Science Scope

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ujss20

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To cite this article: Brian Keas, Peter J. T. White, Christopher B. Brown, David Stroupe, Sara G. Best & M. Letarte (2024) Conducting Authentic Moth Research with Students to Encourage Scientific Inquiry, Science Scope, 47:4, 56-62, DOI: 10.1080/08872376.2024.2363112

To link to this article: https://doi.org/10.1080/08872376.2024.2363112

Conducting Authentic Moth Research With Students to Encourage Scientific Inquiry

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ABSTRACT

Studying moths is an excellent way to include students in science practices by introducing them to a ubiquitous but under-appreciated animal group that can be found in their local places, including urban, suburban, agricultural, forested, and other habitats. In this paper, we share a simple, low-cost method that can allow individual students or groups to collect moth specimens and begin to ask and answer questions about moth diversity and abundance in their local community.

KEYWORDS: Authentic Science; Experiential Learning; Research; Investigation; Ecology; Insects; Moths

Why moths? Moths in all life stages are critically important to ecological communities and food webs. As larvae, they play a key role in converting tough plant matter into nutrient rich frass (i.e., caterpillar droppings), which helps recycle nutrients (Hartley and Jones 2008). Both caterpillars and adults serve as a major food resource (prey) for predators such as bats, birds, small mammals, reptiles, amphibians, and other insects that require eating moths to grow and reproduce. In one account, between 6,000 and 9,000 caterpillars were required to raise one brood of chickadees before they flew the nest (Tallamy 2015)! During the nighttime, bats consume hundreds of nocturnal insects, including adult moths, each hour they are active.

Adult moths commonly visit flowers to feed on nectar where they can pick up pollen. As a result, they can serve as pollinators and facilitate the development of fruits and seeds for plant reproduction. These fruits provide food for both wildlife and humans. In fact, some flowers, including the Evening Primrose and Moonflower, rely strictly on moths for pollination and only open at night. The Joshua Tree of the Mojave Desert and other yucca species are pollinated solely by the yucca moth, whose caterpillars then feed on the developing seeds in a unique symbiotic relationship (Pellmyr 2003).

Although consisting of a very small percentage of all moths, some moth species are important as pests when voracious caterpillars consume crops, trees, clothing, or stored grains and flour in our homes. In some habitats, population sizes can increase dramatically in certain years, resulting in naturally occurring boom-and-bust cycles. For example, forest tent caterpillars can consume so many leaves that many acres of forests may be defoliated in 10 to 16-year cycles. Such outbreaks, though slowing tree growth, are beneficial to birds and other predators as they can produce up to four million caterpillars per acre of forest (DNR Forest Health Program 2021).

Beyond their importance as prey, pollinators, or pests, the diversity of moths in an area is also a good indicator of ecosystem health (An and Choi 2013). Moths are an incredibly diverse group with over 12,000 species in North America, and different moth species require a multitude of host plants for larval development, additional plants for adult feeding, and intact habitat for hiding and surviving seasonal extremes. Only when all of these are present, along with the appropriate levels of control by predators that prevent moth outbreaks, do we see the integrity of ecological relationships in a healthy balance.

Authentic research

Despite a general understanding of the importance of moths in the environment, relatively little is known scientifically about moth ecology and potential changes to moth populations. Declines in abundance have been reported for many insect groups across the globe, including moths (Fox et al. 2014; Hallmann et al. 2017; Wagner 2012; Wagner et al. 2021). By researching moths in local places, students can learn about the interdependence of species, the importance of biodiversity, and the impact of human activities on the environment. Because they are most active at nighttime, investigating moths also encourages students to consider that ecological systems extend beyond what people see and observe during their typical daily activities.

Before building traps and collecting moths, we have found it helpful to establish some background knowledge of moth biology that can inform potential research questions posed by students. Please see the "Moth primer for teachers" in Supplemental Materials for some beneficial information. Additionally, moth research necessarily involves the killing of a small number of insects, which raises ethical considerations regarding collecting insects. Although it is not practical in this article to provide a comprehensive review of insect collecting ethics, we do provide a beginning point for teachers (see "Ethics of collecting moths for education and conservation" in Supplemental Materials).

Finally, we advocate that having students engage in field science—science that occurs outside of a classroom or laboratory—potentially offers two opportunities to disrupt and expand boundaries of commonly envisioned science teaching and learning. First, field science allows students to experience science as a collective and community endeavor, rather than as an individual enterprise. Second, field science offers students opportunities to feel the awe and wonder of scientific work that is often devalued in other science settings (Stroupe and Carlone 2022).

Collecting moths safely

Placing traps

Moths can be found in many different types of habitats and part of the excitement for students (and adults) is the mystery of what can be collected in "my habitat." Thus, allowing students to wonder and to collect moths in places that they find interesting should be encouraged. Traps should only be placed where permission has been granted, and safety in placing and collecting traps should be considered (e.g., away from roads or hazardous sites). It is important that teachers consider the environments and safety hazards that students could encounter in their local communities. These will vary depending on the location of schools from urban to rural and should be addressed with students prior to placing traps. Because moths require vegetation for feeding and reproduction, areas with a variety of plants are likely to have higher moth diversity or abundance in traps. Additionally, other environmental factors can affect the likelihood of capturing moths in the traps. Some examples are listed next as a help to teachers, but keep in mind that allowing students to place traps in a variety of settings will allow the excitement of discovering information about moth diversity themselves. An important principle in scientific research that can be shared with students is that getting a result of "zero" (no moths collected in a trap) is not a "wrong answer." It helps us to answer questions such as what moths can be found in an area and what determines how we can catch them.

Factors potentially affecting moth captures

The following factors may affect the capture of moths:

- Temperature—moths are more active on warmer nights (nighttime low temperatures remaining above ~60 degrees F).
- Wind—many moths are weak fliers and are more active on calm nights (<12 mph winds).
- Light—artificial lights (and moonlight) can make it more difficult for the moths to be attracted to the trap blacklight so traps placed in darker locations may attract more moths.
- Rain—moths will avoid flying in rain, and even brief periods of rain can introduce water into the collection bucket and damage any collected moths. Humid nights following rains during the day are often good for moth activity.
- Time of day—because battery powered lights will dim over time (brightest light is in the first 4–6 hours), placing the traps and turning on lights as close to sunset as possible is desirable. Placing the traps and turning the light on during school hours will cause it to be dim and ineffective by the time darkness arrives and most moths are active. Preferably, students would have traps with them and be able to place them safely before dark at a place accessible from their homes. If this safety cannot be assured, we have had teachers work with their students to place traps on school property or in local natural areas during the school day. The teacher or other adult would then return in the evening to turn on the lights and students could collect the traps the following day.

Adding pesticide strip

Once the trap is placed outdoors in the desired location with the black light turned on (make sure the switch is fully clicked in the "on" position), place a small piece of protected pest strip (a 1.5 cm pest strip square

wrapped in several layers of window screen) into the bottom of the collection bucket. While transporting the pest strip and when collecting it, it is recommended to keep it in doubly sealed containers (zipper-style plastic bags or plastic containers with tight fitting lids). Even though the pest strip is covered by screen, it is recommended that anyone handling the strips wear disposable gloves or use forceps.

Pesticide strip safety

The pesticide strips used to kill the collected moths contain chemicals that disperse in the air in very small amounts over time and are relatively odorless. Even though you may not be able to smell it, you must limit your skin-to-skin contact and inhalation of vapors in small, enclosed spaces. If possible, work with the pesticide strip outdoors or in well-ventilated areas.

Depending on the age of your students or school policies, you will need to decide how to provide the pest strip for trapping. Some teachers only handle it themselves and place traps on school property, others arrange for adults to obtain the pesticide from the school, and others will allow students to take the pesticide strip home in well-sealed and labeled containers. Regardless of the methods, it is important to stress safety in handling the strips. The strips are active for many months if kept in sealed containers and can be reused over time.

Lesson implementation

A general outline for the implementation is provided with variation allowed for in the amount of time required. Teachers have reported that the flexibility to spend more or less time with moth research allows them to emphasize varying content of the science curriculum that they use in a particular year.

Step 1: Background information and setting the stage (1–2 class sessions)

The first class session can be used to get students to start thinking about moths. Ask them what they know about moths, where they have seen moths, or what they may have heard about moths. Have them draw a picture of what they think a moth looks like. When we have implemented this curricular unit, we typically have students work in groups of three to six so they can share their ideas more easily with one another. Finally, ask students to come up with a list of things that they would like to know about moths in their local habitats. These can form the basis of the scientific investigations that students will later carry out in this unit.

Once students have had a chance to share with you what they know about moths and have developed questions, you can share with them some information about basic moth biology and ecology. When they have questions that you cannot answer, you can point out that this is how science works! People come up with questions and wonderments about the natural world that they then test. You may ultimately want to share information with them about the importance of moths in local ecosystems and their roles as nocturnal pollinators. We recommend finishing the first part of the moth unit with a discussion of how to trap moths, looking ahead to when they will conduct their own investigations.

Step 2: Trap building (1–2 class sessions)

In this segment of the unit, students will construct their own do-it-yourself moth traps. Each student or group will be required to bring in two empty, rinsed, and dried two-liter soda pop bottles. You will also need to purchase a suitable number of binder clips and black light keychains which act as an attractant for moths. Students will need to make precise cuts on their bottles to make the parts for the trap. For younger students, you may want to opt for a limited number of traps for the entire class and to do the bottle cutting and partial assembly yourself. A full guide describing how to build the traps is provided in Supplemental Materials (see "Building a simple moth trap"; see also the moth trap in Figure 1).

Step 3: Questions and hypothesis (0–1 class sessions)

We recommend that students be given agency to choose their own scientific questions (Miller et al. 2018; Stroupe, Caballero, and White 2018). For younger grades or class dynamics, where you may need greater facilitation in helping with the moth trap building and trap placement, you may want to allow them to choose a *single question* for the entire class. As the teacher, you would then deploy the trap(s) for

FIGURE 1: Moth trap built using instructions in "Building a simple moth trap" (available in Supplemental Materials). Shown with small keychain UV LED light turned on and ready to attract moths.

them and bring in the nightly moth captures. If students wonder about what counts as a "good" question, ask them to think about the habitat around their schools or in their neighborhoods. Questions that students have used before, as part of this unit, include: (1) Where will we catch more moths? Under deciduous trees, or under coniferous trees? (2) Will backyards with swimming pools result in more or fewer moth captures? (3) Will I catch more moths near my front door on nights where the outside light is turned *on*, or on nights where the light is turned *off*?

Inherent in this stage is the need to come up with a research methodology. Students need to decide *where* the traps will be set, and for *how many* nights. This entire step in the project can be done in a single class session or, in certain circumstances, could be folded into Steps 1 and 2.

Step 4: Collecting data and interpreting findings (2–5 class sessions)

Here, students begin to collect data with the goal of answering their research question. We have found that students have been able to safely and successfully work with moth specimens and were eager to participate in hands-on activities.

We recommend that teachers divide their classes into small teams of three to six students and work within these groups to demonstrate handling of moths, including the safe pinning or gluing of moths for examination. Teachers have reported that students who are less comfortable or confident in their ability to pin the moths often self-select into "specialist" positions. For example, one student may be the primary pinner, another makes the label or records notes, and another prepares the trap for another night. If the school system and additional adult support permits, teachers have included parents/guardians or older students to provide additional support during early stages of the moth research, especially in trap building and this first time bringing in collected moths.

Nightly catches should be brought into class each morning, and time needs to be set aside so that students can document their captures. The moths from each night can be counted (*abundance*), sorted by morphospecies (i.e., to get a measure of *species richness*), and the necessary data pertaining to the question being asked recorded. See "Sorting and identifying moths" and "Moth sorting sheets" in Supplemental Materials for help in sorting and identifying moths.

Identification of moths is much easier if both the front (fore) wings and back (hind) wings are visible. This can be accomplished with the larger moths by pinning and spreading the wings. For smaller moths, simply gluing the moths to a small piece of cardstock is adequate even if the hindwings are not visible. We also have found that some students may have difficulty pinning moths, and the ability to glue them allows them to participate more fully. Once moths are pinned or glued, as appropriate, a student group or class moth collection can be assembled as a visual record of student captures. Methods for pinning and gluing moths for display are provided in Supplemental Materials (see "Pinning and gluing moths"). See also the results of student moth collections in Figure 2.

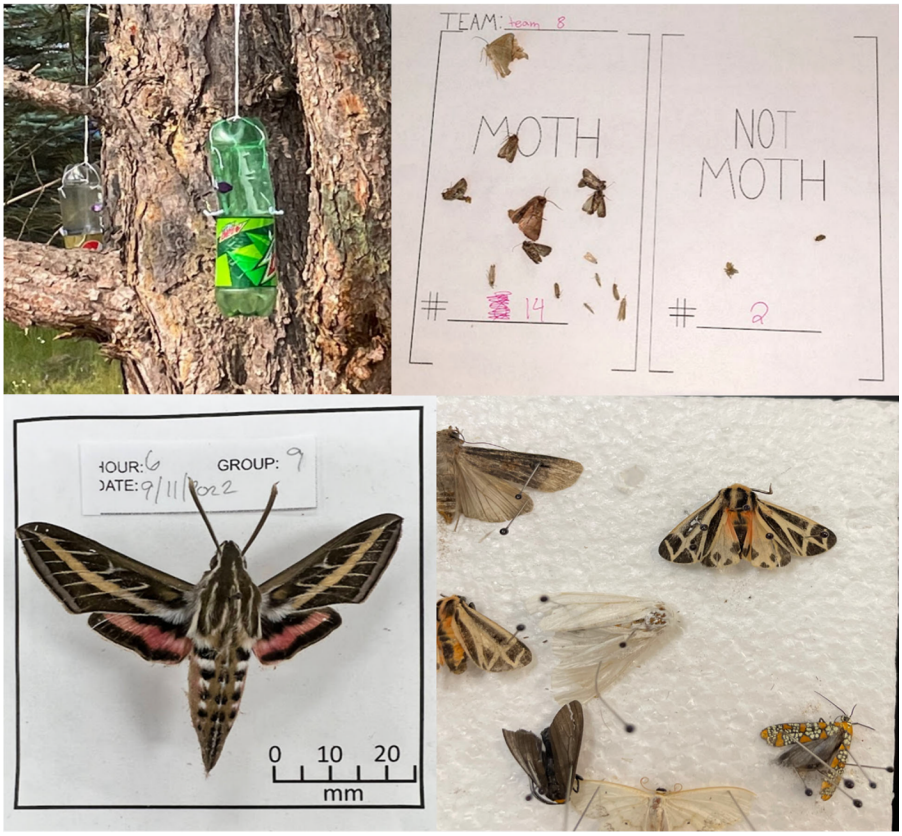
Once your students have trapped for an appropriate number of nights, students will need to make a representation of their data so that they can try to answer their research question. (Note: you will need to decide what an "appropriate" number of nights is. This may be based on the amount of time you are able to dedicate to the moth unit during the school year or the availability of good weather conditions.) Students may want to make graphs of the number of moths caught in different locations or draw pictures of the moths they caught. Ultimately, students should work toward figuring out how the data informs their scientific question. Here, it may be helpful to have the students in each group work together to write out their original research question/hypothesis and then to summarize their results and conclusions, before class discussion begins.

We often end the moth unit by circling back around to the same activities that we used at the start of the unit so that we can get a sense of what the students learned. For this, simply re-run some of the activities from the first and/or second class sessions. Ask students what they know about moths, ask them to draw a picture of a moth, ask them what questions they have about moths, and so on. This activity may identify gaps in knowledge or additional questions, providing an opportunity for further investigation and exemplifying again the scientific process. See "Lesson extensions" and "Additional resources in Supplemental Materials.

Conclusion

Incorporating the study of moth ecology into a middle school classroom is a great way to introduce students to the importance of biodiversity, the impact of

FIGURE 2: Results of moth collection. Examples of student moth collections by sixth- and eighth-grade students. Clockwise from top left: placement of two moth traps to compare bottle colors as a student research question; sorting and counting the abundance of moths and "not moth" insects; pinned moths from a trap; hawk moth pinned and displayed.



human activities on the environment, and the role of insects in our ecosystem. By studying these fascinating insects, students will gain a deeper appreciation for the natural world and the importance of protecting and conserving our planet's biodiversity while using authentic science research practices. •

ACKNOWLEDGMENTS

We thank the following teachers who have contributed to the development and implementation of moth research using these traps: A. Bunker, R. Field, K. O'Brien, M. Kasik, and G. Picconatto-Anderson.

FUNDING

This material is based on work supported by the National Science Foundation (NSF) under Grant No. DRL-2100990. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

SUPPLEMENTAL MATERIALS

Moth primer for teachers.
Ethics of collecting moths for education and conservation.
Building a simple moth trap.
Sorting and identifying moth.
Moth sorting sheets (can be printed and laminated for repeated use).
Pinning and gluing moths.
Lesson extensions.
Additional resources.
Supplemental data for this article can be accessed online at http://dx.doi.org/10.1080/08872376.2024.2363112.

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