

Like Namib tenebrionids, neither of these Antarctic arthropods have wings. Antarctica is the windiest continent on Earth, and the islands around Palmer Station are similarly gusty—an arthropod with wings would be easily blown off these islands into the ocean. In fact, there are no flying arthropods native to Antarctica. Also similar to Namib tenebrionids are the prolonged development times of Antarctic arthropods. Both Antarctic species live for two or more years, giving them time to gather enough energy during the short Antarctic growing seasons to reproduce (Convey 1997). However, unlike *Onymacris bicolor's* white, sun-reflecting coloration, these Antarctic arthropods are both darkly pigmented, enabling some absorption of heat from sunlight.

Belgica antarctica is the world's southernmost holometabolous (undergoing complete metamorphosis) insect, and is considered Antarctica's largest terrestrial animal (penguins and seals do not remain on land year-round). This wingless midge (Order: Diptera, Family: Chironomidae) is the only Antarctic arthropod known to be freeze-tolerant—able to survive the freezing of its body water. It lives for two years, all but two weeks spent in a series of four worm-like larval stages. In its second summer, it pupates and emerges as an adult, lives for about 10 days, mates, and lays eggs (Sugg, Edwards, and Baust 1983). *Belgica* synthesizes a variety of cryoprotectants (antifreezes), including glycerol, fructose, glucose, trehalose, and sorbitol, which help it to survive internal freezing (Baust and Lee 1980). During the long winters, *Belgica* larvae are frequently encased in ice, and freezing causes extensive cellular dehydration as ice forms extracellularly (Baust and Lee 1987). They can also lose water quickly to the air, and survive the loss of up to 70% of their body water—it is, in fact, likely that *Belgica* dehydrates protectively, using lack of water to survive low temperatures (Elnitsky et al. 2006). The larvae can also survive immersion in meltwater and penguin guano, and tolerate wide swings in salinity, pH, and oxygen availability (Baust and Lee 1987).

Cryptopygus antarcticus is a springtail (Order: Collembola), a "proto-insect" that does not undergo metamorphosis. In other words, it grows in size but does not significantly change its body form throughout its life, which lasts three to seven years. Unlike the midge, *Cryptopygus* is not able to survive freezing, and is thus considered freeze-susceptible. However, like other Antarctic arthropods, it can cool to -20 to -30°C without freezing. These springtails avoid freezing in part because they are very small: If you wanted to make a tiny droplet of pure water into an ice cube, you would have to wait until the water reached -15°C or below. *Cryptopygus* can also lower its freezing point by synthesizing cryoprotectants and clearing its gut of food particles that could act as nuclei for ice-crystal formation. Finally, this species has a waxy, hydrophobic cuticle that enables it to float on water and avoid being encased in ice, and promotes the formation of large "rafts" of individuals on the surface of meltwater pools (Cannon and Block 1988).

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