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To cite this article: Laura Wheeler, Rita Hagevik & Kathy Cabe Trundle (2024) BEE Ambassadors for Pollen, The Science Teacher, 91:3, 48-59, DOI: [10.1080/00368555.2024.2337557](https://doi.org/10.1080/00368555.2024.2337557)

To link to this article: <https://doi.org/10.1080/00368555.2024.2337557>

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 Published online: 16 May 2024.

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LAURA WHEELER , RITA HAGEVIK , AND KATHY CABE TRUNDLE 

ABSTRACT

During this lesson, students engage with the phenomenon of the coevolution of structures of pollen and pollinators and their functions. Students collect pollen, prepare pollen slides, and make observations of the features and structures of pollen. Next, students investigate the various structures of pollinators and consider the efficiency of native bee dry pollination techniques. Students consider the field of engineering by designing and building a prototype of a native bee and consider the role that pollen hairs and electrostatic charges play in increased pollination efficiency. Finally, students write an argument based on evidence that native bees should be used as pollinators in gardens and farms to mitigate human caused pollinator decline and to increase pollinator biodiversity.

Keywords: Biodiversity; pollinators; engineering design; pollen; structures

In the spring, nature awakens from its slumber, temperatures rise, trees and flowers bloom, and birds and insects resume their flights through the air. Some people, however, dread springtime because it brings seasonal allergies with sniffles, itchy eyes, and sneezing. How is it that pollen, which is responsible for the beautiful diversity of flowering plants, can cause those with allergies so much misery? This lesson allows students to engage in sensemaking through the analysis of the form and function of pollen, carried by pollinators.

Students observe the microscopic features of pollen and how insects transport these fine, but critical, grains of life. Students recognize that pollen are specialized cells within plant organisms that perform the essential function of life. Using engineering design skills, students create models of the structures that native bees use to transfer the pollen from an anther to a stigma. We (the authors of this article) teach these concepts in high school classrooms and in summer programs focused on the human impacts on biodiversity as related to bee conservation.

This lesson is the second in a series of pollinator biodiversity and conservation lessons. The first lesson develops student understanding of the coevolution of flowering plants and pollinators through plant dissection and considering what would happen if half of the world pollinators disappeared. In the third lesson, students design native bee homes and habitats to mitigate human-caused pollinator decline.

Pollen: an introduction

Pollen carries the male genetic material (DNA) from the anther to the female stigma of flowers. The genetic information is encapsulated in a cellulose layer called *intine*. The intine is protected by a tougher outer layer called the *exine*. The exine layer protects the DNA from changes in temperature, humidity, UV radiation, and pH changes. Finally, the exine layer is surrounded by the *pollen kitt*, a sticky layer that allows the pollen grain to adhere to surfaces (Edlund, Swanson, and Preuss 2004).

Pollen comes in varying shapes, sizes, colors, and flavors, sometimes with outer ornamentation so that it can easily attract and be carried by specific pollinators as they move from flower to flower. Bees need nectar and pollen, and are directed by their sense of sight, taste, charge, and other environmental factors to flowers that meet these needs. Bees see, taste, and smell the flowers that

they like best. Many bees have hairs called *scopa* on various parts of their bodies to which the sticky pollen may adhere. As bees fly, they electrostatically become positively charged so that when the bee lands on a negatively charged favorite flower, the attracting opposite charges aid in pollen pick-up (Cole 2013). Even when accounting for variables like flight velocity, wind, and moisture, the pollen can travel great distances attached to a bee's scopa.

Once the bee finds another favorite flower with available high protein pollen or sweet nectar to eat, the pollen rubs and/or is shaken from the scopa and releases onto the sticky stigma. Pollen can be released when the pollinator reaches deep into the flower to access the nectar. In contrast to non-native honeybees, which use the wet pollination method, many native bees are effective pollinators due to their hair-covered bodies, buzz pollination, and use of a dry pollination method (Avery et al., 2017). For more information about native bee biodiversity, Crown Bees offers free online modules (see Mason Bee Edu Educator Modules, 2022).

Dry pollination allows pollen to transfer readily from their hair-covered bodies to the flowers the bees are pollinating. Pollinator adaptations include structures to collect, carry, and release pollen. Pollen grain adaptations include structures that allow for protection of genetic information and adhesion to pollinators, while still allowing pollen grains to fall off at appropriate times (USGS 2017). The coevolution of pollen and pollinator forms and structures functioning efficiently to transport pollen provides an example of a natural engineering marvel (Van der Kooi, Vallejo-Marín, and Leonhardt 2021).

Students use The ITEEA 6E Learning byDesign model developed by Burke (2014) to explore the connections between pollen and pollinator forms and structures. Through the steps of the 6E's which include Engage, Explore, Explain, Engineer, Enrich, and Evaluate, students make sense of the lines of evidence supporting the use of native bees to pollinate many of our food crops (e.g. fruits, nuts, and vegetables) (Kaplan 2016).

Engage (10–30 minutes, depending on proximity to pollinating plants)

Students engage in a pollen observation walk in the spring, summer, or fall through their school grounds or to a nearby park to focus on the phenomenon of pollen and pollinator biodiversity:



The students take a careful look at the flowering plants and trees around them and notice the size, shape, and color of the pollen. Since pollen is small, students use a hand lens for observation. Students choose a few types of pollen to collect from the flowering plants or the trees. Students collect pollen with a small brush or cotton swab and deposit it on wax paper or in small cups using a different swab for each flower type. The students record observations of the flowers from which they collected the pollen (Mayer 2018). Students observe characteristics of the pollen collections such as stickiness, amount of pollen available, and the number and type of bees observed on the pollen source.

As an alternative to a pollen observation walk, we also bring flowers into the class from which students gather pollen from the anthers. Flowers may be collected or purchased, and if purchased from a local florist, make certain to request that the anthers (with their pollen) be left intact. We prefer to use *Alstroemeria pelegrina*, a relatively cheap and easily accessible lily.

Explore (20-minute preparation, includes overnight setting; 20 minutes to draw, record, and compare pollen images)

Students explore pollen further by preparing permanent slides (see Figure 1) of the pollen grains (video explanation of pollen grains) and studying the structure of pollen through a compound microscope. To make a pollen slide, a glass slide and coverslip work best. Gently tap to release some pollen onto the slide. Be careful, pollen is tiny, and you only need a small amount. Place one drop of glycerin jelly, (gelatin, glycerol, dis-

tilled water) which has been melted on a coffee warmer or in a hot water bath by the teacher and cooled in a glass beaker, on the pollen slide. Gently place the coverslip on the slide over the pollen at an angle and slowly lower using the tip of a pencil to avoid air bubbles. Students label the glass slide with a glass or wax pencil with their initials and allow the slide to dry overnight on a heating pad set on low. The next day we seal up the pollen slide by placing a small amount of clear nail polish on all four sides of the coverslip's edges. Allow to dry for a few minutes and then the pollen slides are ready!

Students place their pollen slides under the microscope and draw the shape and structure of the pollen grains. See [Supplementary Materials](#) for details and laboratory materials needed to make a permanent pollen slide (Zander 2003). Students further examine examples of electron microscope images of different pollen grains, make observations, and compare these images to their observations (see Figure 2). In groups, students consider the function of a pollen grain and its form. Students draw and label the parts of a pollen grain in their science notebooks (see additional materials). Students generate a list of questions they develop in groups after completing their models of specialized pollen grains, such as

- Why is pollen shaped like that?
- What is the function of a pollen grain?
- How does the pollen get to the correct plant?

Students share their group-generated questions and a list is made on the board.

FIGURE 1

Student preparing pollen slide.

We direct students to consider the phenomenon of pollinator biodiversity. We show students the Backyard Anthecology PDF, which has images of different pollinating insects and ask them to observe the common features. The students brainstorm a list of common pollinator features that typically include hair, size, shape, and mobility. Students watch a video of different pollinators and pay attention to forms or structures and how these forms or structures relate to pollinating efficiency.

Students then draw the different features that assist native bees in carrying pollen from plant to plant. Through guided discussion, students consider how the shape and form of the scopa, found on the legs, under the abdomen, along the sides,

and back of the thorax of bees, work to carry pollen from flower to flower. We direct students in groups to generate a list of questions about pollinator biodiversity based on the observations. Now that students have engaged in the sense making of pollen, new student questions arise, such as:

- Which pollinators are designed for carrying maximum amounts of pollen?
- Are different species more efficient pollinators?
- What pollen features may assist in pollinator delivery?
- Is there a difference in pollinating efficiency of different bees?

FIGURE 2

Sample pollen image.



Students record their thoughts and ideas as they discuss these questions in groups while using their observations (see [Supplemental materials](#)).

Explain (15 minutes)

We return to our original phenomenon of native bee forms by viewing the bee species listed in the Backyard Anthecology PDF. We tell students we will focus on their question, which pollinators are designed for carrying maximum amounts of pollen? Many bee species are completely covered in hairs, which produces greater surface area for transporting maximum amounts of pollen. Students should conclude that many native bee species contain more hairs and therefore should be better pollinators. We explain that many native bee species are dry pollinators, which is a more effective pollination method than the honey-bee wet method.

We ask students to consider human dependence and human impacts on pollination while we watch the Crown Bee video. Following the video, we ask students to evaluate the use of native bees to mitigate the human-caused impacts on pollinator biodiversity. If non-native honey bee colonies continue to decline, the engineers and scientists of the future will need to consider native bees as possible pollinators of food sources. We tell students to ask questions about the use of Mason bees

in agriculture as a possible solution to the decline of pollinators. Possible student questions include:

- What forms do Mason bees have that make them excellent pollinators?
- Why is the dry pollination of Mason bees more efficient than honeybees?
- Why should scientists and engineers consider the form and function of native bees when studying pollination?

Students' comments reflect their understanding of coevolution when they suggest that native bees may have specific forms that have adapted to only one type of pollen. Sometimes students may ask if native bees are designed to pollinate multiple food source plants? We tell students that this is an excellent question that scientists are working to answer. We explain that humans depend on pollinators for many human food sources, including much agriculture. North American farmers heavily rely on non-native honey bees, but due to their decline, researchers and engineers are now looking to mitigate pollinator declines through native bee conservation.

We connect the students globally to a phenomenon in China, where many fruit tree farmers are forced to hand-pollinate their orchards due to a decrease in pollinating insects that followed

the overuse of pesticides (Fercsik 2021). Hand-pollinating the orchards is accomplished by degreasing chicken feathers and then attaching them to bamboo sticks. The chicken feathers mimic the hairs on bees and as farmers move the feathers from blossom to blossom the dust-like pollen is moved from anther to stamen. Mechanical (hand) pollination is costly and time-consuming; increasing native bee populations is essential across the world to ensure a secure food supply for everyone.

Engineer (20–30 minutes)

We tell the students that today they are engineers who have been tasked with creating a working prototype of a native bee (bumble bee) that can pick up the greatest amount of pollen grains from an anther. We use laminated pictures of flowers (see [Supplementary materials](#)) and tell the students to use the dry erase marker and label the flower with negative signs (–) representing the negative charge of flowers. We tell students that traditional pollination of food sources has focused on the non-native honeybee, but in the wake of honeybee colony collapse disorder, we want to study and learn more about native bee species that could be used to pollinate food sources.

Focusing on native bee species allows the students to explore an often-neglected source of pollination in North America (Crown bees 2022). We tell students that native bees are dry pollinators that rely on hairs that become electrostatically charged

when they fly, which may increase the amount of pollen that adheres to the sticky pollen kit layer. Considering pollen and native bee structures from the crosscutting concept of form and function allows students to develop greater sense-making of co-evolution in their engineering design.

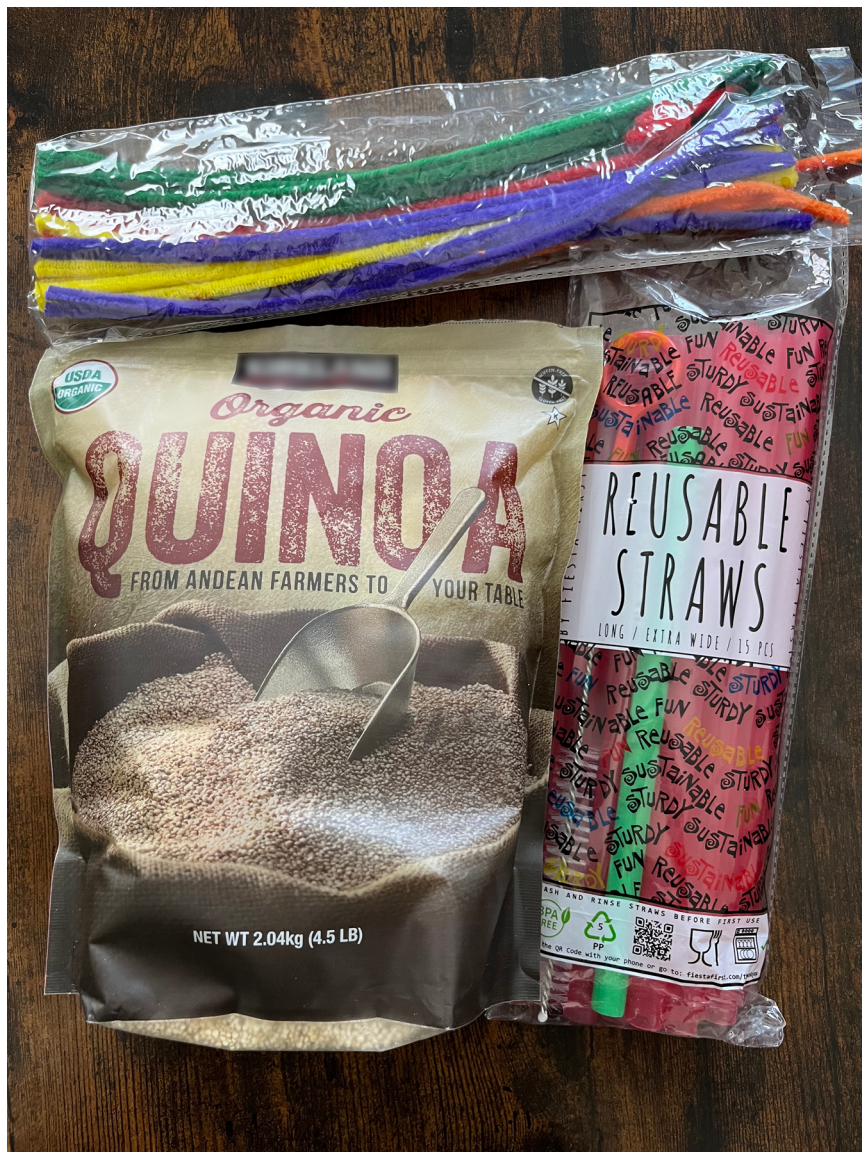
Students work through the engineering design process in their lab notebook or provided student handout (see [Supplementary materials](#)). Students are encouraged to follow the engineering design process as described in [NGSS Appendix I \(Supplementary materials\)](#). We challenge the student groups to engineer a working prototype that can pick up the maximum amount of pollen grains and remain attached to the bee without assistance from their hands. We provide an 8-inch long by .5-inch diameter straw for each group (see [Figure 3](#)). This straw represents a native bee (bumblebee). Students have access to pipe cleaners, feathers, and cotton balls to represent bee hairs and we ask them to design a bumblebee with legs and hairs that mimic structures in nature. Students may choose to engineer bee hairs with feathers or other materials after the pipe cleaner bee is constructed as a baseline.

Once the native bee, covered in hairs, is designed, it's time to electrostatically charge the model. We tell students to use a dry erase marker to label the bumblebee with positive charges. We accomplish the task of “charging” the bumblebee by running a silk scarf or other material over the straw by rubbing the



FIGURE 3

Sample engineering materials.



straw back and forth. After the straw is “charged,” we provide quinoa to represent the pollen and ask the students to consider its electrostatic and adhesive properties.

Quinoa is used in this activity because it is lightweight, adheres to pipe cleaners, and can be counted to measure the efficiency of the design. Students will need to place many pollen grains (tablespoon) on the anthers of their positively charged flower pictures (see [Figure 4](#)). We ask students to consider co-evolution in their design with the question: “Why do you have to consider the forms of both pollen and pollinator?” Students reason that through time, pollen and pollinator forms influenced the evolution of each other. Currently, pollen has a sticky

outer layer and shapes that increase their likelihood of pollination, and pollinators, like native bees, evolved electrostatic hairs to increase the amount of pollen they can carry as food.

Enrich (20–30 minutes)

After engineering the bumblebee, students iteratively test their electrostatically charged designs by bringing the bee in contact with the pollen (quinoa) and counting the number of pollen grains that successfully adhere to the bumblebee (see [Figure 5](#)). We guide the students to draw a prototype and receive teacher permission before building and testing their prototype. We encourage students to revise and improve their initial models

FIGURE 4

Flower with quinoa representing pollen.

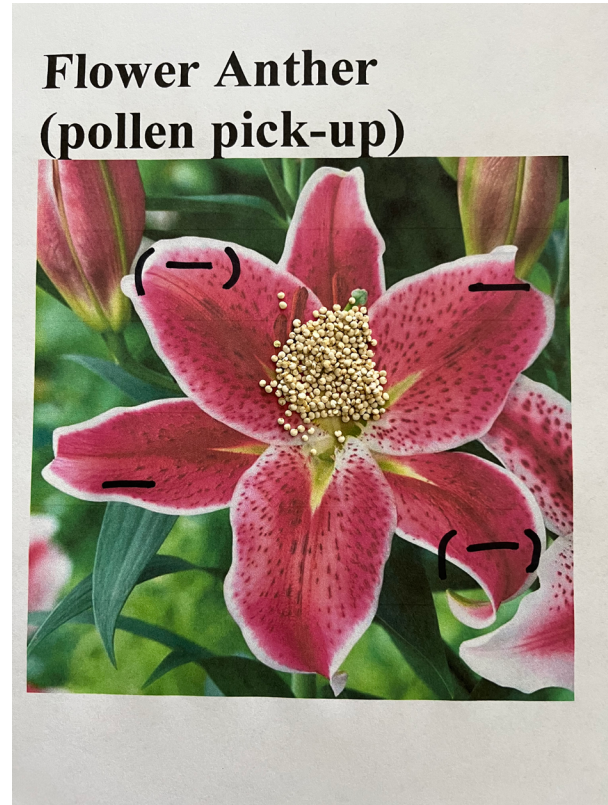


FIGURE 5

Testing bee design by rolling in quinoa (pollen).



based on our feedback and suggested changes before they begin modifying and testing new prototypes (see [Figure 6](#)).

Engineering provides an opportunity for students to practice failure and perseverance. Thus, we stress the importance of multiple trials following a redesign. Students may compute the average of three trials per prototype (see [Figure 7](#)). Students determine success by comparing the average number of pollen grains picked-up during each redesign and trial. We encourage students to notice that increasing the number and the arrangement of the hairs (pipe cleaners) as the body of the bee, allows the bee to collect more pollen (see [Figure 8](#)). We engage the class in a discussion of how the simulation to test a possible solution (efficiency of native bees dry pollination techniques) may mitigate adverse impacts of human activity on pollinator biodiversity and subsequent pollination in agriculture.

Evaluate

Following the design of a working prototype, we ask the students to consider the success of their model and the forms that allowed for maximum efficiency: “What does this look like in nature?”

We end the lesson by showing a video about the importance of native bees in agriculture and asking the students to create an argument for the claim that native bees should be used as pollinators in gardens and farms to mitigate human caused pollinator decline. We use the arguments as a summative assessment. We encourage students to use at least three lines of evidence from the lesson on the forms of various pollinators and pollen.

Students explain their reasoning based on the lines of evidence and focus on the efficiency of native bee and pollen forms in dry pollination. We provide a rubric (see [Supplementary materials](#)). Differentiated instruction occurs throughout the lesson when we encourage small group investigations, hands-on learning, and inquiry discourse. We allow ELA students to draw models or observations of pollinators and pollen. The engineering guide may also serve as a performance-based task allowing us to better see how a student is making sense of content and ideas and creatively applying concepts. Students are encouraged to iteratively test and draw prototypes. Iteration serves as a differentiation allowing students multiple attempts. Evaluation can be done by allowing students to illustrate their lines of evidence or work in small groups.

FIGURE 6

Prototype with countable quinoa (pollen) grains.



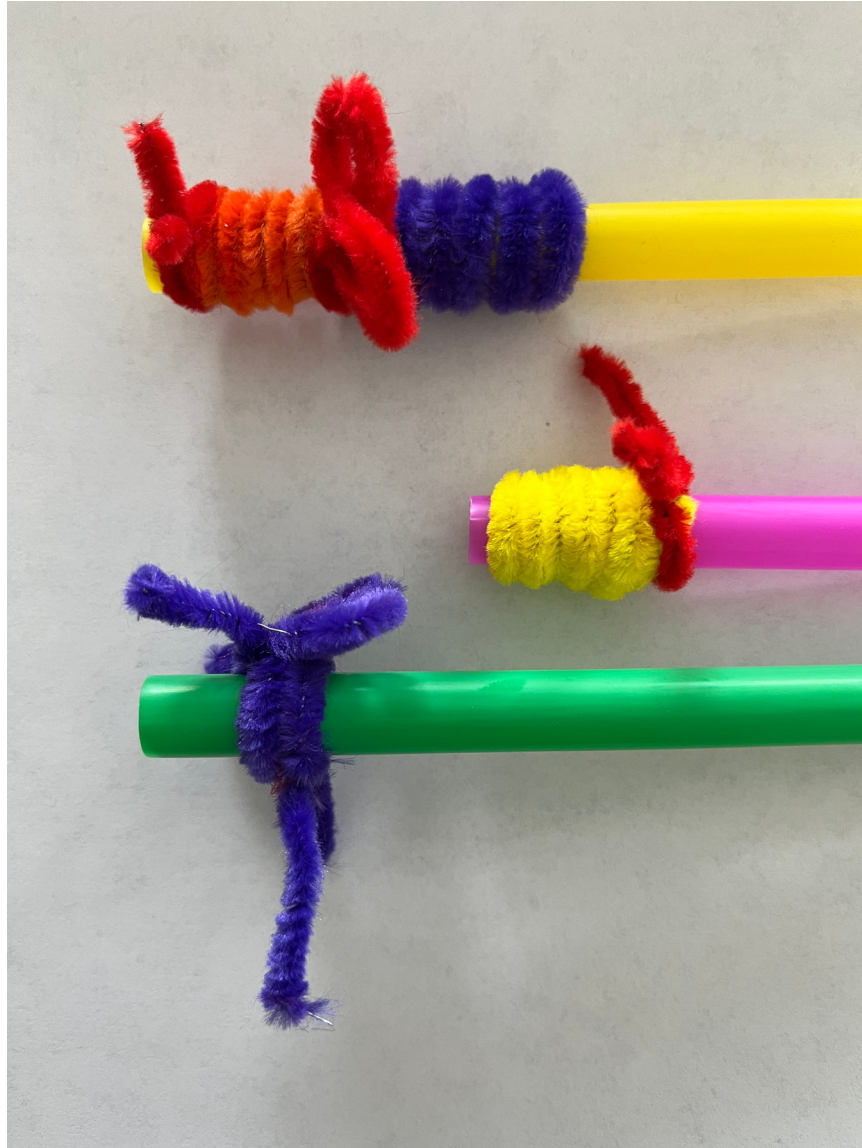
Art and technology

We encourage students to view the microscopic world using wireless digital microscopes with 250–1000X magnification (see Resources). These devices allow students to capture images or videos of pollinators and flowers during the nature walk. Students can make pollen slides of different flowers, draw them, and even possibly digitize and 3D print them. There are 3D printing files of pollen grains that are freely available (see the 3D Pollen Project). We ask students to draw and design prototypes of pollinators before creating and testing them.

Conclusion

Students initiate sensemaking of native bee use in agriculture based on the efficiency of pollen and pollinators forms and functions. By creating working prototypes of pollinators and the pollen they transport, students reason the importance of nature's complementary engineering design. Students understand that in creating working prototypes, the most efficient designs are those that mimic nature (biomimicry). Pollen needs specifically shaped structures to be carried by pollinators. Native bees are specifically engineered to carry maximum amounts of pollen, and students should be conscious of our dependency on bees to pollinate many of our food sources.

FIGURE 7

Iterations of bee designs.

Using the 6E model with our students allowed them to engage with nature, explore with their hands, engineer a bee prototype, and develop cognitive skills as they reason through the design process. Students can explain that pollen is a specialized sex cell adapted to carry plant DNA. Pollinators depend on pollen as a food source; the decline of pollinators will lead to a decrease in plant production. Scientists and engineers are studying the efficiency of native bee species in the wake of the honey bee colony collapse disorder. Native bees are efficient pollinators and a possible solution to human caused pollinator decline. The students will realize that while spring pollen

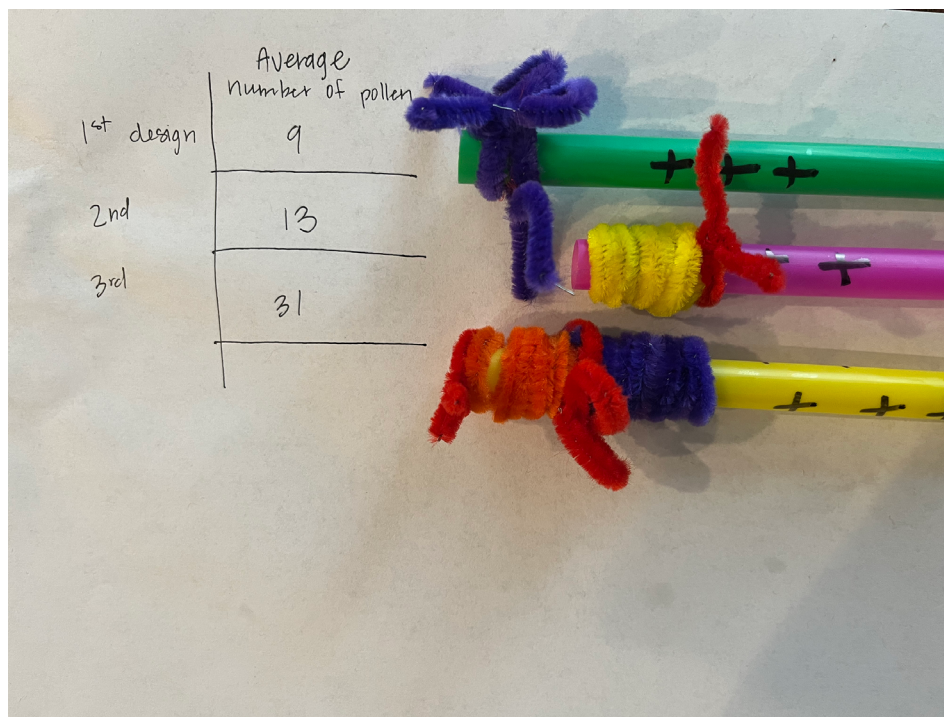
may be bothersome to some of us, we all rely on this system to sustain us and the bees!

Safety considerations

If students are allergic to pollen, they wear gloves and a mask. Students wash their hands after collecting or handling the pollen. Pollen grains can be stored in a closed container in the refrigerator for a few days as needed. Teachers should prepare the glycerin jelly using proper heat resistant equipment. Students wear gloves when applying the nail polish to the pollen slides.

FIGURE 8

Average number of quinoa (pollen) grains with prototype.



DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

SUPPLEMENTARY MATERIAL

Supplemental data for this article can be accessed online <https://doi.org/10.1080/00368555.2024.2337557>

FUNDING

This work was funded by: Using Smart Foodscapes to Enhance Sustainability of Western Rangelands Agriculture and Food Research Initiative, Sustainable Agricultural Systems Competitive Grant No. 2021-69012-35952, USDA National Institute of Food and Agriculture, and Using Smart Foodscapes to Transform Cowherd Nutrition on Western Rangelands, Utah Agricultural Experiment Station Seed Grant Program, Utah State University.

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