

Does it pose a threat? Investigating the impact of Bt corn on monarch butterflies

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Abstract

Aspiring scientists know that a hallmark of science is that experiments are repeatable and testable. However, students do not often get opportunities to explore the replicability of science. Using a current “hot topic” of genetically modified organisms, this lesson enables students to use a series of primary literature articles to explore the impact of Bt corn on the monarch butterfly. Through the experience, students read primary literature, apply scientific argumentation skills, reason using data and evaluate data from multiple sources to draw conclusions. While targeted for introductory students, this lesson can easily be adapted for upper division ecology students.

Learning Goal(s)

By completing this exploration of monarch butterflies and Bt corn, students will appreciate the complexity and uncertainty of ecological systems, understand the importance of replicability in science and demonstrate the ability to critically evaluate multiple data sources.

Learning Objective(s)

Students will be able to:

- Apply genetics concepts to a relevant case study of Bt corn and monarch butterflies
- Read figures and text from primary literature
- Identify claims presented in scientific studies
- Evaluate data presented in scientific studies
- Critically reason using data
- Evaluate the consequences of GM technology on non-target organisms

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Materials and Supplemental Materials: Table 1. Does it pose a threat-Teaching Timeline, Table 2. Does it pose a threat-Summary of papers used in activity, Supplemental File S1. Does it pose a threat-Lesson Presentation Slides, Supplemental File S2. Does it pose a threat-Pre-Class Reading Assignment and Rubric, Supplemental File S3. Does it pose a threat-In-Class Worksheet Part 1, Supplemental File S4. Does it pose a threat-In-Class Worksheet Part 2, Supplemental File S5. Does it pose a threat-Homework, Supplemental File S6. Does it pose a threat-Rubric for Homework

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INTRODUCTION

One challenge I face as an ecologist teaching introductory biology courses is how to prepare students to understand evolution when I can't assume that my students have operational knowledge of DNA, genes, and genetics. The solution for me has been to review these concepts through a unit on genetically modified organisms (GMOs). This 7-class unit enables us to review DNA and the central dogma, mitosis and meiosis by asking the questions: What are GMOs? How does one make a GMO? Taking advantage of Bethel University's location in the upper Midwest, we focus our discussion around the development of Bt corn.

Naturally, during the course of these activities, students raise excellent questions regarding the impact of GMOs on non-

target organisms. As a result of their questions, I developed a 1.5 class session lesson at the end of the unit that uses primary literature to help them explore the question: What is the impact of Bt corn on the monarch butterfly population? The lesson is built around a series of papers published from 1999 to the early 2000s, enabling students to see how one published study spurred several other studies that repeated and expanded upon the work of the original researchers. This choice of papers exposes students to controversy in science, repeatability of experiments and the importance of the experimental design in research studies, as well as providing students with practice using scientific argumentation (1) and data interpretation.

Background on Bt corn and Monarch Butterflies

The European Corn Borer (*Ostrinia nubilalis*), an introduced

agricultural pest, has been negatively impacting corn plants (*Zea mays*) in the United States since at least 1917 (2). The European Corn Borer (ECB) is of the order Lepidoptera and has a caterpillar (larvae) stage and an adult stage wherein the moth is nocturnal and about a half inch in size (2). The ECB is particularly destructive because it impacts corn plants during different stages of the plant's growth (e.g., seedlings and mature plants) and different parts of the plant (e.g., shoots, leaves). For example, ECB's lay their eggs on the corn plants, after which larvae burrow into both the stalks and the ear of the corn, thus damaging both the plant, specifically the vascular tissue, and the seeds (2).

Insecticides have been the most common line of defense against the ECB; however, such insecticides have many environmental consequences. One particularly effective insecticide was commonly known as "Bt Dust." This biological insecticide is considered "safer" because it is derived from a naturally occurring soil bacterium known as *Bacillus thuringiensis*. *B. thuringiensis* produce a toxic crystal (i.e. delta-endotoxin) that, when ingested by the ECB larvae, renders the digestive system of the ECB caterpillar inactive. Within a few hours of consuming the endotoxin, the ECB dies. With the advent of genetic technologies, scientists created Bt corn by inserting the Bt *Cry* gene, which is responsible for the toxic crystal formation, into the genome of the corn plant. These genetically modified Bt corn plants now produce toxic delta-endotoxin crystals and express them throughout the plant. As a result, the Bt corn produces its own defense against ECB, eliminating the need to spray insecticides on thousands of acres of corn. While the Bt toxin is only detrimental to susceptible insects (i.e., some of those in the order Lepidoptera including moths and butterflies), there is great concern that Bt corn may be harmful to non-target species, such as the monarch butterfly (*Danaus plexippus*).

Losey and colleagues (3) conducted a study to test the impact of Bt corn on *D. plexippus*. While the study has some strengths, its conclusion that Bt corn pollen is harmful to *D. plexippus* larvae created quite a stir in the scientific community. Numerous follow up studies were conducted in the field and laboratory; the results from these studies were used to determine the relative ecological risk to *D. plexippus* larvae posed by the Bt corn. In the end, scientists determined the risk to *D. plexippus* larvae to be less than "1/100 or 1%" (4). That is, there is less than a 1% chance that monarch larvae would encounter a high enough toxicity of Bt pollen in their natural environment, at the right stage of their life, to kill the larvae. The results of these studies were featured in a special issue of Proceedings of the National Academy of Sciences (PNAS) in 2001.

Intended audience

The Bt corn and monarch butterfly lesson is intended for an introductory (first-year) ecology course for biology majors. However, it could easily be adapted for students in introductory biology or upper level ecology courses.

Learning time

This activity is designed for 110 minutes of class time, typically divided into two days (70 and 40 minutes respectively). Additionally, students complete some pre- and post-class work for the sessions.

Pre-requisite student knowledge

For students to be successful in this activity, they should have basic knowledge of DNA, genes, proteins, phenotypes, central dogma, and GMOs. Prior to the first day, students should do a little background reading to familiarize themselves with *Bacillus thuringiensis* (Bt), *Cry* gene, toxic crystals, Bt corn and monarch butterflies (*Danaus plexippus*). Students can be directed to read about the ECB on the Iowa State University Department of Entomology page (www.ent.iastate.edu/pest/cornborer). Students should also be familiar with scientific argumentation (i.e., claim, evidence, warrant), and basic graph interpretation skills.

SCIENTIFIC TEACHING THEMES

Active learning

- Activities outside of class: Reading, modeling, writing, Just in Time Teaching
- Activities in class: Small group discussion, data interpretation, informal presentation, jigsaw

Assessment

- Formative assessment: Feedback in-class, clicker questions
- Summative assessment: Homework

Inclusive teaching

The Bt corn and monarch butterfly activity engages every student in some aspect of individual preparation for the lesson and also enables students to contribute in what may be an area of strength (e.g., writing, creating, analyzing, speaking, etc.). Furthermore, because there are five primary literature articles in the class session, students need one another in order to answer the question completely. Therefore, this lesson is inherently structured to be inclusive and help many students to be engaged. For particularly advanced students, the ease with which you can increase the challenge in this exercise enables differentiation as well.

LESSON PLAN

This lesson is divided into two class sessions (Table 1 on page 3).

Day 1 - Pre-class

Teacher preparation: To begin, please read the papers you will be using in class (Table 2 on page 4). These papers include Losey et al. (3) and the 5 follow-up papers published in PNAS in 2001 (5-9). This reading should take ~1-1.5 hours of your time, depending on how familiar you are with the topic.

Then, assign the pre-reading questions that students need to answer on-line prior to the first session of the lesson (Supplemental File S2: Pre-Class Reading Assignment and Rubric). If your students have not read a scientific paper yet, allot some time in the class period before this lesson to overview the flow and structure of a scientific paper. If you are unable to do the review face-to-face, you could accompany your pre-reading activity with a short 5-minute video overviewing the scientific paper. (Jing (<http://www.techsmith.com/jing.html>) is a great free resource to produce 5-minute videos.) In addition to providing the overview of the paper, I provide students with some reading suggestions: (1) look for the scientific argument (i.e., claim, evidence, and warrant), (2) take notes or write your questions in the margins as you read, (3) sketch out a diagram of the experimental set up from the methods, and (4) spend more time on the figures than the text.

Table 1: Does it pose a threat-Teaching Timeline

Lesson Period	Activity	Approximate Time	Notes
End of Class period prior to Lesson	<ol style="list-style-type: none"> 1. Introduce the Losey et al paper and suggestions for reading a research paper 2. Assign pre-reading questions 	10 min 5-10 min	Introduce parts of a scientific paper and questions students will need to answer prior to coming to class on the first day of the activity. Post or handout the pre-reading questions (supplemental materials)
Preparation	<ol style="list-style-type: none"> 1. Read papers 2. Set up groups/teams 3. Photocopy handouts for teams 	1 hour	Papers include 3, 5-9 (Table 2) Establish cooperative learning teams of 3-4 Print and photocopy handouts (supplemental materials)
Before Lesson Day 1	Read through responses to questions and determine any information that should be revisited	1 hour	Following JiTT, skim through student responses to the pre-reading questions. Look for any commonly occurring conceptions that need to be revisited.
Lesson Day 1	<ol style="list-style-type: none"> 1. Setting the stage 2. Evaluating claims 3. Introducing the problem 4. Student work time 5. Wrap up 	10 min 10 min 5 min 50 min 5 min	Begin by recapping the relevant background Provide students time to evaluate Losey's article for strengths and weaknesses Share with students the scenario that unfolded as a result of the Losey publication Give student teams their paper and associated handout; visit teams as they are working to answer questions and/or help interpret findings Conclude by revisiting objectives and tasks
After Lesson Day 1	<ol style="list-style-type: none"> 1. Post papers to course management system 2. Photocopy homework 	5 min 5 min	After class, post the full papers (5-9) to your course management system Make photocopies of homework assignment (supplemental materials)
Lesson Day 2	<ol style="list-style-type: none"> 1. Review 2. Presentations/Notes 3. Discussion and Synthesis 4. Conclusion 	5 min 25 min 15 min 5 min	Begin with a short review of the context Students give a 5-minute presentation on their research study Give teams (or the whole class) a chance to discuss the findings of all the research studies; synthesizing multiple pieces of evidence. Students revisit the claim that Bt corn has no effect on monarch butterfly larvae and evaluate that claim based on the evidence
After Day 2	Homework	30-45 min	Students complete a reflective, synthesizing homework assignment that is handed out at the end of class.

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Table 2: Does it pose a threat-Summary of papers used in Lesson

Authors	Research Question	Methods	Results
Losey et al.	Does Bt corn pose a risk to monarch butterfly larvae?	Leaves from milkweed plants were dusted with Bt corn pollen (from N4640) by first misting the leaves with water and then dumping pollen grains over the wet leaves in densities relative to what occurs naturally. 5 Monarch larvae were placed in cages with these dusted leaves; bringing the total tested to 25 trials of control and 25 trials of treatment larvae.	Larvae ate less and lived shorter when consuming leaves dusted with Bt corn pollen.
Oberhauser et al.	Is it likely that monarch larvae will encounter Bt pollen in field conditions?	Oberhauser et al (2001) chose 4 regions in the monarch breeding range. These ranges included cornfields, cornfield edges, agricultural fields, and non-agricultural fields in MN, WI, MD and southern Ontario. All sites had non Bt corn planted in/near the location of the study (except MD, where one field did have Bt corn present). Weekly from May- August, researchers searched milkweed plants to record the number of monarch egg and larvae. Teams identified weeks in which 20% of the corn plants in the area were releasing pollen (corn anthesis).	Larvae will encounter Bt corn pollen in field conditions; in MN/IA and Ontario, there is a 30%-80% overlap between when the corn plants were releasing pollen and when the larvae were active. The overlap was greatest for milkweed plants located within corn fields.
Stanley-Horn et al.	Does Bt corn pollen negatively impact monarch survival and growth?	Researchers collected data from field studies (IA, Ontario, NY, MD) to assess the impact of Bt corn pollen on monarch larvae survival. At each site, milkweed plants were placed in the study site about 2 days before corn pollen was released. When 50-75% of the plants had shed pollen, leaves were collected from the milkweed plants to determine pollen densities. Then, monarch larvae (less than 24 hours old) were placed onto the milkweed plants in the field; one site was caged to prevent predation. After 5 days, larval survival and weight were recorded. A second leaf was removed from each plant to count the pollen density by Bt variety present in the field.	Pollen grain density ranged from 127-309 grains/cm ² across the four field sites. There was no difference in survival rates for monarch larvae who were placed on plants covered with Bt corn pollen vs. those that had non-Bt corn pollen. Event 176 had the greatest negative impact on survival and growth.
Hellmich et al.	What is the relative toxicity of 6 varieties of Bt corn?	In a laboratory setting, Hellmich and colleagues tested pollen from actual Bt plants by (1) placing the toxin in an artificial food source for monarch larvae, (2) applying pollen directly to 20mm diameter milkweed discs treated with different densities (ranging from 150 grains/cm ² to 4000) and types of pollen, and (3) applying pollen that also contained corn tassel pieces to the 20mm discs. Individual larvae were exposed to pollen on two milkweed discs in a small, enclosed area for 48 hours. Following, then an untreated disc was swapped; this was repeated 4 times.	(1) CryAb and CryAc toxins incorporated into monarch food decreased weight and increased mortality. (2) Weight for all monarch larvae was lower for Bt varieties, but not significantly so. (3) Contaminants can interfere with monarch larvae feeding, and as a result show decreased weight gain. Having a high density of pollen grains did not change the results. Event Bt11 and Mon810 along with Cry1F will not negatively impact monarch larvae.
Hanson Jesse & Obrycki	What is the survivorship of monarch larvae under different field-collected pollen densities?	To do so, researchers placed potted milkweed plants in a cornfield planted with four different Bt corn varieties. They placed these milkweed potted plants 0.2, 1 and 3 meters from the edge of the field, and later added 5 and 10 meter placements. Holes were punched in the leaves (top, middle and base of the plants) of the milkweed plants to create 0.79cm ² discs that were used for counting the number of pollen grains. Monarch larvae were placed on the discs for 48 hours (including a control where all the pollen had been washed off the discs). In total, 143 discs were included in the study (35 from the Bt corn, 36 from non-Bt corn, and 72 control). After 48 hours, they determined survivorship by counting living larvae.	Monarch larvae are most likely to be impacted at a distance less than 3m from the edge of a Bt corn field, however natural deposits of Bt corn pollen were detected up to 10m away from the field. After 48 hours, larvae who fed on Bt corn pollen (at high and low densities) had decreased survivorship compared to those who fed on non-Bt corn; this was especially pronounced for Event176.
Pleasant et al.	What are the naturally occurring densities of Bt pollen on milkweed plants?	To do so, they measured pollen accumulation on the leaves of naturally occurring milkweed plants, or potted plants inside and outside cornfields. Field edges were defined as 0 and negative numbers refer to milkweed locations within a cornfield whereas positive numbers represent the number of meters away from the field edge. Leaf samples were collected both during anthesis (i.e., pollination) and at the end of anthesis. Five sites were involved: IA, MN, WI, MD and Ontario, Canada. Rain events were noted. Pollen samples were counted with a dissecting microscope.	Milkweed plants growing inside cornfields have the highest density of naturally-occurring Bt pollen. The density of pollen-grains decreases significantly moving towards the edges of the cornfield. The range of densities was from 170 grains/cm ² to 14 grains/cm ² . Rain events had the potential to greatly reduce the pollen grains located on milkweed plants. Larvae feed on the top of the plant, and these leaves had 30-50% less pollen than the middle leaves of the milkweed plants.

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Since the first day of the activity relies on Just-in-Time Teaching (JiTT,10), you will want to plan time to skim through and/or read student responses to the pre-reading questions. JiTT (10) is a pedagogy wherein students complete pre-class reading and submit answers to questions related to the reading prior to class. The instructor views these responses before class, looking for themes in response patterns that helps the instructor identify areas that should be addressed in the class session. I ask that students submit their answers at least 1 hour before class begins and then I plan accordingly and skim through their responses for themes during that hour. My class size is less than 50 students; if yours is larger, you might consider an earlier deadline such that you have time to skim through the responses before class. At this point, I am not grading their responses but only looking for common themes in the responses and any pre-conceptions or questions that I might need to address. For example, are students discussing the sample size and controlled lab setting as a strength of the experimental design? Did they catch the fact that this is a lab-based study of a natural ecosystem as a potential limitation? Do they understand the claim that Losey and colleagues made from their findings? And, what questions do students have that you might need to be prepared to address during the class session?

Finally, if your students do not work regularly in teams, you will need to take time to establish teams. Recommended team size is 4 students.

Student preparation: Before coming to class, students need to read Losey et al. (3).

Following their reading and prior to the first class period for this lesson, students use the course management system to submit a response to the following questions: (1) What do you think are the strengths of the Losey et al. experiment? (2) What are the weaknesses or limitations of the Losey et al. experiment? (3) What did Losey et al. conclude about the impact of Bt corn on monarch butterflies? (4) What questions do you have? The grading rubric for these questions is available in the supporting materials (Supplemental File S6). Upon request, I am happy to provide the key to other instructors, but want to ensure that answers are not available to students online.

Day 1 - Class Period

Setting the stage for the Lesson (Time: 10 minutes): I begin class with an overview of the learning objectives (Slide 1, Supplemental File S1: Lesson Presentation Slides), and then have students do what I call a 4-Minute Summary based on their pre-reading questions. A 4-Minute Summary is guided by a slide (Slide 2), and asks each student in a group of four to explain one of the questions or statement to the other members in their group. To read a more detailed description of this technique, please see the *CourseSource* article *The 4-Minute Summary: Helping students recall, recap and explain the big picture... and much more!*

The four questions I have students discuss are:

- What did Losey and colleagues set out to study? (i.e. What was their research question/hypothesis?)
- How did Losey and colleagues set up their study? (i.e. What were their methods?)
- What did you think were the strengths of Losey and colleagues' experimental design?
- What did you see as the limitations of Losey and colleagues' experimental design?

Following the 4-Minute Summary, I randomly call on student groups to share with the class the answers to their questions. For example, I might call on the Leaf Cutters (a student group name) and ask student #1 to tell me the answer to question 1. Then, I might call on the Corn Borers to recap question 2 to the class. This approach enables me to check in with student groups to see if they have a sufficient understanding of the needed background from the Losey study to proceed. If you happen to be teaching in a SCALE-UP classroom (12) rather than calling on student groups, you can include personal accountability for each person by having them write their answers up on their whiteboard space. Then, you can use their writings during a summarizing period.

Note: Since students in my course are accustomed to frequently doing 4-Minute Summaries in my class (i.e. at least once per class period), this activity does take 4 minutes in my class. If this is your first time using such a strategy, plan to allow an extra 2-3 minutes to assign numbers in groups and share the structure of a 4-Minute Summary with your students. In addition, if your students have not regularly been talking with this group of peers during the semester, you might also want an additional 2-3 minutes of talk time during the 4-Minute Summary.

We end this introduction with a clicker question that asks each student to evaluate the validity the statement: Bt corn poses a serious threat to monarch butterflies (Slide 3 from Supplemental File S1). Student results will likely be uniformly dispersed across all three answer choices.

Evaluating Claims (Time: 10 minutes): Pass out Handout (Supplemental File S3: In-Class Worksheet Part 1) to all students. Using the questions on the handout as prompts, students begin by working in teams to revisit the experimental design and data from the Losey paper. Many questions emerge about the experimental design and the strengths/weaknesses of the design. This prompting of student questions is intentional, and I recommend letting the students use the paper and evidence to draw conclusions about the efficacy of the methods, and how exactly these researchers conducted their experiment. The Part 1 Handout directs students to revisit Figure 1a and 1b from the Losey paper with some prompted questions focused on scientific argumentation. Specifically, students are asked to (1) identify a claim that can be made from the results and (2) explain their reasoning behind their chosen claim (see In-class worksheet). During this time (about 10 minutes), I walk throughout the room answering questions. I listen as students talk through the graphs, ask them guiding questions to get them to read the axes and interpret the figure legend. I encourage them to check their claim against the evidence presented in the figure. Most of the time, however, I let the students draw me over to their group at their own initiation.

Again, we revisit the clicker question: Bt corn poses a serious threat to monarch butterflies. Students re-vote, and likely their response pattern will have changed a bit after re-evaluating the figures, as they consider specifically the claims that are supported from the available data and discussing with others. Regardless of whether or not response patterns change, ask a few randomly selected students or groups to explain if they changed their answer after revisiting the figures and if so, why.

Introducing the problem (Time: 5 minutes): At this point, students will have come to see that the experiments described in the Losey paper have some strengths and limitations (e.g.,

well controlled, not a field study), and likely, they will be asking if there are more data available! Their interest in the case should be elevated at this point, which provides a great context in which to introduce a jigsaw activity (11) focused around the question: What is the impact of Bt corn on monarch butterflies?

Teacher script for introduction of the problem: “As you have just discovered, the Losey paper has many strengths and weaknesses. When it was published, the scientific community had a similar reaction to yours – many scientists wanted to see if the results could be replicated by others and to try other experiments, perhaps even in field settings to see if the results could be repeated outside of the laboratory. In the years following the paper, a series of follow-up experiments were published in a variety of journals and today, we will be exploring 5 of these papers. Each team will be responsible for reviewing one of these papers and becoming an expert on the study design and results. After working to understand your paper, your team will present the paper’s research question/hypothesis, method, claim and evidence to the rest of the class. Tomorrow, each team will have 5 minutes to present your findings and we will conclude by evaluating all the data together.”

This activity is designed to be a whole class jigsaw (11). In my course, my students sit at tables of 9, and I have 5 tables in the classroom. Each table group receives one citation for their assigned scientific paper. Advanced students can search and access the article and read it without additional assistance. Introductory-level students can also search and find their article, but I accompany the article with a worksheet that guides them through reading it (Supplemental File S4: In-Class Worksheet Part 2). The articles contain a lot of details that will quickly overwhelm introductory level students, and therefore, the Part 2 Handout provides a synopsis of the article and asks them to treat the article as a reference. The goal is not to have them read the article word-for-word, but be able to reason about the figures/data in the article with reasonable background information provided. There are 5 versions of the Part 2 handout, A-E. Each version corresponds to a different publication that examines the effect of Bt corn on Monarch butterflies. Pass out the Part 2 Handout so that team receives a different version and all members of a team receive the same version (e.g., all members of the Leaf Cutters receive handout version B).

Student work time (remainder of the class time, ideally 50 minutes): During the work time, students work in pairs, or teams, to complete the Part 2 handout. This handout asks them to read a summary of the paper, and then to view the graphs/tables and make claims based on that data. As the instructor, I move around the room and check in with student groups, answer questions, and push their thinking with additional questions that arise during conversation. Students struggle the most with interpreting graphs, so much of my initial interactions with them are reminders about how to read a figure (e.g., start with the axes, link the axes to the methods to determine where these data come from, interpret the legend). I often approach groups and have them walk me through the figure so I can check their interpretation. I check in with them and have them share their claims with me. On occasion, I have written a reminder on the board about half way through the class period that lists the criteria for a good claim (e.g., specific, accurate, related to the data, etc.) and have them self-

check their claims and refine them based on the criteria.

To prepare for their class presentation, students are instructed to create one slide that reviews the paper’s research question, overviews the experimental approach, and summarizes the claim and evidence. They also need to include their evaluation of whether or not they were convinced by the evidence (i.e. Was there a strong warrant that led them to be confident in the findings?). I allow students to continue to work until just before the end of the class period.

Wrap up (Time: 5 minutes): Conclude the session by revisiting the learning objectives for the day and checking in with each group to see their status. This goal can be accomplished through a quick status update, wherein a spokesperson from each team reports where they ended their work time today. In the four times I have taught this lesson, most groups are able to get at least a skeleton of their informal presentation together before class is over. Remind them that the next class session will begin with their 5-minute presentations.

Day 1 - Post-class

Students may wish to access the other articles for their own reading/learning outside of class, so I make sure those are available to students through our Course Management System. Students will likely need to work outside of class to complete their presentations.

Day 2 - Pre-class

No additional preparation is needed on by either the instructor or students for Day 2. If you did not yet photocopy (or post to your course management system) the homework assignment that should be the only thing you would need to do today.

Day 2 - In-class

Review (5 minutes): Begin class the second day by sharing the learning objectives with students once again and follow that with a chance for groups to touch base in advance of their presentations. This time could quickly balloon, so I keep track of the 5-minute time window by using a countdown timer projected on the screen in the classroom.

Presentations & Notes (25 minutes): Instruct the students that they should take notes on the presentations of their peers. Specifically, they should take note of the claims and evidence presented by the various student teams summarizing each paper. You may wish to announce that this information will be valuable to the students for their homework assignment (Supplemental File S5: Homework) as that assignment will ask them to evaluate the findings of the other studies presented by their peers.

Each team presents their article in a 5-minute window. Team presentations are easy to manage in a SCALE-UP classroom, or room equipped with LiteShow (a screen projection software, <http://www.infocus.com/peripherals/INLITESHOW3>), but can easily be done in a standard classroom by having students present from the teaching station (or even using flipchart paper if they need to have visuals with their presentation).

Discussion (10 minutes): Following the presentations, have students at their tables (n=9) or in smaller groups (n=2-4) recap the 5 studies and ask one another any clarifying questions they have about the studies. Students are encouraged to seek out the “experts” in the room (i.e., get up and walk over to them) to

ask additional questions that no one at their table can answer.

Students now vote a third time on the same clicker question: Bt corn poses a serious threat to monarch butterflies. Results will likely have changed a lot at this point! Most students will have likely decided that it is plausible (option b), with very few saying definitely (option a), whereas earlier, most were likely to choose option (a).

If time remains in your class session, or in your course schedule, ask students to provide evidence to support their vote. They can write the answers on their whiteboard space, or discuss it with a partner or in a small group. If you do not have time, these same questions will be addressed in the homework assignment post-class.

Homework – Synthesis: Students are asked to complete a short evaluative homework assignment (Supplemental File S5: Homework) wherein they synthesize the findings from the 5 papers (and the Losey paper) and evaluate the findings. Students are asked to rank the papers based on the strength of the evidence contained within the papers. I do not ask them to justify their choice for the ranking, but you may wish to modify the assignment to have them do this. The second part of the homework synthesis assignment asks the students to make a claim about the impact of Bt corn on the monarch butterfly and support their claim with evidence from the studies. For an extension or additional challenge, students can include the biological warrant if they are familiar with the scientific argumentation framework (1, 14, 15). An example homework assignment as well as rubric (Supplemental File S6: Rubric for Homework) are available in the supplementary materials.

TEACHING DISCUSSION

This lesson was designed to help students understand the complexity and uncertainty of ecological systems, understand the importance of repeatability in science, and develop skills in critically evaluating and synthesizing multiple data sources related to the same topic. Specifically, it asks them to read primary literature and figures, identify and write claims, reason with data, and think critically about a real-life case study related to GMOs and non-target organisms.

In the times I have taught this lesson, I continue to be surprised by the level of student engagement during this activity. Students are genuinely interested in the monarch butterfly. Admittedly, this interest may reflect that we live in the upper Midwest. During their K-12 school experience, many Minnesota-raised students are likely to have participated in the citizen science project: Monarch Watch (<http://www.monarchwatch.org/>). If monarch butterflies and Bt corn might be concepts less familiar to your students, you could adapt the format of this case study to a more locally relevant system. However, the principle of connecting topics in undergraduate classes with topics that many students have encountered previously may be a useful strategy to purposely pursue.

Beyond generating excitement and engagement, this case gives students additional practice with understanding and applying the skills and practices of scientists. Since this lesson is typically done near the beginning of the semester, students are still learning how to write effective and accurate claims (i.e., claims that do not go beyond the scope of the results) and frequently make claims that are unacceptably vague. I have seen students refine their claims during the activity in response to peer and instructor feedback, and in some cases, self-reflection after listening to claims presented by other

groups. For example, a very generic and broad-sweeping claim of “Bt corn has an effect on monarch larvae” was refined to “In milkweed plants covered with Bt corn pollen, monarch larvae consume less than in plants covered with non-Bt corn pollen.” Furthermore, students became more fluid in the use of specific evidence to support their claims.

In my conversation with students, they commented on how interesting it was to see the way groups of scientists repeated and tested the original paper through experiments that built on and overcame the design weaknesses of the Losey paper. Of course, much more can be done here to help students more formally see this aspect of the process of science. Thus, this lesson can set the stage for later discussions or examples during the remainder of the course.

Finally, in the synthesis homework assignment, students repeatedly commented on the challenge of drawing a conclusion because some studies showed that Bt corn did not impact monarch larvae whereas other studies showed they did! They struggled with how to make a decision in the face of varying evidence, and some went back to the strength of the experimental design to explain why they decided on their conclusion. When student questions arose, I encouraged them to revisit the evidence and think about the strength of the scientific argument as they make their decision. I don’t scaffold too much here because I do want them to come away with an appreciation of the nature of science and the varying and sometimes conflicting results of studies that address the same question.

While I have not tested this lesson in an upper division course, the papers are sufficiently complex to enable the activity to be adapted for a 300 or 400-level ecology course. For example, instead of providing students with summaries of the papers, students could read the entire paper on their own. In fact, they could create their own summaries that you could use (with their permission) in a lower-division course! For more advanced students, you could increase the number of papers given to the class as a whole, build in a more formal critique of the experimental designs, and even have students look for more recent studies. For example, a more recent study in *Insect Conservation and Diversity* (13) suggests that the abundance of milkweed plants is decreasing as a result of Round-Up Ready GMO crops. The possibilities are endless!

Students at any level could look for popular press articles that are related to these findings and evaluate how well the popular press article captures the claims and evidence. Furthermore, you can easily take the structure of this activity and replace the content with a case that is relevant to your particular learning goals and content. Scientific controversies in any discipline could easily be placed into this structure, by identifying the paper or idea at the center of the controversy and finding 4-5 studies or dialogs that happened as a result of the initiated idea/study. The activity forces students to think about multiple pieces of evidence from different studies, evaluate risk and ultimately come to a conclusion about the issue, critical thinking skills essential for all graduates.

SUPPLEMENTAL MATERIALS

- Table 1. Does it pose a threat-Teaching Timeline
- Table 2. Does it pose a threat-Summary of papers used in Lesson
- Supplemental File S1. Does it pose a threat-Lesson Presentation Slides.
- Supplemental File S2. Does it pose a threat-Pre-Class

Reading Assignment and Rubric.

- Supplemental File S3. Does it pose a threat-In-Class Worksheet Part 1.
- Supplemental File S4. Does it pose a threat-In-Class Worksheet Part 2.
- Supplemental File S5. Does it pose a threat-Homework.
- Supplemental File S6. Does it pose a threat-Rubric for Homework

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