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EXPERIMENTS

Rapid adaptation of bean beetles to a novel host

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Female bean beetle on a mung bean (squares in mm). Photograph by L. Blumer

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ABSTRACT

Bean beetles (*Callosobruchus maculatus*) are phytophagous insects that lay their eggs on the surface of several species of beans in the family Fabaceae. Larval development is completed within the bean. Therefore, we would expect strong selection when the beetle switches to a new host. Students are provided with live cultures of beetles containing adults that have been raised on mung beans (*Phaseolus aureus*) for many generations; they are also given cultures that were originally grown on mung beans, but were recently switched to another bean species. In this exercise, students design and conduct an experiment to determine whether beetles have adapted to the new host. In the first class period, students design and set up the experiment. In subsequent sessions, they isolate beans with eggs and record data on life history traits including time to emergence and mass at emergence to evaluate the success of beetles on their historic and novel hosts. Based on the pooled data from the entire class, each student writes a scientific paper.

KEYWORD DESCRIPTORS

- **Ecological Topic Keywords:** adaptation, evolution, individual ecology, life history, host specificity
- **Science Methodological Skills Keywords:** data analysis, evaluating alternative hypotheses, experimental design, factorial experiment, hypothesis generation and testing, quantitative data analysis, scientific writing, statistics, graphing
- **Pedagogical Methods Keywords:** Cooperative learning, guided inquiry

CLASS TIME

One 2-3 hour class period and a 1 hour class period 48 hours later.

OUTSIDE OF CLASS TIME

Students will spend 15 minutes daily for 2 weeks between weeks 4 and 6 (approximately) after the experiment is established. In addition, they may spend several hours analyzing their data, conducting library research, and writing papers based on their results.

STUDENT PRODUCTS

Each student prepares a written scientific paper in the style of *Ecology* based on the pooled data from the entire class.

SETTING

The experiment is carried out entirely in the lab.

COURSE CONTEXT

The experiment as described is used in an upper-level ecology course with a maximum of 24 students per lab section.

INSTITUTION

This experiment has been conducted at a mid-sized private university. Similar experiments have been conducted at a small private college.

TRANSFERABILITY

Since this exercise is a guided inquiry, it could be transferable to other levels, depending on the degree of support and direction given to the students as they design the experiment and analyze the data. Bean beetles have been used for other experiments in high school biology classes and are reliable experimental organisms. Other phytophagous insects that are easily reared in the laboratory and can be induced to use a variety of host plants, such as tobacco hornworms (*Manduca sexta*) and the Brassica butterfly (*Pieris rapae)*, could be used in this experiment.

ACKNOWLEDGEMENTS

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SYNOPSIS OF THE EXPERIMENT

Principal Ecological Question Addressed

Are phytophagous insects, specifically bean beetles (*Callosobruchus maculatus*), able to adapt rapidly to a change in larval host species?

What Happens

In an initial lab period, students work individually and then in small groups to design an experiment to determine whether bean beetles have adapted to a new larval host. Second, groups present their proposed experimental designs to the class and are guided by the instructor to a consensus experiment. Third, each student sets up one replicate of each treatment of a reciprocal transplant experiment. A minimum of 48 hours later, students isolate beans with single eggs. Approximately 4 weeks later, students collect data on life history traits of emerging adult beetles. The resulting data are analyzed to determine if bean beetles have adapted to the new host.

Experiment Objectives:

1. Design an experiment to evaluate whether bean beetles (*Callosobruchus maculatus*) rapidly adapt to a change in larval host.
2. Conduct a consensus experiment to evaluate rapid adaptation in bean beetles.
3. Analyze and interpret the resulting data to determine whether adaptation to a new larval host has occurred.

Equipment/ Logistics Required:

The experiment requires having dense cultures of bean beetles from which females can be isolated. Beetles should be from cultures reared on a natal host (typically mung beans) and from cultures switched to a new host several generations prior to the experiment. If new cultures are initiated approximately 2 months before the lab period, there will be sufficient time for two generations of beetles, which will result in dense cultures. When possible, we supply one culture of each type (natal and new host) to each group of students working in pairs; however, each culture should have sufficient beetles for use by multiple student groups. As bean beetles are a tropical species, they develop most rapidly in warmer temperatures. The time estimates for the experiments are based on rearing beetles in incubators at 30˚C. Beetles can be reared at room temperature. However, this will extend larval development by 1-2 weeks.

Currently, cultures of bean beetles reared on different host types may be obtained from the authors. In the future, they may be available from commercial suppliers.

Below is a list of materials for a class of 24 students.

- 24 magnifiers 2.5x, 4” diameter self-standing with folding base (Fisher #14-648-19 or VWR #62379-535, approximately $50.00 US per unit) or dissection microscopes
- 24 bean beetle cultures with newly emerged adults (12 cultures for each host type)
- 12 plastic 150mm Petri dishes for picking adults females from cultures
- 96 plastic 35mm Petri dishes for oviposition by isolated beetles
- Many 35mm Petri dishes for holding individual beans OR flat-bottom tissue culture plates (6 or 12 well)
- 0.1mg analytical balance for weighing beetles
- 30 Vernier calipers for measuring beetle characteristics
- Dried beans (preferably organic) of the species used for culturing the beetles. Typical hosts that beetles colonize include mung beans, adzuki beans, and blackeye peas.

Summary of What is Due

During the first lab period, students will produce an experimental design to examine rapid adaptation to a new host in bean beetles. After collecting and analyzing the data, each student will write a scientific paper based on the pooled results of the class.

DESCRIPTION OF THE EXPERIMENT

Introduction (written for students)

If individuals of a species are adapted to a particular environment, any change in the environment may lead to reduced fitness. As a result, a rapid evolutionary response to environmental changes can be advantageous. Environmental changes that might lead to an evolutionary response include changes in the local environment, changes in the global environment (e.g., global climate change), or changes in the natural range of environments that a species inhabits due to range expansion.

In phytophagous (phyto=plant, phagous=eating) insects, different species or different populations of the same species are often specific to a particular host plant species (i.e. are specialists). Therefore, a change in the availability of a particular host plant or the introduction of a new host plant may lead to a shift in the host plant used, which in turn could lead to strong natural selection for adaptation to the new host plant. Adaptation after host shift in herbivorous insects has been documented in a wide range of species (Via 1990). In some species, the evolutionary response of insects to a new host can be very rapid. For example, soapberry bugs (*Jadera haematoloma*) historically used balloon vine (*Cardiospermum corindurn*) and the soapberry tree (*Sapindus saponaria*) as their hosts (Carroll et al. 1997). However, in the 1950s, the goldenrain tree (*Koelreuteria elegans*) was introduced into Florida. By 1990, soapberry bugs that had switched to using goldenrain trees as a host had evolved shorter beaks. In addition, when soapberry bugs from both balloon vine and goldenrain tree were reared on goldenrain tree, those that had switched to using goldenrain trees were larger and developed more rapidly on goldenrain (Carroll et al. 1997). Similarly, in the checkerspot butterfly *Euphydryas editha*, females evolved a preference for a novel host and rejected their native host in just seven years (Singer et al. 1993).

Bean beetles (cowpea seed beetles), *Callosobruchus maculatus*, are agricultural pest insects of Africa and Asia. Females lay their eggs on the surface of beans of several species in the family Fabaceae. Although bean beetles are generalists, females prefer to lay eggs on their natal host (Messina 2004a). Eggs are deposited (oviposition) singly. Several days after oviposition, a beetle larva (maggot) burrows into the bean and cannot move from the bean on which an egg was deposited. As a result, the quality of the food resources available in a bean will influence the developing individual's growth, survival, and future reproduction (Mitchell 1975, Wasserman and Futuyma 1981). At 30°C, pupation and emergence of an adult beetle occurs 25-30 days after an egg is deposited, completing one generation of the life cycle. Adults are mature 24 - 36 hours after emergence, and they do not need to feed. Adults may live for 1-2 weeks during which time mating and oviposition occurs. Because the ability to use the resources of the host bean efficiently is important in determining larval growth, survival, and future reproduction, we would expect populations to adapt rapidly to the host plant species that are available.

Materials and Methods (written for faculty)

Overview of Data Collection and Analysis Methods

Week 1. In class, you will be provided with live cultures of bean beetles containing adults that have been raised on mung beans (*Phaseolus aureus*) for a large number of generations and other bean beetle cultures that were originally from mung beans but were switched to adzuki beans (*Phaseolus angularis*) only 2-3 generations ago. Supplies of organic mung and adzuki beans also will be available. **(Note to instructors: The preceding sentences should be changed depending on the alternative host species and how long ago beetles were switched to that host.)** Female beetles are easily identified in the live cultures because they have two dark stripes on the posterior of the abdomen, whereas the posterior abdomen of males is uniformly light in color (Figure 1).

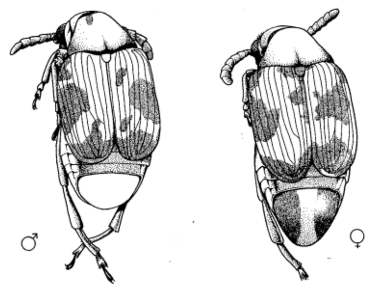

Figure 1. Dorsal view of male and female bean beetles (*Callosobruchus maculatus)*. The sex specific coloration of the posterior abdominal plate (pygidium) is shown (Figure from Brown and Downhower, 1988).

Prior to the laboratory class, each student should design an experiment or set of experiments to address whether rapid local adaptation has occurred in the bean beetle cultures that were recently switched to adzuki beans. Each individual will discuss his or her experimental design with others in a small group, and each group will present a consensus design to the class. Based on the experimental designs presented by the groups, we will discuss common experimental approaches for the entire class.

After you have read the background information and before the laboratory class meeting:

- Describe at least one experimental design for evaluating whether local adaptation to host species has occurred.
- Predict the outcomes for the experiment.
- List the dependent variables you would measure to determine if your predictions were true.
- Identify and list the variables you would manipulate in each experiment.
- Identify and list the variables you would keep constant in each experiment.
- Describe the statistical analyses that you would carry out to test your predictions.

Come to class prepared to present your experimental designs. Each individual will share his or her experimental design with their group, and then the group will present their consensus experimental design to rest of the class. Together, we will develop a class-consensus experimental design. Based on this experimental design, each person should set up one replicate for each treatment. We will pool the data from the entire class for analysis.

Week 2

(Note: this information wouldn't be given to the students because it would provide too much information about experimental design)

Each student should check their replicates for beans with single eggs. Each bean with a single egg should be placed in its own Petri dish or well of a tissue culture plate. At a minimum, the host of the female that laid each egg should be noted.

Daily Checks (outside of class time)

(Note: this information wouldn't be given to the students because it would provide too much information about experimental design)

After the instructor notes that beetles have begun to emerge (approximately 4 weeks after oviposition), students should check their isolated beans daily and note the date of emergence and body length or mass at emergence. Typically, students measure mass at emergence because it is easier to weigh beetles than to measure body length. At the end of the experiment, students should determine emergence success.

Questions for Further Thought and Discussion:

1. Based on your results, have bean beetles adapted after a change in host species?

2. How might the results of your experiment been different if you had used a species of phytophagous insect with greater host plant specificity? What if the insect were more of a generalist?

3. Because bean beetles are an agricultural pest species, how could the results of your study be used to design an effective protocol for reducing the impact of bean beetles on stored beans?

4. If phytophagous insects are able to adapt rapidly to a new host, what might this suggest about the impact of these insects in monoculture versus polyculture agricultural systems?

5. Many studies have examined whether female bean beetles exhibit a preference when given a choice of several host species on which to lay their eggs. Based on the literature on host preference, how might host preference influence adaptation of bean beetles to specific host species? Contrast this with a species in which females do not exhibit a preference for host species.

References and Links

- An extensive bibliography on the ecology, evolution, and behavior of the genus *Callosobruchus* can be found at www.beanbeetles.org/biblio/

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Tools for Assessment of Student Learning Outcomes

Assessment could be carried out in a variety of ways. In the past, students have been evaluated based on a scientific paper written by each student individually. In some cases, students are evaluated on both first and second drafts of a paper, with first drafts being evaluated by a peer and by the instructor.

The scoring rubric for the papers varies with instructor. Below is an example scoring rubric used at Morehouse College for a “results summary,” which has all of the components of a scientific paper except the methods. In this evaluation rubric, “audience” concerns the choice of appropriate audience by the student. Students are expected to write their report as if it were a scientific paper. So, the appropriate audience is one of peers who have not conducted the experiment but who are scientifically literate. Reports written to the instructor or to other students in the class do not address the appropriate audience. “Format” is the overall organization of the report in sections that have parallel organization and build on each other. For example, the Discussion should evaluate the findings reported in the Results and put those results into a larger context. The Discussion also should address the hypothesis stated in the Introduction.

Results Summary Evaluation (50 points possible)

Introduction and Title Page (10 points) _____

Results (10 points) _____

Discussion and Conclusions (10 points) _____

Literature Use and Citations (10 points) _____

Format, Audience (10 points) _____

Comments:

A more detailed rubric for evaluating student papers that could be adapted for this study can be found here. In addition, a more general rubric that takes a holistic approach to evaluating student writing can be found here. In addition to individual scientific papers, students could present the results of the experiment in the form of group scientific papers, group oral presentations, or group poster presentations. However, since all of the students are carrying out the same experiment and therefore presenting the same results, individual or group scientific papers or posters would be the most effective.

The approaches to student assessment described above are intended for use after the students complete the experiment. Students could be assessed earlier in the exercise. For example, the proposed experimental designs that students bring to class could be collected and evaluated. In addition, after the class has discussed experimental approaches, students could be asked to write a minute paper explaining how reciprocal transplant experiments can be used to test for adaptation. Both of these approaches could be used for formative evaluation as well.

NOTES TO FACULTY

Challenges to Anticipate and Solve

1. **Challenge #1. Determining appropriate dependent variables.** Students often have difficulty determining what dependent variables to measure. Time to emergence, body size at emergence, and emergence success can be measured in a reasonable time span. Students may suggest other offspring characteristics, such as lifespan, reproductive success, hatching rate, and sex ratio. Characters such as lifespan could be measured, but would add another two or more weeks to the experiment. Other dependent variables are appropriate, but difficult to measure (i.e., reproductive success and hatching rate). Finally, for other offspring traits like sex ratio, the predictions are not clear.

2. **Challenge #2. Identifying eggs on beans.** Students sometimes have difficulty distinguishing between eggs on beans and frass. Eggs are larger and have a distinct dome shape when viewed with magnification. If students are shown examples of eggs on beans, they are better able to find them on their own. Typically, we do this by rotating through the room and showing individual students beans with eggs. Alternatively, the instructor could place small petri dishes with beans with eggs attached at each lab station.

3. **Challenge #3. Statistical comparisons.** Students also have difficulty determining the appropriate statistical comparisons and then interpreting the results. After allowing the students to discuss the comparisons in groups, the instructor may want to review the possible comparisons and their interpretation. We have this discussion after the final data are collected. It could take place after the consensus experimental design is determined during the first lab period. However, given the time span between the initial lab period and the data analysis, students may have difficulty recalling the discussion if it takes place during the initial lab period.

Experiment Description

Introducing the Experiment to Your Students

Prior to this exercise, we present the concept of adaptation to our students in lecture and distinguish adaptation from acclimation and phenotypic plasticity. We also discuss approaches for determining genetic differences among populations, including common garden and reciprocal transplant experiments.

Since this exercise is designed as a guided inquiry, the role of the instructor is to facilitate the discussion among members of each group and then the discussion of each group's experiment in the class as a whole. We guide students to a consensus experiment that is carried out by the entire class. It is possible that individual groups could carry out their own experimental designs. In this case, each student will need to increase the number of replicates that they set up in order to have sufficient replication for statistical analysis. In our experience, most groups propose very similar experiments and therefore the process of coming to a consensus experiment for the class is more a confirmation of the ideas of each group rather than rejecting the ideas of most groups in preference to that of a single group.

When discussing the experimental design with the students, it may be helpful to review a little of the natural history of bean beetles and the materials that will be available to the students. Most of our bean beetle cultures have been reared on mung beans for many generations and then switched to either adzuki beans or blackeye peas (*Vigna unguiculata*) for several generations.

To determine if adaptation has occurred, students will want to conduct a reciprocal transplant experiment in which females from mung bean cultures and females from either adzuki bean or blackeye pea cultures are allowed to lay eggs on both types of beans. In effect, the experiment is a 2 x 2 factorial design with maternal host (mung or adzuki/BEP) and offspring host (mung or adzuki/BEP) as the two factors. Then, students will examine the life history traits of the resulting offspring.

Data Collection and Analysis Methods Used in the Experiment

Consult the Laboratory Methods section of the Bean Beetle website (www.beanbeetles.org) for detailed information on growing cultures and handling techniques, as well as tips on identifying the sexes.

The experiment requires having dense cultures of bean beetles from which females can be isolated. Beetles should be from cultures reared on a natal host and from cultures switched to a new host several generations prior to the experiment. If new cultures are initiated approximately 2 months before the lab period, there will be sufficient time for two generations of beetles, which will result in dense cultures. When possible, we supply one culture of each type (natal and new host) to each group of students working in pairs. However, each culture should have sufficient beetles for use by multiple student groups. Sufficient cultures for one class section can be established in less than an hour. Once cultures are established, they do not need to be monitored or recultured until 2 months later. Cultures of bean beetles reared on different host types can be obtained from the authors.

Each student should set up a single replicate of each treatment combination of the reciprocal transplant experiment. To set up a replicate, a single female from a stock culture (either mung or adzuki/BEP) is added to a 35mm Petri dish with a monolayer of beans (either mung or adzuki/BEP). Oviposition will readily occur during a 48-hour period. Although most adult females in an active culture will have been inseminated, some females may have only recently emerged (and be infertile) and others are near the end of their adult life (and laid most of their eggs). Replication in the class will allow for failures in egg laying.

For offspring life history traits, one of the biggest confounding factors is the number of eggs laid on beans. If more than one egg is laid on a bean, then the larvae may compete for resources. As a result, only beans with single eggs should be used in tabulating data. Students may want to record the identity of the female that laid the egg to be able to consider differences among females in their analysis. However, data on female identity is not essential. Students can isolate beans of each species with single eggs into the wells of tissue culture plates or small Petri dishes. As the beetles emerge, students can record the offspring characteristics that they chose to measure. Accurate data on time to emergence and mass at emergence require that students check for emergence on a daily basis. As a result, measuring these life history traits may be feasible only in smaller, more advanced classes. The daily checks take between 15 – 30 minutes depending on the number of beetles that have emerged on that day. Students carry out these checks outside of class time. Emergence success could be determined on a single day (potentially as a 1 hour part of a longer lab period) after sufficient time for emergence (approximately 40 days). Therefore, emergence success is more tractable for larger classes.

Because the experiment is a 2 x 2 factorial design, the data are most appropriately analyzed with a multifactor ANOVA, assuming a normal distribution, which is commonly the case. If adaptation has occurred, we would expect a significant interaction effect between maternal host and offspring host, with offspring having higher fitness on the same host as their mother. In bean beetles, some life history traits differ between the sexes. Therefore, the analysis should be done for males and female separately. Students also could look at correlations between life history traits.

Questions for Further Thought

1. Based on your results, have bean beetles adapted after a change in host species?

    Although students generally have little trouble in designing the appropriate experiment, they have more difficulty in interpreting the results in relation to adaptation. The instructor may need to help students understand what the main effects and the interaction effect are testing in the multifactor ANOVA.

2. How might the results of your experiment been different if you had used a species of phytophagous insect that was specialized on its host plant to a greater degree? What if it were more of a generalist?

    The intent of this question is to get students to think about the fact that selection for adaptation should be stronger on specialists. However, at the extreme, you could not conduct this experiment with a specialist, because no offspring would be viable on an alternative host.

3. Because bean beetles are an agricultural pest species, how could the results of your study be used to design an effective protocol for reducing the impact of bean beetles on stored beans?

    Beans could be stored as single species or mixed. Students could consider which method might be more effective in decreasing damage by bean beetles, if beetles can adapt to new hosts.

4. If phytophagous insects are able to adapt rapidly to a new host, what might this suggest about the impact of these insects in monoculture versus polyculture agricultural systems?

    This question is similar to question 3, but asks students to think beyond bean beetles to other herbivorous insects.

5. Many studies have examined whether female bean beetles exhibit a preference when given a choice of several host species on which to lay their eggs. Based on the literature on host preference, how might host preference influence adaptation of bean beetles to specific host species? Contrast this with a species in which females do not exhibit a preference for host species.

    This question allows students to examine the literature on host preference in bean beetles. Students can be sent to literature databases or to the bibliography found on the Bean Beetle website (www.beanbeetles.org/biblio/). Females do tend to show a preference for bean species from which their offspring can successfully emerge. They also seem to prefer their natal bean species. As a result, female preference might decrease the strength of selection due to a host switch as females would tend to avoid novel hosts. Female behavior may mediate selection due to novel hosts if both natal and novel hosts are available.

Assessment of Student Learning Outcomes

Student assessment through scientific writing is standard practice, and therefore does not warrant additional comments here. However, in addition to the scientific writing, in one year in which this experiment was tested at Emory University, students were given a pre-test/post-test to determine whether conducting the experiment changed their understanding of the scientific method. The pre-test was administered immediately before we discussed the experiment. The post-test was given the following week before any additional experiments were done in lab.

Sixteen of the 17 students in the course completed both the pre-test and the post-test. We found a marginally significant increase in understanding of the scientific method from the pre-test to the post-test (Wilcoxon signed rank test, $Z = -1.9$, $P = 0.06$). The small sample size in the class may have contributed to the lack of clear significance. Of the 16 students who took both the pre-test and the post-test, 50% of them exhibited an increase in understanding of the scientific method and 31% (5 of 16) showed no change. In general, our results suggest that the experiment was effective in increasing students' understanding of the scientific method.

Assessment on scientific method with scoring rubric

Below is the pre-test/post-test that was used for assessing student understanding of the scientific method. Also, we have included a rubric for scoring the test.

Ecology Laboratory Name ___________________________

Date: Semester:

Diagnostic Test *(Answers are shown in italics. Total possible score is 10 points.)*

This is a non-graded test that will assess your understanding of experimental methods. **Completion of this test is part of a research study so your responses are voluntary.** Please print your name on this test so we can determine how your understanding changes as a result of your work in this course. Your instructor will be the only person who sees your test results and individual results will not be released.

1. When conducting an experiment, what is the purpose of a control treatment?

   Total Points Possible = 3

   “Treatment with no manipulation” (1 point)
   “Treatment for comparison to a manipulation treatment” (2 points)

   Partial Credit

   “Normal conditions treatment” (0.5 points)

2. What is the “null hypothesis” in an experimental study?

   Total Points Possible = 2

   “The hypothesis of no effect or no response to an experimental manipulation” (2 points)

   Partial Credit

   “The hypothesis that excludes or negates something from being true” (1 point)
   “The opposite of the hypothesis you wish to prove” (0.5 points)

3. What is the purpose of replicating a given treatment in an experiment?

   Total Points Possible = 2

"Replication ensures an adequate sample size for a given treatment" (1 point)
"Replication improves the accuracy and reliability of the results" (1 point)

Partial Credit

"Replication is performed to reduce errors" (0.5 points)

4. What is the function of conducting a statistical test on the results of an experiment?

Total Points Possible = 3

"Statistical tests permit us to establish the probability of the observed results occurring by chance alone" (1 point)
"Statistical tests permit us to reject the null hypothesis if differences occur by chance alone less than 5% of the time" (2 points)

Partial Credit

"Statistical tests show whether there is a significant difference between the control and experimental treatment results" (1 point)

Formative Evaluation of this Experiment

Students in the ecology course at Emory University (Fall 2006) were asked to rank each experiment they completed on a ten point scale with respect to how useful each experiment was in reinforcing their knowledge and understanding of the subjects covered in the lecture portion of the course. A score of 10 meant that the study was the most useful. In addition, the students were asked which studies were the most and least enjoyable and which study best increased their understanding of the scientific method. The students completed seven experiments (including the current experiment) plus an independent project during the semester.

Thirteen of the 17 students in the course completed the course evaluation. The average ranking of the current experiment was 8, while the average ranking of all the experiments combined was 7.2. Twelve of the 13 students ranked this experiment higher than the average of all the experiments. Furthermore, five of the students gave the experiment the highest ranking. Only one student considered it the most enjoyable experiment; however, no students considered it the least enjoyable experiment. More than half of the students (7 out of 13) thought that this experiment was the one that best increased their understanding of the scientific method. Of the remainder, four students thought that the independent projects were most important to their understanding of the scientific method. Therefore, of the planned experiments conducted, this experiment was the most important at increasing student understanding of the scientific method, as self-reported by the students.

As noted above in “Tools for Assessment of Student Learning Outcomes,” students could be evaluated before completion of the experiment. For example, the proposed experimental designs that students bring to class could be collected and evaluated. In addition, after the class has discussed experimental approaches, students could be asked to write a minute paper explaining how reciprocal transplant experiments can be used to test for adaptation. Both of these types of formative evaluation would allow an instructor to determine how well students understand the concept of adaptation and how to test it, which may influence how instructors discuss the results of the experiment with their class at a later date.

Translating the Activity to Other Institutional Scales or Locations

(1) Translating this experiment to larger scales if you teach at a smaller school and vice versa,

Because bean beetles are easy to rear in large numbers and the materials for the experiment are inexpensive, this experiment could easily be scaled up to larger institutions. The main change would be to consider only emergence success rather than other life history traits, as evaluating emergence success does not require students to examine beans for beetle emergence on a daily basis.

(2) Using this lab in different regions of the country or world, in different seasons, or using different study species or systems,

Because the experiment is a laboratory experiment, it could be used in most regions. The only restrictions would be those associated with the shipment of bean beetles. However, at present, we (the authors) legally can ship bean beetles to all 48 states in the continental United States, the District of Columbia, Alaska, and Puerto Rico.

This experiment could be conducted with other phytophagous insects. Other phytophagous insects, such as tobacco hornworms, *Manduca sexta*, and the Brassica butterfly, *Pieris rapae*, that are easily reared in the laboratory and can be induced to use a variety of host plants could be used in this experiment. Both are commercially available. However, keep in mind that populations would have to be reared on separate host types for multiple generations before beginning the experiment.

(3) Using this activity to teach ecology to students with physical or other disabilities, and

Students with physical disabilities may have difficulties with this experiment, as it requires the manipulation of small insects. In addition, distinguishing between the sexes and identifying eggs on beans would be difficult for students with visual disabilities.

(4) Using this activity to teach ecology in pre-college settings (K-12).

Although this experiment has not been tested in pre-college settings, bean beetles have been used for other experiments in high school biology courses.

STUDENT DATA COLLECTED IN THIS EXPERIMENT

Sample data are provided in the file: [local adaptation in bean beetles data.xls]

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