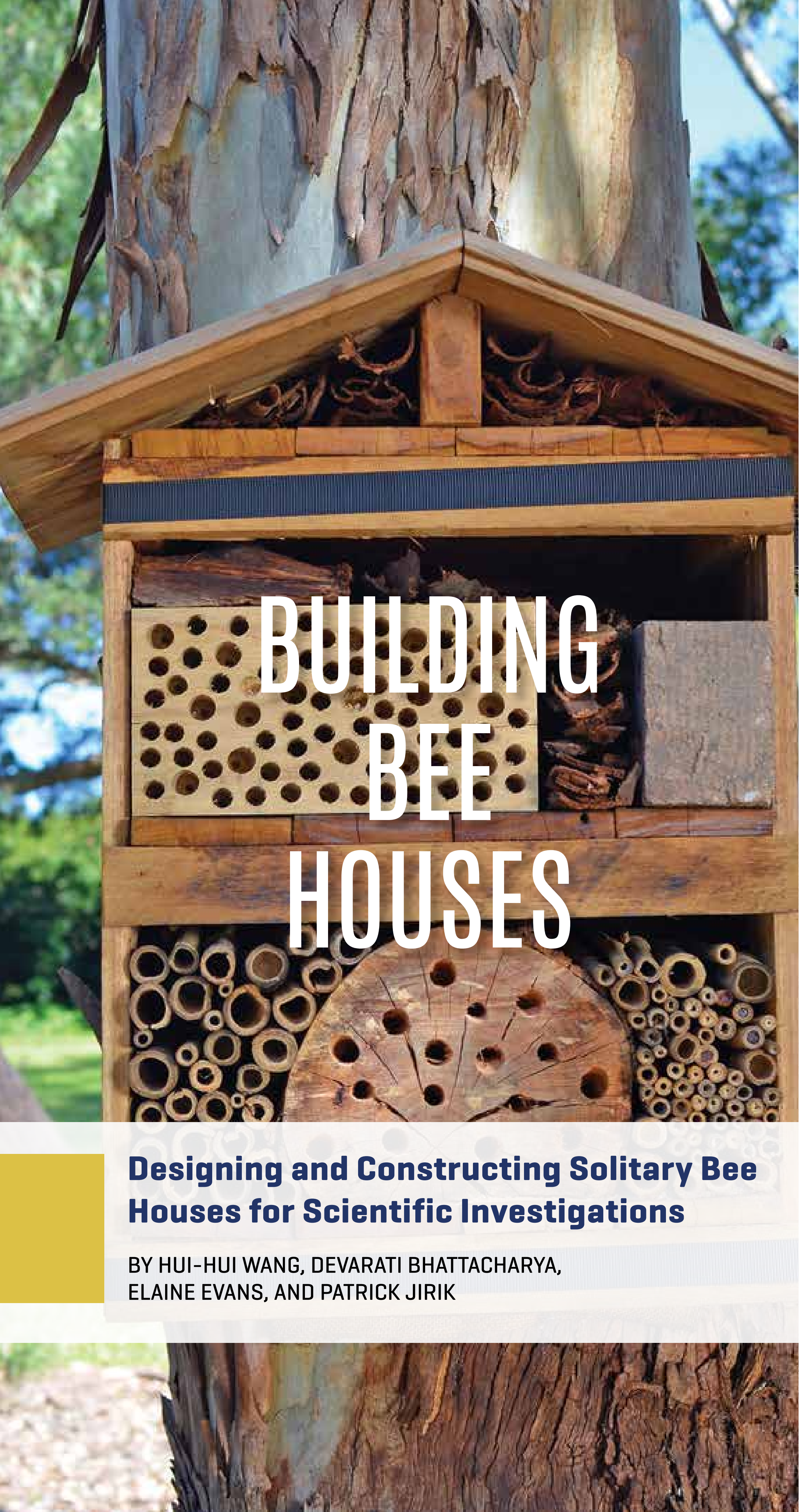

BUILDING BEE HOUSES

Designing and Constructing Solitary Bee Houses for Scientific Investigations

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CONTENT AREA

Life science, engineering design, scientific inquiry

GRADE LEVEL

6–8

BIG IDEA/UNIT

Designing a house for solitary bees

ESSENTIAL PRE-EXISTING KNOWLEDGE

Pollinator and pollination, plant science

TIME REQUIRED

12-week after-school unit, meeting 90 minutes weekly

COST

$20 per student (materials to build the bee house)

SAFETY

See "Concerns for Safety" and the Online Supplemental Materials

Many resources essential for human life are dependent on pollinators that assist plants in their reproduction. In general, a pollinator is an organism that transfers pollen from one plant to another, such as bees, butterflies, hummingbirds, and flies. Due to exposure to parasites and pesticides and habitat loss, a significant decline in the native pollinator population has been observed and identified as an environmental and economic threat (Pollinator Health Task Force 2015). Providing artificial habitats for pollinators can significantly increase their numbers and diversity. Therefore, efforts to develop and create alternative habitats for pollinators are ongoing all across the nation.

Developing and creating habitats for pollinators has been identified as an engineering design problem with the potential to facilitate scientific inquiry among students and educators alike. This article focuses on designing and constructing insect pollinator houses for solitary bees to engage students in engineering design and scientific experimentation. Solitary bees include many species, such as leafcutter bees, mason bees, carpenter bees, and mining bees. Unlike honeybees, solitary bees live alone and do not produce honey or wax. Similar to honeybees, they play a critical role in pollinating flowers during plant reproduction. They are typically much more docile than swarm bees, and the threat of them stinging a person is low.

Overview: Design a solitary bee house

We collaborated with a local middle school to develop an after-school program focused on native pollinators. The program was implemented during a weekly 90-minute, after-school session over the course of 12 weeks during the spring semester. Three sixth-grade students and two seventh-grade students who were interested in learning about pollinators and designing an insect pollinator house participated in this program.

In this article, we describe how students generated their research questions about pollinator habitat, designed their own solitary bee house, and conducted a scientific investigation to answer their research questions about pollinator habits and habitat. Out of the 12 weeks of the program, the first four weeks focused on providing basic knowledge about native insect pollinators, their habits, and their habitat. The program team (a researcher, a bee expert, and a teacher) shared information about local pollinators, including how to identify them, their behavior and habitat, and their role in plant pollination. Students also learned about the impact of weather on the physiology and behavior of pollinators. (Additional resources related to bee pollinators and insect pollinator houses are listed in the Resources.) To address safety concerns, the teacher reviewed the guidelines shown in the sidebar on page 43. Students were also taught how to maintain journals and make daily observations of temperature, wind intensity, precipitation, and any pollinator sightings.

During the four weeks that followed, students collected observations in their science journal and prepared their research question with the help of an instructor. The teacher followed students' work closely and discussed each of the students' research questions in detail. As students refined their research questions, they also began to design their experiments and their solitary bee house. During this time, the teacher assessed students' ability to apply what that they had learned about pollinators to the design of their bee houses and to develop an inquiry-based investigation of pollinators. The design of the bee house was evaluated by the teacher using general criteria regarding the type of material used to construct the house, the amount of space available for the bees to lay eggs, and how easy it was to make observations. Students also evaluated their own design with a second, customized rubric based on their research question, which was also created by the teacher.

Finally, during the last four weeks of the program, students created and installed their bee houses, took outdoor field observations, collected data corresponding to their research questions, performed data analysis, and drew conclusions. The program concluded with students presenting their research findings to researchers, educators, native bee keepers, and other members of the community.

Phase 1 (two days/90 minutes per day): Generating a research question and a research plan

During phase 1, the program team helped students generate and refine their research questions by having them research the habits, behavior, and physiology of native solitary bees. With this information, students were able to identify the big ideas that interested them. For example: How can my garden attract diverse pollinators? How can we provide food sources for a variety of pollinators? The team then assisted students in refining their research questions. Students' initial research questions were not specific and hence not testable. For example, a student interested in attracting pollinators focused her question by asking, "What color house will attract more pollinators?" This question prompted her to collect information on colors visible to insect pollinators. She discovered that certain solitary bees can only see the blue and green colors. This allowed the student to refine her question even more: "Does a blue-colored solitary bee house attract more bees than one painted yellow?"

A specific and testable research question led students to develop a research plan. Most of our students were able to come up with a research plan, but some plans lacked details needed to conduct a robust investigation. For example, we asked a student, "What is your data collection plan?" The student said, "I think I need to check the house once every day to see if any bees occupy the house." However, upon discussing the importance of habitat and surrounding environment, the student modified his research plans to include observations about the flora and fauna in the location where the house was placed. Additionally, the student conducted a survey of the pollinators observed in the area surrounding the bee house. This exploratory data about the frequency of pollinator sightings, their habitat, and potential food sources was recorded in the student's science journal. Using these data, the teacher was able to critically assess the validity of the research question. Additionally, the student was able to assess the validity of his research question. He was able to determine which

Concerns for safety

This study does not require students to handle or trap bees in order to collect experimental data. All observations about the solitary bee house were made from a distance (1–2 m) to avoid disturbing the inhabitants. Students modified their designs to make this possible. Additional information on safety included:

1. Students should not to attempt to collect specimens of bees for identification or other purposes.
2. Student should know how to avoid outdoor hazards, such as stinging insects, poison ivy, and ticks, before venturing into the field.
3. To avoid attracting insects, students should
    - not wear perfumes, colognes, or use anything (such as lotions, shower gels, shampoos, hand washes, and so on) that have a strong scent;
    - avoid wearing brightly colored clothing to avoid attracting insects;
    - not eat any food while in the field to avoid attracting insects.

5. Students should wear appropriate clothing when in the field: closed-toed shoes, long pants, long-sleeved shirts, hats, and sunscreen.
6. Students with seasonal allergies or immune-suppression issues should consult a physician to determine the best course of action to avoid allergens and situations that might create a health issue.

(See Herndon 2017 for additional safety considerations.)

FIGURE 1: The eight science and engineering practices rubric

Performance for science and engineering practices	Exceeds expectations	Meets expectations	Does not meet expectations
Asking Questions (for science)	Questions are specific and testable. Questions are able to identify dependent and independent variables. They require evidence to answer.	Questions are testable and require evidence to answer. However, questions are too broad to be answered.	Questions are ambiguous, nontestable, and can be answered without generating evidence.
Defining Problems (for engineering)	The student conducts extensive research on the experiments and pollinator house design to come up with the best design for scientific experiments and pollinator houses. Intent for the design fully corresponds to the science investigation. The student is able to explain how the proposed design will address the needs of the scientific investigation. The student is able to fully articulate the requirements and constraints for their experiment and pollinator house design.	The research that the student has done only addresses either experiments or pollinator house design. Intent for the design partially corresponds to the science investigation. The student is able to partially articulate the requirements and constraints for their experiment and pollinator house design.	The student does not conduct research on both experiment and pollinator house design. Intent for the design does not correspond to the science investigation. Design is impractical. The student is not able to articulate the requirements and constraints for their experiment and pollinator house design.
Developing and Using Models (for science and engineering)	Models (3-D objects, drawings, or diagrams) created by the student are accurate and labeled, and the student is able to explain the system investigated, components of that system, and processes involved in the functioning of the system.	Accurate and labeled models are created and the student is able to moderately explain the system investigated using the model.	Models are constructed, but they are incomplete or are erroneous. The student is unable to explain the system investigated using the model.
Planning and Carrying Out Investigations (for science and engineering)	The investigation is planned with attention to details, variables are identified and explained, plans for collecting data on the identified variables exist, and data collected will provide ample evidence for the questions asked.	Planned and proposed investigation produces evidence but with minimal details, not all variables are identified, and minimum data are collected.	Planned and proposed investigation is unable to produce evidence for the question asked.

Analyzing and Interpreting Data (for science and engineering)	Data are analyzed using appropriate methods. There are no missing values and omissions. Student interprets data based on analysis.	Appropriate methods are employed for data analysis. There are missing data. Student interprets data partially based on data analysis.	The student doesn't use appropriate methods for data analysis. There are major errors and missing data in the analysis.
Using Mathematics and Computational Thinking (for science and engineering)	The student is able to accurately apply mathematical concepts (average, ratio, rate) to identify trends within the data and discuss them in context of the design solution.	The student is able to partially apply mathematical concepts (average, ratio, rate) to identify trends within the data and discuss them.	The student is not able to apply mathematical concepts (average, ratio, rate). The student is unable to identify trends.
Constructing Explanations (for science)	Explanations are based on the evidence supported by data analysis. The student is able to identify the limitation of the experiment and is able to give reasons and explain how to improve the experiment.	The explanations do not represent the complete information derived from data analysis. To a degree, students identify the limitation of the experiment but cannot provide a way to improve the experiment.	Explanations are insufficient and not supported by data analysis. The student cannot identify the limitation of the experiment.
Designing Solutions (for engineering)	The redesign of the prototype addresses the problems identified earlier and the rationale for redesign is provided. The rationale corresponds to and is supported with data from the science experiment.	The redesign of the prototype partially addresses the problems identified earlier. Rationale is provided but not corresponded and supported with data from the science experiment.	No rationale for redesign is provided.
Engaging in Argument from Evidence (for science)	The student articulates why the evidence is important and relevant. Student generates the claim and backs it up with evidence that can be confirmed with a logical argument.	The student can slightly articulate why the evidence is important and relevant. They are missing either explanation, data-based evidence, or the importance and relevance of the evidence. The student generates the claims that are partially backed up with a logical argument.	Arguments are not supported by data-based evidence and explanations are missing.
Obtaining, Evaluating, and Communicating Information (for science and engineering)	A variety of independent resources are selected. Resources are scientific, peer-reviewed, credible, and accurate. The student is able to present and answer questions to communicate the findings by designing a poster, 3-D objects, drawings, or diagrams.	Few independent resources are selected. Student doesn't evaluate the credibility and accuracy. To a degree, the student is able to answer questions to communicate the findings by designing a poster, 3-D objects, drawings, or diagrams.	The student does not provide information and is unable to answer questions to communicate the findings by designing a poster, 3-D objects, drawings, or diagrams.

data were accessible and which questions he could answer with the help of these data. This showed that the student's performance of planning and carrying out investigations moved from meeting expectations to exceeding expectations (Figure 1).

FIGURE 2: Types of solitary bee houses: From the left to the right, bundle of bamboo, wood block with grooves and an opaque cover (removed in photo), and an observation block with a clear plastic cover

PHOTOS COURTESY OF THE AUTHORS

Phase 2 (two days/90 minutes each): Connect the research question to engineering design

After students finalized their research questions and research plans, they moved on to the design of their solitary bee houses. The teacher shared with students a variety of designs for bee houses, such as a bundle of bamboo lengths, wood blocks, and observation blocks (Figure 2). Different designs serve different

FIGURE 3: Comparing features of different nest designs

	The bundle of bamboo	The wood block	The observation block	Comments
Type of pollinators that the houses may attract				
Easy to build				
Easy to find materials				
Easy to maintain and clean				
Type of location required for bee house				
Easy to make observations				
Cost				
Other				
What features can I use to design my insect pollinator house(s)?				

FIGURE 4: Example of a student's insect pollinator house

purposes and have their own advantages and disadvantages. For example, it is very easy to determine the number of occupants with the observation-block design that has a transparent cover, but this can be difficult using a bundle-of-bamboo design that requires students to peer into the darks tubes. The teacher asked students to observe different models of houses and compare their features on a worksheet (Figure 3). Using the examples that the teacher shared as inspiration, students designed a house that would help answer their scientific question. The designs included many of their own unique modifications, such as adding a clear acrylic panel to the back of a house to facilitate occupant viewing, and draping houses with acrylic viewing panels with a black cloth to keep the interior dark. Students drew sketches of their prototype house designs in the classroom.

The bee houses were constructed in a woodworking shop at a local university. All materials, equipment, and guidance for use of equipment were provided to students during the program at the school site. Students followed safety procedures (wearing safety glasses, checking for nails and metal objects before sawing and drilling, safe handling of non-power tools) while building the houses, per their woodworking instructor. Students were also encouraged to use recycled materials from home for their design. For example, instead of using a bundle of bamboo, students used rolls of newspaper to create tubes for a bee house.

In addition to the design and construction process, phase 2 also required students to justify the design of their houses based on their own research question. For example, the student with the research question, "Does a yellow-colored solitary bee house attract more bees than one painted blue?" selected the wood block house design. She provided the rationale that, "I want my houses to have surfaces that I can paint, because my research is about the color of the house. So, I chose wood block design" (Figure 4). She also wanted to be able to see through the holes to verify occupancy by an insect. Therefore, she adapted the concept of an observation block and added an acrylic glass sheet at the back of the wood block to enable her to observe the insects inhabiting the house. In another case, a student was interested in placing his bee house in between some flowering shrubs. He had identified this location as the food source of some bees. Because these shrubs were very small, the student opted to place his bee house on the ground. Inspired by a wood block design, the student designed a box with a window on top that had a removable cover. This allowed the occupants of the house to be observed without having to pick up the house.

Phase 3 (six weeks/determined by students' research design): Collect data and test and redesign the pollinator houses

During phase 3, students placed their houses and began collecting data. Originally, we planned for students to place their bee houses in the school

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standard

MS-LS2: Ecosystems: Interactions, Energy, and Dynamics
www.nextgenscience.org/dci-arrangement/ms-ls2-ecosystems-interactions-energy-and-dynamics

Performance Expectation

MS-LS2-5
Evaluate competing design solutions for maintaining biodiversity and ecosystem services
www.nextgenscience.org/pe/ms-ls2-5-ecosystems-interactions-energy-and-dynamics

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Planning and Carrying Out Investigations	Students design and refine an investigation about a pollinator and its habitat. Students collect data, including weather, habitat, frequency of pollinator sightings, and pollinator house occupancy.
Disciplinary Core Ideas	
LS2.C: Ecosystem Dynamics, Functioning, and Resilience • Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health. (MS-LS2-5)	Students incorporate knowledge of bee pollinator habitat when designing an investigation to determine if a pollinator house will attract occupants.
ETS1.B Developing Possible Solutions • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.	Students compare different pollinator nest designs to come up with an optimum design that can help them answer their research question.
Crosscutting Concept	
Patterns	Students were asked to look for patterns in their observations by answering the following questions: Did the data demonstrate that the pollinators were visiting the bee house once it was installed? Were the pollinators visiting the bee house, but not nesting?

garden. However, construction at our school over the summer created access problems, so our students placed their houses either in their own backyards or in a community garden. Teachers checked in with all students at the community garden once every week to answer queries and ensure that students followed their research plans for data collection. Students gathered information about weather, habitat, frequency of pollinator sightings, and house occupancy at three designated times every day for two weeks. During weekly meetings, teachers reviewed students' journals and discussed their observations about weather, frequency of pollinator sightings, and house occupancy.

Students graphed their data and were asked to look for patterns to determine the impact of house design on the rate of occupancy. For example, did the data indicate that bees were visiting the house? Were the bees visiting the house but not nesting? Students then tried to explain their findings. The student who wanted to find out the influence of the color of the house on occupancy, for example, reported that her house did not attract any pollinators. However, another bee house built by a family member demonstrated occupancy. This prompted the student to think about why pollinators colonized one house but ignored the other. She recorded, "The other house has multiple holes with various sizes and was put out much earlier [in the season] than mine. So, I will first change the size of holes in my bee house and put the house out earlier next season." We asked, "Will you change your research question?" She said, "No, because I have not yet answered my research question. It is a good research question. I just need to change the design of my houses first, and put them out earlier next season."

At the end of phase 3, the teacher hosted a showcase event for students to share their research findings with other students' families, friends, scientists, and community members. For their presentations, students decided to make posters with pictures of the bees, diagrams of the bee house designs, and maps showing the location of the bee houses. Each presentation lasted about 15 minutes, during which students discussed research questions, data collection methods, observations, challenges, and their plans for the next year. The positive reaction of the audience helped validate students' work and confirmed that they were making a positive contribution to their community.

Assessment and conclusion

Our objective was to integrate the process of engineering design with scientific inquiry. Students started this activity by creating a research question in the context of declining pollinator populations and the need for designing artificial habitats for pollinator species. The research question determined their design for constructing a bee house. Finally, students conducted their experiment and tested their design to generate their findings. Students collected observations every day for two to three weeks and were able to report on weather, habitat characteristics, frequency of bees visiting their houses, and the number of bees occupying their houses.

Figure 1 was used as an assessment between every phase, providing a rigorous review of students' understanding of the scientific inquiry and engineering design process, and insight into students' abilities to use the eight practices of science and engineering. This activity provides a unique opportunity to integrate scientific inquiry and engineering while engaging students in a hands-on activity that connects the classroom to the natural world. ●

REFERENCES

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NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Pollinator Health Task Force. 2015. National strategy to promote the health of honey bees and other pollinators. *www.whitehouse.gov/sites/default/files/microsites/ostp/Pollinator%20Health%20Strategy%202015.pdf.*

RESOURCES

Bumble Boosters: Bombicile project—*http://bumbleboosters.unl.edu/node/8*

Pollinator Partnership—*www.pollinator.org*

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