ARTICLE

Testing Honey Bees' Avoidance of Predators

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Abstract

*Many high school science students do not encounter opportunities for authentic science inquiry in their formal coursework. Ecological field studies can provide such opportunities. The purpose of this project was to teach students about the process of science by designing and conducting experiments on whether and how honey bees (*Apis mellifera*) avoid predators. Students summarized their findings in scientific papers and presentations to research scientists. We found that this project increased student knowledge of the scientific process, scientific writing, what scientists do, and the importance of the environment.*

Key Words: *Scientific method; inquiry; science writing; ecology;* Apis mellifera.

Bees are important to our environment because they pollinate plants and help maintain a healthy ecosystem. Many people do not know, however, that approximately one-third of the food we eat is pollinated by animals (Klein et al., 2007). Bees are arguably the most important crop-pollinating insects and are thought to account for 75% of crop pollination requirements (Nabhan & Buchmann, 1997). Recently, bees have been the topic of environmental discussions, because they have been suffering from a population decline. The population decline first received mainstream attention in 2006, when large numbers of honey bee colonies died, a phenomenon termed "colony collapse disorder" (U.S. Environmental Protection Agency [EPA], 2011). There have been many theories about the cause of colony collapse disorder, and the researchers who are leading the effort to find it are now focused on four main causes: the invasive *Varroa* mite (a pest of the honey bee); new or emerging diseases such as Israeli acute paralysis virus and the gut parasite *Nosema*; exposure to pesticides applied to crops; and stress from bee management practices (EPA, 2011). These different factors, often acting synergistically, have contributed to poor honey bee health, weakened immune systems, and decreased queen longevity (EPA, 2011). Exploring these causes of colony collapse disorder allows teachers to discuss the importance of pollinators in our ecosystem, issues of biodiversity and biodiversity loss, population fluctuations, and human impacts on the environment. It also serves to interest students in bees and in conducting experiments on their behavior.

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The *National Science Education Standards* (National Research Council, 1996, 2000) advocate that students engage in authentic science and be able to develop their own questions about science, design experiments, and actively investigate phenomena. Ecological field studies can provide students with opportunities to engage in real science inquiry. We used our field experiments to teach the process skills of science identified by Harlen and Jelly (1997): observing, questioning, hypothesizing, predicting, investigating, interpreting, and communicating.

The purpose of this project was to teach students about the process of science and ecology by designing and conducting experiments on how honey bees (*Apis mellifera*) may detect and avoid predators. Academic work has highlighted that bees are able to avoid predators such as spiders at flowers (Dukas, 2001; Abbott & Dukas, 2009), but there is much still to learn about what senses (such as vision or olfaction) they use to detect predators and what kinds of predators they can avoid. Bees' avoidance of predators will affect their ecology, so this project offers students the ability to be involved in cutting-edge science related to an environmental issue currently in the news.

In this project, students learn how scientists start with observations and questions, use those questions to develop hypotheses and design experiments, and then analyze their data and communicate their results. This semester-long project was tested on 11th-grade biology students, but we think the project could be adapted for all levels of high school and college. In order to teach these science process skills, we first taught the students about bees and their current decline in the United States. Next, the students visited honey bee hives and watched a demonstration experiment, where bees were tested to see whether they avoided a dead bee. After this, the students collected and identified bee predators (spiders) on a field trip. Then they brainstormed an experimental method and conducted their experiments at local honey bee hives. After conducting the experiments, the students statistically analyzed data to determine whether honey bees' feeding behavior was affected by predator presence, using a binomial probability test. Each student then wrote a scientific paper about their experiment and results. The students concluded their work by giving a presentation of their findings to research scientists working with honey bees.

The American Biology Teacher, Vol. 74, No. 7, pages 452–457. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2012.74.7.5

This project was done with students from an urban public high school. Classrooms throughout the country can participate in honey bee field experiments because bee hives are now found in urban, suburban, and rural settings (Harmon, 2009). To find local bee hives, bee suits, and other resources, we suggest contacting your local beekeeping association, beekeeping business, or university. State-by-state lists of beekeeping resources can be found on the American Beekeeping Federation website (http://www.abfnet.org/) or the Honey O website (http://www.honeyo.com/org-US_State.shtml). If access to bees is limited, this project can be adapted for other insects, such as ants. To view sample materials and resources for all steps of this project, a project timeline, and samples of student work, teachers can log onto http://dp.hightechhigh.org/~jwade/projects/PollinatorsinPeril.html. This project covers inquiry and life-science standards according to the *National Science Education Standards*, specifically the life-science standards on the behavior and interdependence of organisms (National Research Council, 1996).

○ Safety Considerations

Honey bees can sting. This does not pose a threat to most people. However, it is estimated that 0.3–3% of the population is allergic to bees, and an anaphylactic reaction is possible (Reisman, 1994). Accordingly, students who have experienced allergies to bees should avoid handling them. In order to know which students had known allergies to bees, a letter went home to all students and guardians. In addition to the letter, we also sent home a waiver to inform guardians of the safety procedures and to release the school and partnering institution from liability related to the project. To view the letter and waiver, log onto http://dp.hightechhigh.org/~jwade/projects/PollinatorsinPeril.html. All students were given safety training on when and how to use personal protective equipment and what to do if stung. Students were required to wear full bee suits when working with the bees, including hats with zippered veils, gloves, long sleeves, long pants, and closed-toe shoes. Proper safety precautions can prevent bee stings. No students were stung during our project.

○ Background Information & Initial Observations

We began the project by providing the students with information about bees and their current decline in the United States. Each student was then asked to conduct individual research on honey bees and find reasons for studying them and their response to predators. Because we knew that the students had very little experience conducting experiments with honey bees, we first brought them to bee hives and presented a demonstration experiment. An alternative to this field trip to the hives is showing a video of a demonstration experiment. In the demonstration experiment, we showed the class how to slowly train the bees from a hive to come to a new feeding source by placing a feeding dish close to the hive. To make the feeding dish, we took a plastic, 3.5-cm-diameter, blue-painted Petri dish and filled it with a 2.5-molar sucrose solution (66% sugar by weight) and put the dish inside a larger plastic, 9-cm-diameter Petri dish painted white (Figure 1). Honey bees can easily see blue colors and distinguish them from white (Dyer, 2012).

Next, we showed the students how to train the bees to feed at a new location, ~5 m from the hive. We did this by first placing the Petri dish at the entrance of the hive until 7 or 8 bees landed and fed from the dish. Once 7 or 8 bees had landed on the feeding dish, we gently moved the dish onto a tripod 0.25 m from the hive. We told the students that they would move the dish back at increasingly longer distances in this manner, until they reached their 5-m goal. To ensure that all the bees were from the same hive, we marked the bees with a drop of green paint on their abdomen using a wooden stick when they were at the feeding dishes on the colony entrance. We advised the students to use as little paint as possible and to avoid painting the bees' wings.

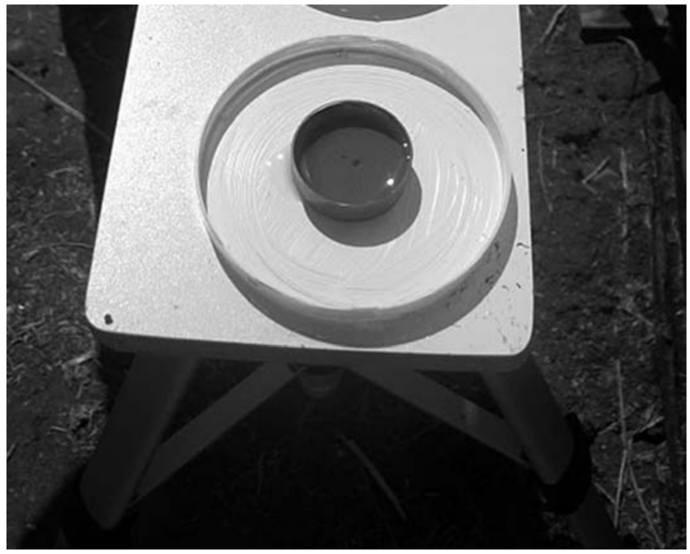

Figure 1. Feeding dish for bees constructed from two painted Petri dishes, shown on a white platform on top of a tripod.

We then began our demonstration experiment for the students. In the demonstration experiment, we had two sets of the blue and white Petri dishes, one experimental set and one control set (Figure 2). Both dishes were placed on the tripod next to each other and separated by 5 cm. We placed one dead bee on the experimental dish and then ran a mock data collection. We told the students that each member of the group would have a job. There would be a timer-observer, a recorder, and a bee catcher, who would remove each bee as soon as she made a choice (landed and began to feed) with an aspirator. An aspirator (Figure 3) is a way to collect bees by positioning the long plastic tubing near the bee, and sucking on the short plastic tubing with the mesh cover. In this way, one draws the bee into the middle plastic cylinder. The bee catcher ensures that the same bee is not counted multiple times and that each bee makes its choice independently and is not influenced by the visual presence of another bee (Figure 4). The timer-observer's job is to watch the dishes to see when a bee lands on a feeding dish and begins to feed. He or she then calls out the time, the bee's color, and whether the bee landed on the control or experimental dish. The timer-observer is also responsible for switching the position of the experimental and control dishes every 2.5 minutes (to correct for potential site bias), and for ending the experiment after 15 minutes. The final group member, the recorder, records the data and any observations of bee behavior in the lab notebook.

○ Preparation: Predator Collection & Designing Experiments

After the demonstration experiments, we divided the students into groups of three to design their own experiments. Before deciding what

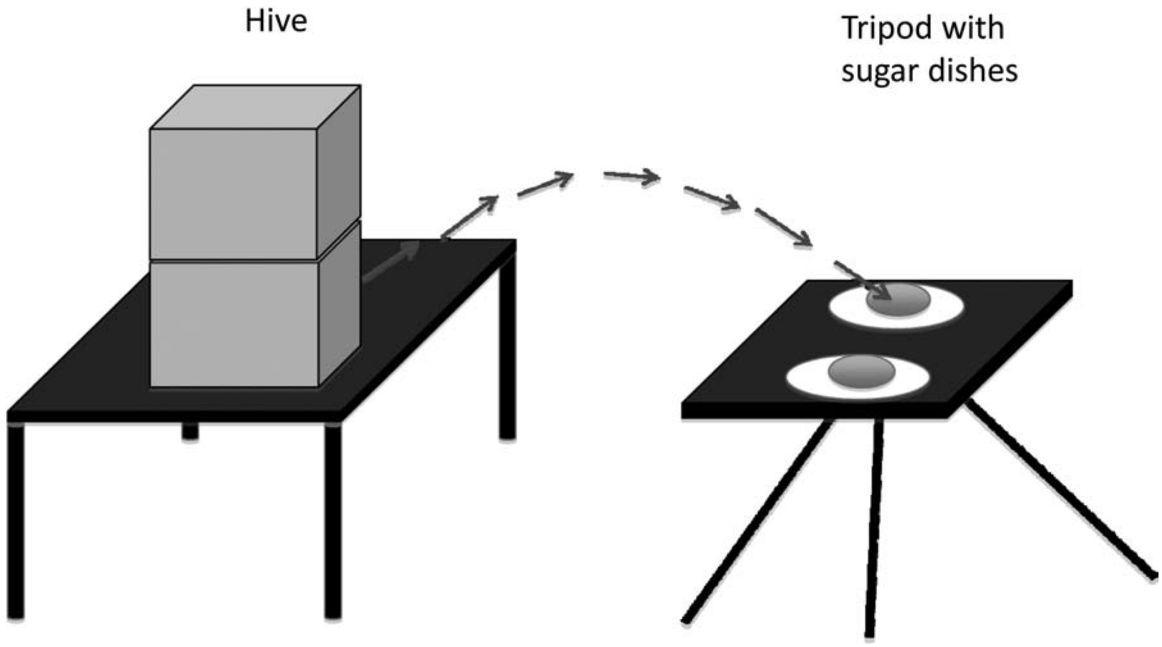

Figure 2. Honey bee hive and tripod with feeding dishes. Arrows show flight path of bees to a feeder dish.

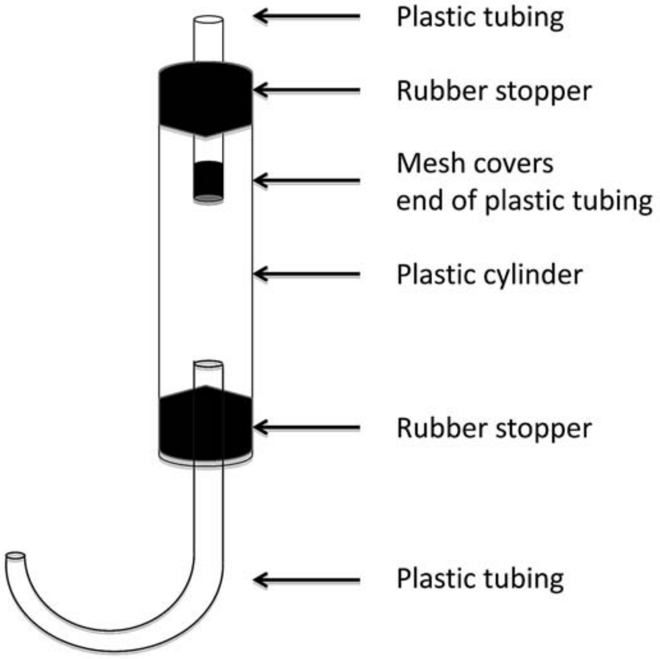

Figure 3. An aspirator.

Figure 4. A student group conducts the experiment. One student is the time keeper and observer, another student is the recorder, and the third student aspirates bees once they have landed on a feeding dish.

predator stimulus they would like to test, we went out into the field to collect bee predators, which were mostly spiders. (Do not collect in state parks or other protected areas without a permit.) To do this, we gave each student group an insect net, scissors, three ice-cream take-out containers with lids, a 0.5-m wooden dowel, and their lab notebook and a pen. We also gave the students a set of cards with common spiders that they might find in the area. We were able to invite guest entomologists to help the students identify the spiders that they found.

Before collecting the spiders, we trained the students in standard scientific collection techniques. They learned how to collect the spiders safely by sweeping their nets over flowering plants, or cutting the webs and spiders from bushes, or beating trees with a stick while holding the insect net underneath to catch the debris. Once they had a spider in their net or plastic bag, the students could transfer the spider to their container. We instructed the students to always empty their nets over the trees or bushes that they collected from, so as to return unwanted insects to their proper home. We set a goal of collecting three spiders per group, or one spider per person. If teachers are unable to schedule field trips to collect bee predators, we suggest having students collect spiders at home and bring them to the class, or raising predators, such as praying mantises, in the classroom. Praying mantis egg cases are available on Amazon.com.

After collecting the predators, the students returned to the classroom to identify their spiders. They examined and photographed each spider under a dissecting scope (binoculars held backwards can also work) and used the Bug Guide website at http://bugguide.net/ to identify the spiders. Responsible for keeping the spiders alive until they conducted their experiments, the students fed them either flightless fruit flies or crickets, depending on the spider's size. Fruit flies and crickets are available at pet stores and can be purchased online.

Next we asked the students to consider the question: How do bees avoid predators? They used this question to formulate their own hypotheses about how bees avoid predators. Each group chose a hypothesis that they liked best, designed an experiment that would test this hypothesis, and made a prediction for the experiment. We had the students start with an "If…then" statement.

The students designed experiments that all followed the general model we demonstrated (Figure 2) but tested different treatments. Some groups decided to test whether the bees would avoid spider webs. Others tested whether the bees avoided the scent of a spider. To extract this odor, a freshly killed spider was washed in hexane for 1 minute and the resulting hexane was presented at the experimental feeder (with an equal volume of clean hexane at the control feeder). Some students developed more complex experiments designed to see whether bees could detect a spider that was the same color as the Petri dish. We encouraged each group to try to find another group that would conduct the same experiment so that they could share their data and have a larger sample size.

○ Materials

The necessary materials for one student group are listed below. In addition, each student will need one complete bee suit, including gloves and a veil. We were able to borrow bee suits from members of the local bee society. Local beekeepers are also a good resource.

- A hive of *Apis mellifera* (honey bees)
- 1 bee predator or cue of a bee predator (spiders, webs, spider guts, etc.). We recommend that each group have 1 or 2 back-up predators in case the predators escape before they are tethered to the experimental dish.
- 3 Petri dishes 3.5 cm in diameter, painted blue, per group
- 3 Petri dishes 9 cm in diameter, painted white
- 50 mL of 2.5-M sucrose solution. This is a saturated sugar solution that bees are highly attracted to because it is so sweet. You can also make up a solution that is 66% sugar by weight, using regular white table sugar. This will require stirring and gentle heating to dissolve.
- 1 disposable 1-mL pipette
- 1 tripod, stool, or small table so that the feeding dishes are elevated to the same height as the bee hives
- 1 stopwatch, or equivalent
- Aspirator to suck bees into after they have landed on a sucrose solution (Figure 3)
- Water-based acrylic paint. This is less bothersome to the bees
- A wooden applicator or stick for painting the thorax of the bee
- Tools for adhering predators to experimental dish (tulle mesh, duct tape, thread, super glue, filter paper)
- Tweezers for holding the predator. Sometimes you can slightly chill the predator in a refrigerator until it is sluggish. It is then easier to work with.

○ Methods

Before beginning the experiments, all students donned bee suits and gathered their equipment. Then each student group was assigned to one of six hives. We recommend no more than six student groups at a time so that the groups can be properly supervised. Once assigned to a hive, the students immediately began training their bees to come to the feeding dishes. During this training process, the students set up their experiments. After approximately 45 minutes of bee training, the students began their experiments. Experiments lasted 15 minutes and followed the general method demonstrated. The students counted how many bees from their hive went to the control feeding dish and how many bees went to the experimental feeding dish (Figures 2 and 4). A tricky part of the experiment involved keeping the spider in the Petri dish, if it was alive. We found that this could be done by keeping the spider under mesh or by attaching the spider to a piece of string with superglue and then attaching the other end of the string to the middle of the dish. When working with superglue, keep some nail-polish remover handy. This dissolves the superglue in case of accidents.

At the end, the students cleaned up their equipment and left the hives. Each group had ~2.5 hours to take on and off safety equipment, train the bees, and set up and conduct their experiments. If time permits, we suggest having the students replicate their experiment on another day to collect a larger sample size.

After returning to the classroom, the students added up the number of bees that landed on the control or experimental dishes. They graphed their data and then performed a binomial test to determine whether their results arose through chance alone. They accepted their hypothesis if the P value was less than 0.05. We used Microsoft Excel software to graph and test the data. The data from different groups were then pooled, if appropriate, to look for interesting trends. For example, do bees avoid larger predators more frequently than smaller predators?

○ Assessment

In order to teach the students more about the scientific process, each student was asked to write a scientific paper summarizing his or her results. Papers were graded on thorough research, correct data analysis, and completeness. After writing the paper, students presented their research to scientists studying honey bee ecology at a local university (University of California, San Diego). Students formed groups based on their experiments and made short PowerPoint presentations, asking for questions and feedback on their research after each presentation.

○ Evaluation

After concluding the project with presentations to scientists, the students were surveyed to find out what they had learned from the project. Two types of questions were used: five-point Likert survey questions and open-ended questions. This project was tested on a mixed-ability group of 11th-grade biology students, and the students reported that the project increased their knowledge of the scientific process, writing a

Table 1. Students evaluate their knowledge before and after the project.

Statement	Before[a]	After[a]
How knowledgeable you were about the scientific process	2.59 ± 0.64	4.18 ± 0.68
How knowledgeable you were about writing scientific papers	2.69 ± 1.01	4.34 ± 0.66
How knowledgeable you were about scientific presentations	2.79 ± 1.06	4.36 ± 0.67
How knowledgeable you are about what a scientist does	3.03 ± 0.84	4.31 ± 0.66
How knowledgeable you are about how humans impact the environment	3.5 ± 1.12	4.38 ± 0.78
How knowledgeable you are about how predators affect prey populations	2.88 ±1.09	4.38 ± 0.67

[a]Mean score for two classes (n = 40) ± SD. Students responded on a numerical scale from 1 (no knowledge at all) to 5 (very knowledgeable). Data are from December 2011.

Table 2. Students evaluate their appreciation for the environment before and after the project.

Statement	Before[a]	After[a]
Your appreciation for the natural environment	3.31 ± 1.00	4.23 ± 0.87
Your appreciation for small organisms	2.74 ± 1.12	4.26 ± 0.82

[a]Mean score for two classes (n = 40) ± SD. Students responded on a numerical scale from 1 (no appreciation) to 5 (very appreciative). Data are from December 2011.

Table 3. Student responses to the question "What did you learn from the bee project?"[a]

Responses
"I learned how the scientific process works. I learned how scientist[s] think, solve problems, analyze data, and conduct professional experiments with quality equipment. I also learned how to better my skills at writing scientific papers, and enhance my knowledge of small organisms and how we affect our biodiversity and environment."
"I learned a lot of new skills from writing scientific papers and doing presentations. I haven't had to do this before and found it a good experience."
"I learned about the importance of bees as pollinators and the major affect they have on our environment and our personal diets."

[a]Responses are from December 2011.

scientific paper, making a scientific presentation, what a scientist does, how predators affect prey populations, and how humans affect the environment (Table 1). The students also reported that the project increased their appreciation for the natural environment and for small organisms (Table 2).

When the students were asked what they had learned from this project, 38 of the 40 surveyed stated either that they learned about the importance of pollinators in an ecosystem or that they learned about the process of science. Table 3 shows typical responses from students to the question "What did you learn from the bee project?"

The students enjoyed this project for a variety of reasons. First, it got them outside of the classroom. One student summarized that sentiment when she reported what she liked most about the project: "I liked how we went to catch our own predators for the project. I also liked how we went to the bee hives." Second, students were able to do real science; something that is not done often enough in science classes. A different student said that what he enjoyed most was the "freedom to conduct our own experiment and working on a real science lab." Lastly, working with bees is exciting. The students enjoyed wearing the bee suits and aspirating and painting the bees.

In conclusion, this field experiment on how honey bees respond to predators taught students about the process of science by having them hypothesize, design, and conduct an experiment, analyze and interpret results, and communicate conclusions about how honey bees respond to predators. The students also learned about ecology and gained a greater appreciation for the environment. Most importantly, this field experiment was engaging and fulfilling to the students.

○ Acknowledgments

Thanks to David Berggren and the students of High Tech High school for assistance with this project. We would especially like to thank Jim Berrian of the San Diego Natural History Museum and James Hung from the University of California, San Diego, for help collecting and identifying local bee predators. We would also like to thank the members of the San Diego Bee Society who loaned us bee suits and other safety equipment for our experiments. Funding for this project was provided from a Blasker Science and Technology grant from the San Diego Foundation and from a National Science Foundation CAREER grant (IBN 0545856).

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