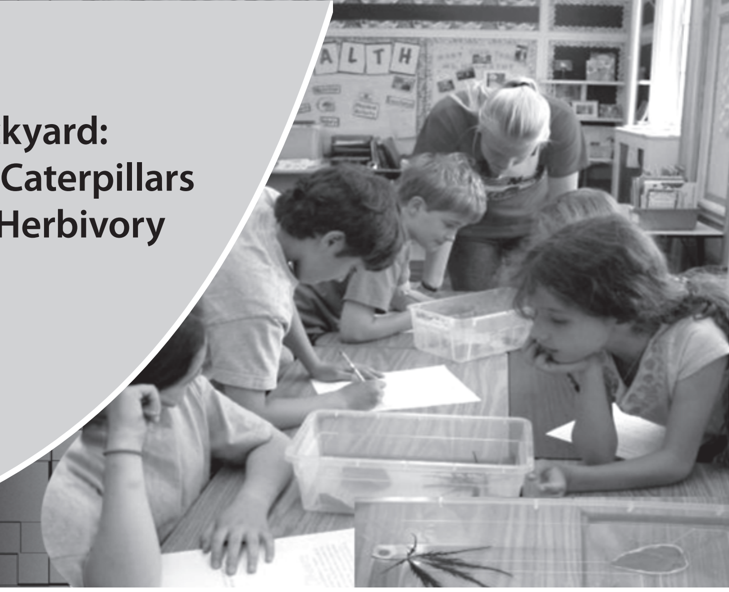
INQUIRY & INVESTIGATION

Science in Your Own Backyard: Using Locally Abundant Caterpillars & Plants to Teach about Herbivory



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Abstract

National science standards require an understanding of animal behavior, diversity, and adaptations of organisms, as well as the concept of science as inquiry. We have developed a hands-on classroom activity that addresses these standards through teaching about herbivory and diet breadth, using locally abundant caterpillars and plants. This activity provides students with opportunities for careful observation, data collection and analysis, and development of testable hypotheses for further experimentation. The lesson can be adapted to different grade levels, with students taking on varied levels of responsibility for formulation of hypotheses, experimental design, data collection, and data analysis.

Key Words: *Herbivory; specialists; generalists; caterpillars; scientific method.*

Herbivory, the consumption of plants by animals, provides an excellent example of adaptive evolution and animal behavior. Insect herbivory is especially tractable, as almost half of all named insect species feed on plants, and plant-eating insects form intimate, often lifelong, associations with their host plants (Schoonhoven et al., 1998). Most people are familiar with insect herbivory in the form of a caterpillar chewing on a leaf, but insects can feed on virtually all parts of a plant, including its fruits, seeds, roots, and stems (Jolivet, 1998; Labandeira, 2002).

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Plants are not passive victims in this relationship; they have evolved defensive adaptations to herbivory that include both physical barriers and chemical defenses. Physical barriers may take the form of spines, thorns, hairs, or toughened leaves, while chemical defenses include compounds that can reduce leaf digestibility, deter feeding, or poison the insect (Strauss & Zangerl, 2002). Insects, in turn, have evolved ways to circumvent plant defenses. Behavioral counter-strategies used by insects include chewing off plant hairs or cutting veins to release toxic latex prior to feeding, and physiological strategies include the ability to tolerate or even sequester and concentrate toxins (Strauss & Zangerl, 2002).

Despite the diversity of defenses and counter-strategies, plants cannot defend themselves from all insects, and insects cannot eat all plants. With respect to the breadth of their dietary choices, herbivorous insects fall into two broad categories: generalists (polyphages) feed on a wide range of different kinds of plants, whereas specialists (monophages) feed on only one or a few plant taxa (Jolivet, 1998; Singer, 2008). The majority of herbivorous insects fall into the specialist category. Several hypotheses, including the "enemy-free space" and the "physiological efficiency" hypotheses, have been proposed to explain the preponderance of specialization (Singer, 2008). The enemy-free space hypothesis posits that insects specialize on particular plants in order to escape their predators in any of a number of different ways: the insect may sequester plant toxins for use in its own defense, it may be cryptic (camouflaged) against a particular plant background, or it may hide out on a plant that the predator does not encounter as frequently. The physiological efficiency hypothesis, on the other hand, states that insects become physiologically adapted to feed on one particular type of plant, and therefore can no longer feed as efficiently from other plants (Singer, 2008).

Both specialist and generalist feeding strategies come with costs and benefits. Specialization can be costly to an insect if a specific host plant is temporally or spatially rare; however, many specialists have evolved methods to feed on plants that few other insects can feed on, and therefore benefit from reduced competition. By contrast, generalist insects are not limited to finding a specific plant, and so have access to more feeding options, but may also face more competition for resources (Jolivet, 1998).

Lepidoptera, the order of insects that contains the butterflies and moths, is made up almost exclusively of herbivores that, as larvae, cover the spectrum from narrow specialist to broad generalist. Lepidoptera are distributed worldwide, with over 11,500 species in North America. Because of their wide distribution and abundance, and the fact that they are easy to find and maintain, caterpillars are great insects to bring into the classroom. Caterpillars are already familiar insects in schools; many teachers use commercially available larvae fed on artificial diet to teach students about the stages of an insect life cycle. Although convenient and useful, raising caterpillars

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on artificial diet, commonly an oatmeal-like material on the bottom of a plastic cup, prevents the students from making the fundamental ecological connection between plants and insects.

In this exercise, students will observe and record the behaviors of caterpillars as the larvae encounter a variety of leaves, all collected from their local habitat. Students will make inferences, based on their data, about the caterpillars' dietary breadth and will begin to develop an understanding of the important ecological relationships between plants and insects. Furthermore, the lesson that not all plants are appropriate food for a particular herbivore has practical applications in biological control and agriculture. For example, when introducing an herbivore for the purpose of biological control of an invasive plant species, it is critical that the herbivore be monophagous so that it does not shift onto native plant species (see McFadyen, 1998). In addition, students who have had some experience with vegetable gardening will understand the basis for the distribution of caterpillar pests on their crops. For example, they are likely to have seen hornworms (*Manduca* spp.) eating the leaves of their tomato, eggplant, or pepper plants (all of which belong to the family Solanaceae), or swallowtail larvae (*Papilio polyxenes*) on the leaves of their carrots, celery, dill, or parsley plants (all belong to Apiaceae).

○ Materials per Group

- Box large enough to contain the caterpillar(s) and plant samples (see below for details)
- 1–3 caterpillars
- 3–4 plant samples, including the host plant(s)
- Paper and pencils for data collection
- Permanent marker for labeling leaves
- Nontoxic paint and small brush for labeling caterpillars (optional, necessary only if using more than 1 caterpillar per box)

○ Caterpillar & Plant Collection

Collections can be made by the teacher alone or can include the students. The best time of year for collection of caterpillars and plants will vary depending on your location. Caterpillars and plants will be available nearly year-round in warmer climates, whereas collections are best done in late spring through early fall in cooler or more northern climates. To determine the best time of year for this activity in your area, to find local contacts, and for a wealth of other information on Lepidoptera, visit the webpages of the Lepidopterists' Society (http://www.lepsoc.org) or the North American Butterfly Association (http://www.naba.org/chapters.html) and look for a local club or chapter. In addition, caterpillar or butterfly field guides, both print and online, provide information on local caterpillar abundances, seasonality, and host-plant identification (recommended guides are listed below).

Caterpillars can generally be located by walking around a park or neighborhood and carefully searching the leaves of trees and plants. CAUTION: Some caterpillars have hairs or spines that can deliver a painful sting! The vast majority of caterpillars are harmless, but be sure to check your field guide before touching any hairy or brightly colored larvae, and make sure you can identify irritant plants such as poison ivy or poison oak to avoid contact. At some times of year, certain species are especially abundant and can be easily found and collected. For example, fall webworms (*Hyphantria cunea*) are readily found in late summer in the eastern United States. (If caterpillars cannot be procured from the field, it is possible to conduct a modified version of this exercise using commercially available larvae. See note at the end.)

Once caterpillars are found, it is best to collect more caterpillars than needed, in case some die or escape. Medium- or large-sized caterpillars (≥1 cm) are best for easy observation; smaller caterpillars should be moved with a paintbrush to avoid injuring them. Collect leaves of the plant that the caterpillar is feeding on, similar in age and size to the leaf on which you found the caterpillar. This plant is referred to as the "host plant." Also collect leaves from several different nearby plants, and again try to match the approximate age and size of the leaf to that of the host leaf. Medium- to large-sized caterpillars will eat a surprisingly large amount of foliage; therefore, you should collect a generous amount (e.g., a gallon-sized plastic bag) of host plant, and sufficient leaves of each alternative plant so that you will have two or three leaves per group. It is best if the alternative leaves vary in color, shape, or texture from the host plant, which will allow students to later hypothesize on how caterpillars choose between the different leaves. Butterfly or caterpillar guides often list potential host plants for a given species of caterpillar, aiding in host plant identification, but note that plant identification is not essential to this activity. Caterpillars can be collected several days in advance and kept in plastic boxes with leaves of their host plant. To motivate caterpillar searching and feeding during the classroom activity, remove host plant leaves from boxes 1–2 hours prior to beginning the activity.

○ Methods

For students in fifth grade and below, arenas should be set up in advance. For older students, supplies can be made available and the students can set up the experiment themselves. Each group of students will need leaves, caterpillars, and a box. The box should be large enough for the leaf samples to lie flat without touching each other, but not so large that a caterpillar placed in the middle of the box would have to crawl long distances to encounter the leaves (Figure 1). Take one leaf from each type of plant and mark it (e.g., A, B, C, or D) with the permanent marker, ensuring that labels are consistent for the plant types across the boxes. Provide each group of two or three students with a caterpillar to place in the middle of the box, ensuring that the caterpillars are not touching any of the leaves. As many as three or four caterpillars may be placed in each box, but individuals should be marked with a small dab of nontoxic paint for identification.

Before starting the activity, students should discuss and agree upon how to classify and record the different behaviors. It is important that each group uses the same criteria and system, to facilitate later compilation of the class data. For example, a caterpillar that takes only one or two bites from a leaf could be considered to be sampling or tasting the leaf, whereas a caterpillar that takes many bites is actively feeding on the leaf. One way to record the movements and behaviors of an individual caterpillar is to list the sequence of leaves it encounters, marking with an asterisk the leaves it tastes, and underlining the leaves it feeds from (e.g., A B* A C A* D C B).

Students should observe their caterpillars for at least 10 minutes, recording when the caterpillar touches, tastes, or feeds on any of the leaves. They should note any other larval behaviors, as well as the caterpillar's location at the end of the observation period. At the end of the observation period, tally and compile the data from each group on the blackboard. Depending on the grade level, data can be graphed and statistically analyzed using a chi-square or Fisher's exact test (see Zar, 1999, for an explanation of these statistical tests).

We have used this lesson with third graders as well as college undergraduates. In a third-grade classroom, students observed a specialist caterpillar, *Battus philenor*, the pipevine swallowtail butterfly (Figure 1). Plants used were viburnum, pipevine, hydrangea, and maple. Summed over all the caterpillars, all leaf types were touched,

Figure 1. Third graders observing their caterpillars with four plant options (inset).

and 10 of the 16 larvae ultimately ate a leaf, with 100% of the feeding occurring on pipevine. The students were enthusiastic about observing their caterpillars, and surprised to find that although the caterpillars came into contact with all of the leaves, they ate only one kind of leaf. Students also noted that during the observation period the caterpillars were pooping, "kissing," resting, and "fighting."

Data from an upper-division college course titled "Plant–Animal Interactions" are shown in Figure 2. Here we used two different species of caterpillars, one a generalist and the other a specialist, with three plant options per box and multiple caterpillars per box. Pipevine swallowtail caterpillars, dietary specialists, were given the option of tulip tree (C), kudzu (D), or pipevine (E). In a second set of boxes, fall webworm caterpillars, dietary generalists, were provided with oak (A), maple (B), and tulip tree (C). This comparison of a specialist (2A) and a generalist (2B) provides a clear, hands-on example of the concept of diet breadth.

Follow-up discussion questions, applicable at all levels, include: Can plants protect themselves from being eaten? Do you see any defensive structures on the leaves in our experiment? For example, did any of the leaves have hairs, thorns, or waxy surfaces? What is a benefit to being a specialist or a generalist? What is a cost to being a specialist or a generalist? How do the different leaf types in our experiment differ? How are they the same? If caterpillars are specialists, how do they (or their mothers, the butterflies or moths that lay the eggs on the host plant in the first place) find the right plant? Do they use their sense of vision, taste, or smell? How could you test these different ideas?

In the college course, after the exercise the students write a brief, three-page report, in which they introduce the concepts of herbivory and host specificity, graph the class results along with completed statistical tests, and summarize and interpret the results of the experiment. On the basis of their initial observations, small groups of students then develop hypotheses and work outside of class time to conduct further experiments in which they assess the importance of leaf shape, color, or chemistry on caterpillar choice. For example, one group tested the importance of leaf shape by cutting similarly sized circles out of each leaf type, repeating the above experiment, and observing whether caterpillars could still identify their host plant without shape as a potential cue. Another group assessed the importance of plant chemistry by making a simple extract of the host plant and painting it on the nonhost plants. Students then wrote a full lab report describing their follow-up experiments and citing appropriate scientific literature. Similar follow-up experiments and written reports are also appropriate for high school students. Alternatively, in a high school course the class could work together to generate hypotheses and methods that could then be tested in class the next day. Students could be required to write a brief report on either the main activity or the follow-up activity.

An optional activity, prior to the in-class choice tests and applicable at all levels, would be careful observation and description of the caterpillars and plants. Students could use a dissecting microscope or a handheld magnifying lens to examine the parts of the caterpillar, and then draw and label a diagram. Younger students might simply depict a head, body, legs, and pro-legs, whereas older students might also sketch and identify the caterpillar's mouth-parts (mandibles, maxillae, labrum), six simple eyes (stemmata), and respiratory openings (spiracles), using caterpillar diagrams available on the Web as a reference. Similarly, leaves could be observed and drawn, with students making note of structures on the leaves that they predicted could serve as defenses against herbivory. These observations and drawings would aid in their later discussion of plant defenses and hypotheses about how caterpillars may locate hosts.

Figure 2. Class data from an upper-division undergraduate course using both a specialist caterpillar (A) and a generalist (B).

○ Conclusions

Using locally collected caterpillars and plants, we have developed a hands-on activity that is easy to do and addresses several national science standards, including animal behavior, the diversity and adaptations of organisms, and the concept of science as inquiry. This activity is highly adaptable and flexible, and students can be involved at many different levels. Not only does this activity help students learn about ecological and evolutionary processes; they will also be excited and engaged when observing and handling living caterpillars. Active engagement in biology assignments is key to fostering interest in science at all educational levels, from kindergarten to college and beyond.

○ Recommended Caterpillar Guides

- Wagner, D.L. (2005). *Caterpillars of Eastern North America.* Princeton, NJ: Princeton University Press.
- Online caterpillar identification: http://www.discoverlife.org/mp/20q?guide=Caterpillars
- Useful for identifying caterpillars as well as other insects: http://bugguide.net/node/view/57
- Online moth and butterfly identification: http://www.butterfliesandmoths.org

NOTE: If butterflies or host plants are not readily accessible because of climate or seasonality, it is possible to conduct this activity using commercially available caterpillars of the cabbage white butterfly (*Pieris rapae*). The Wisconsin Fast Plants program has developed an excellent curriculum, including hands-on classroom exercises that encourage students to investigate connections between the life cycles of the cabbage white butterfly and its host plants in the mustard family. Cabbage white eggs can be purchased year-round, and students can carry out a host-plant-choice experiment using a variety of foods readily available at the grocery store (e.g., Brussels sprouts, cabbage, collards or kale as host plants, spinach or lettuce as nonhosts). Visit http://www.fastplants.org/pdf/activities/Butterfly_Activity.pdf.

References

Jolivet, P. (1998). *Interrelationship between Insects and Plants.* Boca Raton, FL: CRC Press.

Labandeira, C.C. (2002). The history of associations between plants and animals. *In* C.M. Herrera & O. Pellmyr (Eds.), *Plant–Animal Interactions: An Evolutionary Approach*, pp. 26–74. Cornwall, UK: Blackwell Science.

McFadyen, R.E.C. (1998). Biological control of weeds. *Annual Review of Entomology*, *43*, 369–393.

Schoonhoven, L.M., Jeremy, T. & van Loon, J.J.A. (1998). *Insect–Plant Biology: From Physiology to Evolution.* London, UK: Chapman & Hall.

Singer, M.S. (2008). Evolutionary ecology of polyphagy. *In* K.J. Tilman (Ed.), *The Evolutionary Biology of Herbivorous Insects: Specialization, Speciation and Radiation*, pp. 29–42. Berkeley, CA: University of California Press.

Strauss, S.Y. & Zangerl, A.R. (2002). Plant-insect interactions in terrestrial ecosystems. *In* C.M. Herrera & O. Pellmyr (Eds.), *Plant–Animal Interactions: An Evolutionary Approach*, pp. 77–106. Cornwall, UK: Blackwell Science.

Zar, J.H. (1999). *Biostatistical Analysis, 4th Ed*. Upper Saddle River, NY: Prentice Hall.

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