INQUIRY & INVESTIGATION

Promoting Student Inquiry Using *Zea mays* (Corn) Cultivars for Hypothesis-Driven Experimentation in a Majors Introductory Biology Course

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Abstract

The AAAS Vision and Change report (2011) recommends incorporating student research experiences into the biology curriculum at the undergraduate level. This article describes, in detail, how Zea mays *(corn) cultivars were used as a model for a hypothesis-driven short-term research project in an introductory biology course at a small Midwestern university. During the course of this project, student groups generated a research question and hypothesis, designed an experiment, collected data, and reported their findings in a paper modeled after the primary literature. Throughout the project, students experienced first hand the obstacles and accomplishments associated with the process of scientific research and gained a greater understanding of plant biology. By demonstrating biology as a dynamic field centered around hypothesis generation and experimentation, the authors observed an increase in student dedication, interest, and enthusiasm for the course.*

Key Words: *Active learning; corn; hypothesis generation; inquiry; maize;* Zea mays.

The AAAS *Vision and Change* report (AAAS, 2011) made the following recommendation for undergraduate biology education: "Introduce research experiences as an integral component of biology education for all students, regardless of major." This report asserts that an undergraduate research experience in an introductory course is foundational for the comprehension of basic biological knowledge. Additionally, a Survey of Undergraduate Research Experiences conducted by Lopatto (2007) concluded that even a short-term research experience enables students to increase their understanding of the research process and how scientists work to solve problems.

Approximately 5 years ago, the Biology Department at St. Ambrose University in Davenport, Iowa, adopted a mission statement focused on the process of scientific inquiry. As a result, the department incorporated hypothesis-driven student research projects in the year-long introductory biology courses. Because the second-semester introductory course explores the form and function of plants for the first half of the semester, corn (*Zea mays*) was chosen as the research model and is the focus of this article. The second half of the semester explores form and function of animals, using slugs as the model system (Peters & Blair, 2013).

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Corn is an ideal model plant for a short-term research project, in that seeds are affordable and easily obtained at any time of the year, have a good germination rate, and grow quickly enough on lighted plant carts for students to measure multiple quantitative morphological traits (e.g., plant height, root biomass, leaf number). Although most of the corn that students see as they drive through the Midwest is grown for animal feed, there are many heritage cultivars that were bred for particular traits such as color, kernel size, drought resistance, and so on (Levetin & McMahon, 2011). Students were surprised by the variety and number of heritage corn cultivars such as Black Aztec, Mandan Bride, and Roy's Calais, which were introduced by the Aztecs, Mandan Indians of Minnesota and North Dakota, and western Abenaki (Sokoki) people of Vermont, respectively (http://www.seedsavers.org). For example, one student wrote in a course evaluation, "I liked learning about the different types of corn. Wow, I didn't know there were that many!"

At the beginning of this inquiry project, students were provided basic information on various corn cultivars obtained from Seed Savers in Decorah, Iowa, to pique their curiosity and interest as they began brainstorming possible research questions. During this short-term research project, small groups of students (1) formulated a hypothesis using cultivars of *Zea mays*, (2) designed and conducted an experiment to test their hypothesis, (3) collected data and created a computer-generated graph to display their results, (4) drew conclusions based on the summarized data, and (5) recognized problems and errors associated with experimental design and data collection.

In addition to focusing on the corn inquiry project in lab, additional experiences were incorporated into the lecture portion of the course to form a solid link between lecture and lab. For example, on the first day of lecture, students were given a case study examining the pros and cons of genetically modified corn (adapted from Waterman & Stanley, 2010). Additionally, Dr. Tyrone Hayes from the

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University of California, Berkeley, was invited to campus to give a research seminar on atrazine, one of the most widely used herbicides on corn in the Midwest. Prior to his lecture, students read a paper about his research on atrazine (Hayes et al., 2010) and answered accompanying questions about the paper during a lecture period. This integration of the research project with classroom learning objectives enhanced each student's ability to appreciate the interconnectedness of topics such as corn structure, growth, nutrient acquisition, and soil composition.

○ Methods

During spring 2013, approximately 105 students took the course Functioning of Living Systems/General Biology II, and two professors taught the three lectures and five laboratory sections. The students were a mix of freshmen and sophomores. The inquiry-based corn project was the major focus of the first half of the semester in lab. From the development of a testable hypothesis to the final due date of the lab report, students spent 7 weeks working on the project (Table 1). Working in groups of two to four, students were first introduced to the inquiry-based corn project with a handout describing a testable hypothesis, which clearly articulated the relationship between independent and dependent variables. Students had already spent significant time in their first semester of introductory biology developing well-written hypotheses. They were also given a list and description of 8–10 available corn cultivars (purchased from http://www.seedsavers.org). Students had the option to work with seeds or seedlings that were 1 or 2 weeks old. Because there was not adequate space to grow seedlings of all of the different cultivars before the experiments began, three cultivars were selected that students could choose among. Students then brainstormed questions they might ask about germination and growth of corn in general or about differences in drought resistance, growth rate, and nutrient acquisition among the different cultivars. As students were narrowing down to a specific research question and hypothesis, students were steered toward projects that have real-world application. After approximately 1 hour, the class went to the library, where our liaison librarian showed them an assignment-specific web page created in the LibGuides content management system (see http://libguides.sau.edu/Bio200Corn). This page highlights physical and electronic information sources selected by the professors and librarian to provide an entry point for student research, while familiarizing them with discipline-specific resources available through the library. Students had 1 week to write a background and proposed methods to test their specific hypothesis. The following are examples of student hypotheses:

- Growing sweet corn upside-down will increase growth because of assistance, rather than resistance, of gravity for delivery of water and nutrients to the stems and leaves.
- If Stowell's Evergreen is exposed to ethylene released from a banana, then the corn seed will germinate faster and result in a rapid growth rate compared to the corn seeds not exposed to the ethylene.
- The percentage of growth of the Golden Bantam Improved corn seedlings that are 1 week old will be increased due to a low voltage of electric shock, compared to medium, high, and no shock.
- If corn seeds are frozen for storage, then the seedlings will demonstrate greater growth than seedlings from seeds that are stored at room temperature.
- As the acidity of the solution added to Golden Bantam Improved seedlings increases, the plant growth and health will decrease.
- If the drought resistant corn (Bloody Butcher) is grown in sandy soil, then it will have better growth compared to field corn, shown by a higher percentage difference in height and increased germination.
- If given the same amount of water for 2 weeks, the Oaxacan Green Dent corn will grow more than Reid's Yellow Dent corn.

To grade the proposals, provide critical feedback, and acquire the requested project supplies, the instructors had a 2-week turnaround time. During the lab following that 2-week period (week 5), student groups assembled their projects and came up with a data collection plan for the following 2 weeks, which was the time frame for the experimental trials. Although it would be ideal to extend the data collection time, corn seeds germinate within 2 to 3 days, and the young corn seedlings grow rapidly. The projects were placed on lighted plant carts (Flora-Cart; http://www.indoorgardeningsupplies.com) in a room dedicated to inquiry space (Figure 1). Students had access to this room 7 days a week; campus security worked with us to provide access during evenings and weekends. At this point, the students were told that the plants were fully their responsibility.

During the following lab (week 6), students were given time to work on their project. While most groups used the time to collect data and bounce ideas off their instructors, some groups began sketching prototypes of figures or finding additional resources for their final lab report. This workshop took approximately the first half of lab. At that time, 40 minutes of the documentary *King Corn* (see http://www.kingcorn.net/) was shown. The documentary raises many interesting questions about how we grow corn and, more generally, produce food in the United States. Although most of our students are from the Midwest, few have an understanding of the myriad destinations of the corn grown in the region. The students related well to the young filmmakers, and this was one of their favorite labs.

With their final lab-report assignment, students were given a handout on appropriate data presentation. Because these were new concepts for many of our first-year students, the handout described in detail the required components of graphs and tables, as well as information to help them decide what is the most appropriate graph or table based on their data. Students were taught about continuous versus discrete data, and examples from different student groups were used to illustrate these concepts. During the second inquiry project

Table 1. An excerpt from the General Biology II laboratory syllabus, illustrating the timeline for the inquiry-based project on corn.

Semester	Laboratory Topic
Week 2	Developing Hypotheses in Science – Corn Experiment; Literature Review in the Library
Week 3	Hypothesis and Proposed Methods Due
Week 5	Set Up Experiment – Begin Data Collection
Week 6	Data Collection Workshop; Watch an Excerpt from the Documentary *King Corn*; Discussion
Week 8	Full Corn Lab Report Due

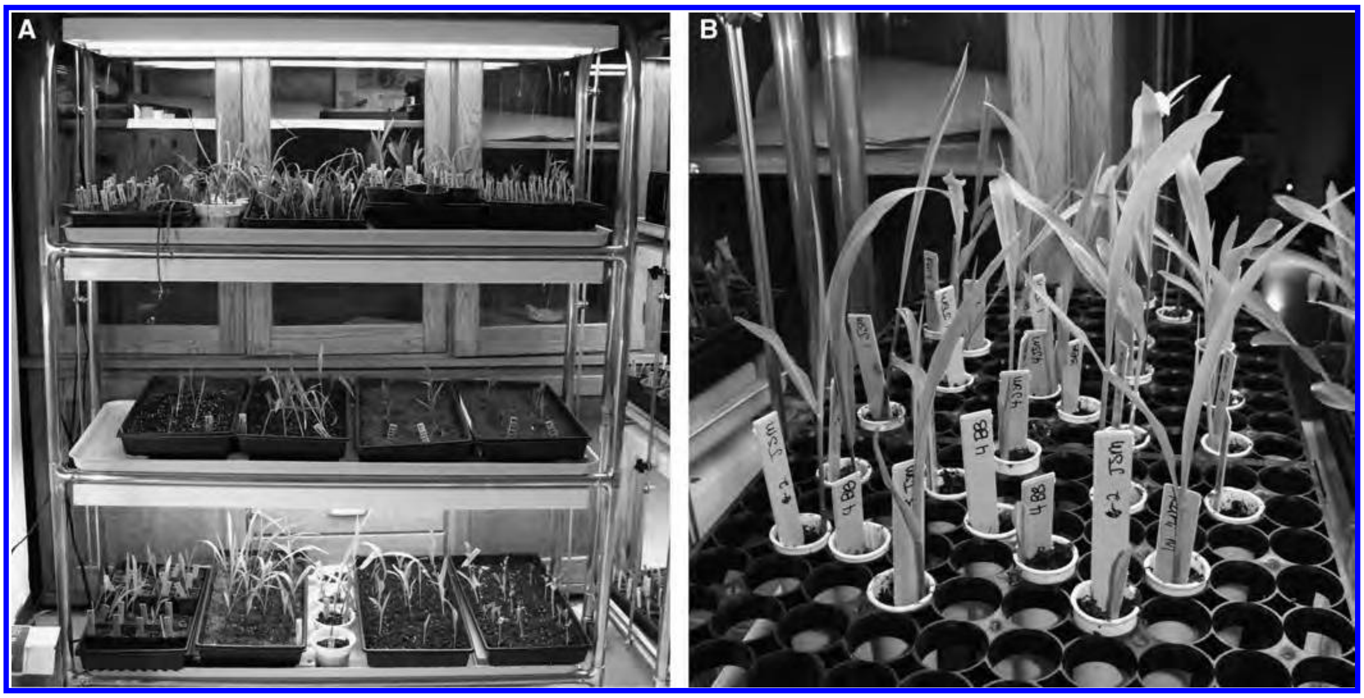

Figure 1. (A) Lighted plant cart containing projects and (B) close-up view of an experiment examining the effect of planting depth on germination and seedling performance.

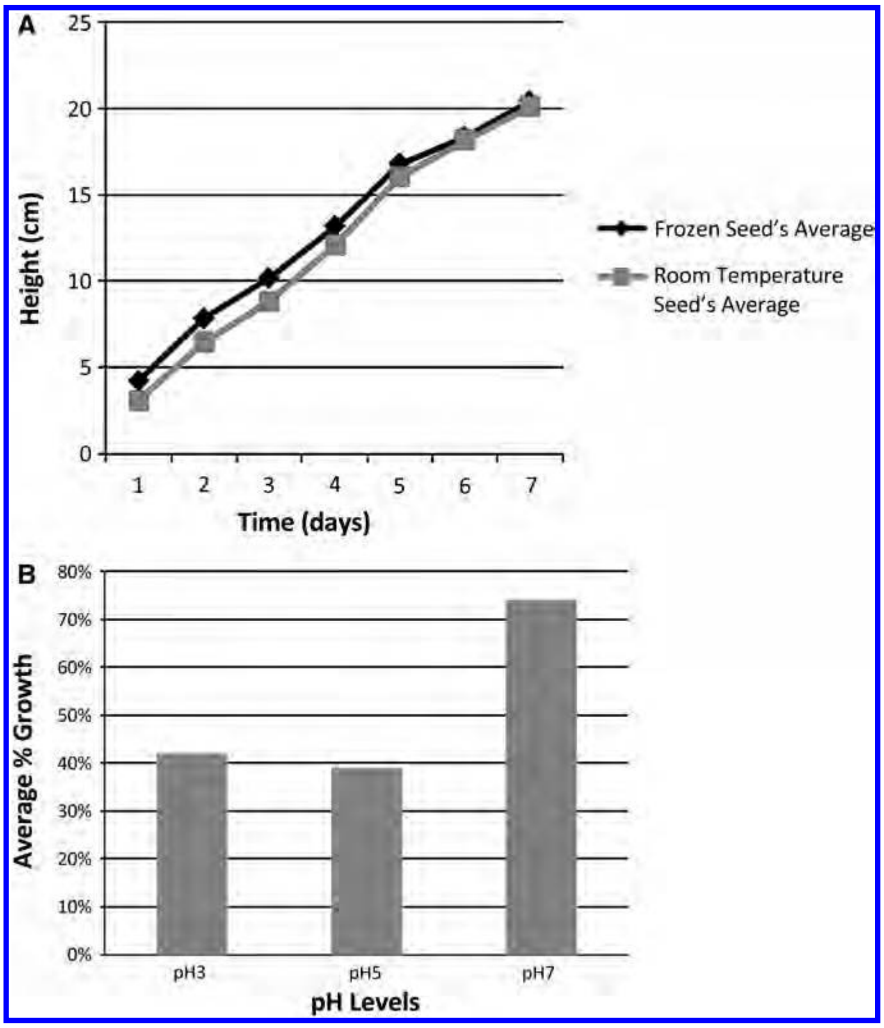

Figure 2. Graphs from final lab reports that (A) compared corn seedling growth from seeds stored at freezing versus room temperature and (B) examined the effects of acidity on the relative growth of 2-week-old corn seedlings. Student-written figure captions: (A) The individual height of both the room-temperature-stored seedlings and the frozen seedlings were recorded and then converted into an average that was graphed in accordance with the day on which the height was taken. (B) Average percent growth in height of the stems of Golden Bantam Improved Corn plants compared with differing levels of pH. Each pH group contained five different plants that were exposed to the same conditions other than the pH itself. The heights of the stems were recorded in centimeters at the beginning and end of a 2-week period. The percent growth was calculated for each individual plant, and then the percentages were averaged.

in this course, focused on animals (see Peters & Blair, 2013), students spend an entire lab period learning how to report appropriate statistics and include standard error bars on their graphs. The basic graphs and tables included with the final corn report were generated in Excel (for examples, see Figure 2). The grading rubric for this final assignment is shown in Table 2. The lab-report format

Table 2. The grading rubric for the final lab report for the inquiry-based project on corn.

	Points
Title	
Clearly stated; no errors (1 point)	
Hypothesis & Introduction	
Hypothesis stated clearly with independent and dependent variables (1 point)	
Introduction background information sufficient (3 points)	
Materials & Methods	
Control and experimental variables and groups identified (1 point)	
Procedures clearly spelled out (3 points)	
Results	
Tables/graphs are properly titled and labeled (3 points)	
Written narrative of tables/graphs (3 points)	
Discussion	
Support or rejection of hypothesis (1 point)	
Appropriate interpretation of data (2 points)	
Problems encountered (1 point)	
Proposed future experiment (1 point)	
Tie-in to literature from Introduction (1 point)	
Citations	
Used in-text citations correctly (1 point)	
Followed APA format (1 point)	
Reads well; few grammatical errors; no misinformation (2 points)	
Total points (out of 25)	

was modeled after a primary paper, and the expectation for concise, scientific writing was set and hopefully taken forward to the next inquiry experiment focused on slugs (Peters & Blair, 2013) and our upper-level biology courses.

○ Conclusions

Multiple studies have demonstrated that students participating in inquiry-based instruction are better able to solve scientific problems (Lord & Orkwiszewski, 2006), have an enhanced understanding of the scientific process (Lopatto, 2007), and have more interest in the laboratory experience than students taught using traditional methods (Lord & Orkwiszewski, 2006). Based on these findings and the recommendations of the AAAS *Vision and Change* report, the instructors describe here how they included inquiry-based learning in an introductory biology course, enabling the students to become familiar with the experimental process of science and to gain knowledge about the research model, corn, and its interactions with the living world.

Because we incorporated this inquiry-based project in our course, students took greater responsibility for their own learning. Students were required to use critical-thinking skills and problem-solving strategies as they navigated the obstacles of their research project. One student commented, "It was a mind-blowing experience because I had no idea that getting corn seedlings to grow and not die was such hard work." This pedagogical approach allows the instructor to facilitate the process of discovery and learning, but he or she is not the primary disseminator of knowledge (Uno, 1990). Uno (1990) noted that students have a higher level of satisfaction, investment, and responsibility when involved in a student-driven experiment rather than one prescribed by the instructor. The instructors directly observed an increase in each student's dedication and overall interest in this dynamic research process. In fact, each day during the data collection period, at least one group of students typically stopped by to ask a question, receive help with data interpretation, or just express delight or disappointment with the data. One student commented, "The experiment was very personalized and original. It is a lot more enjoyable to choose your own topic."

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