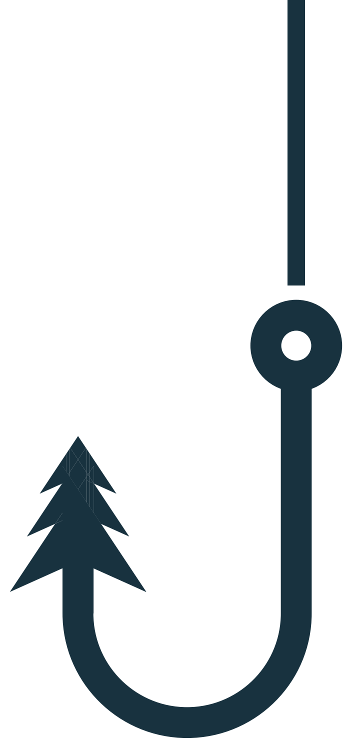


WHY DO FISHERMEN NEED FORESTS?

Developing a Project-Based Learning Unit With an Engaging Driving Question

BY TOM BIELIK, DANIEL DAMELIN, AND JOSEPH S. KRAJCIK

If teachers are to align their lessons with the goals of the *Next Generation Science Standards* (*NGSS*), they must reconsider their current instructional practices (NGSS Lead States 2013). Project-based learning (PBL) is one instructional approach to science learning that supports the NGSS and can help teachers shift toward three-dimensional learning goals. In *project-based learning*, students engage in relevant and meaningful learning experiences designed to solve a real-world problem. PBL classrooms have six key features (Krajcik and Shin 2014; Krajcik 2015). In these classrooms, students:

- **Meet important learning goals.** PBL learning tasks are structured to support students in meeting key learning goals, such as one or more performance expectations (PEs) identified in the *NGSS*.

- **Pursue a solution to a meaningful question to solve a problem.** Students engaging in PBL explain real-world phenomena or solve real-world problems. By doing so, students exercise the first *NGSS* scientific practice of asking questions to identify information needed to explain phenomena or solve a problem. Engaging students with a driving question and an anchoring phenomenon builds toward this goal. We elaborate on this feature in the next section of this article.

- **Explore phenomena using scientific practices.** To answer the driving question, students use a variety of scientific practices. Among these, Developing and Using Models has been shown to be valuable in providing students with the opportunity to explain and predict phenomena (Schwarz et al. 2009).

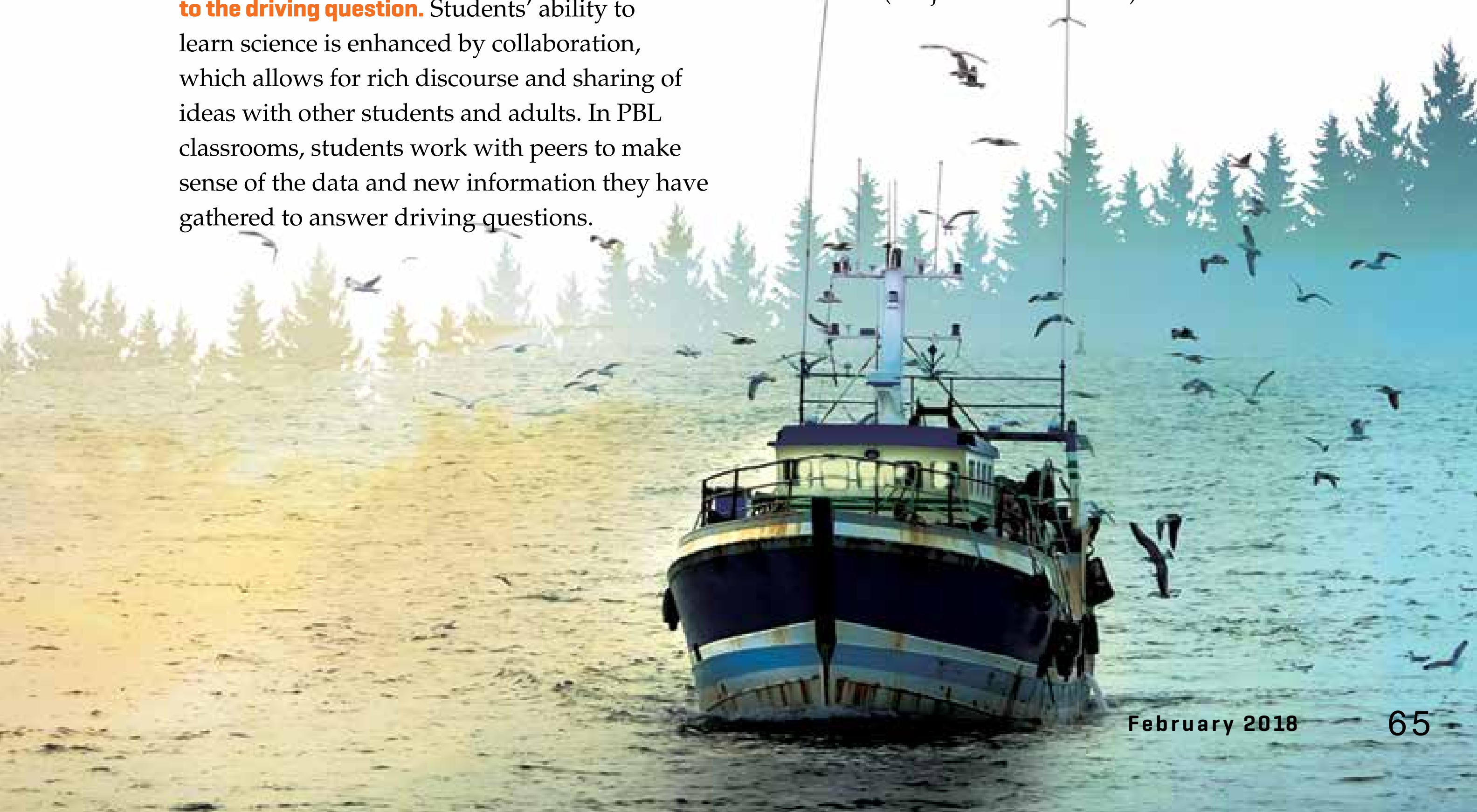
- **Engage in collaborative activities to find solutions to the driving question.** Students' ability to learn science is enhanced by collaboration, which allows for rich discourse and sharing of ideas with other students and adults. In PBL classrooms, students work with peers to make sense of the data and new information they have gathered to answer driving questions.

- **Use learning tools and other scaffolds to support students' learning.** Students use learning tools to assist them in obtaining, evaluating, and communicating information related to making sense of the phenomenon or problem. Technologically advanced learning tools can be used to provide instructional supports to students and increase students' interest, motivation, and engagement in science lessons.

- **Create artifacts (tangible products) that address the driving question.** Students use the three dimensions to create artifacts that address the driving question and represent their emerging understanding.

Why are driving questions and anchoring phenomena important?

Investigating a driving question is a crucial part of PBL. Classroom instruction is organized around the driving question, promoting student exploration of the phenomena and providing coherence across lessons. The driving question should be situated in a real-life context, providing students with an engaging motivator and increasing their interest to pursue a solution (Krajcik and Shin 2014).



A good driving question has several features. It should provide a sense of wonderment about why the phenomenon occurs. It should be feasible for students to plan and conduct investigations to answer the question, and in doing so, students should include important science ideas and build toward learning goals. The question should be contextualized with a real-world phenomenon to provide relevance for students. It should also sustain interest and engagement, so that students continue to pursue the solution. The driving question should not have a simple and straightforward answer, or students will not feel challenged enough and will not be interested in pursuing an in-depth investigation to answer it. The challenge is what helps promote wonderment. The driving question, however, should also not be too complicated or difficult to answer, or else students will think it is above their ability to answer. Finally, the driving question should be ethical, such that answering it is not dangerous or harmful to anyone or anything, including the environment. The anchoring phenomenon that accompanies the driving question provides the context from which the driving question emerges, and it can originate from a range of sources such as active demonstrations, videos, readings, or experiments (Krajcik and Shin 2014). The driving question and anchoring phenomenon also provide students with opportunities to ask their own questions, making the learning process more engaging and relevant for them (Weizman, Shwartz, and Fortus 2008).

How to design *NGSS*-aligned curricula with an engaging driving question

To demonstrate how PBL features can be integrated into a middle school curriculum, we discuss a unit developed by our research team. The unit development process followed the procedures elaborated on by Krajcik et al. (2014). The result, a three-week curricular unit focusing on the carbon cycle and ocean acidification, was implemented in a rural, Midwestern, public middle school during the 2015–2016 academic year.

The unit was designed to provide opportunities for students to construct, test, revise, and share models using a newly developed online modeling tool, SageModeler (see Resources). This tool was designed to enable students to build models and run simulations to answer driving questions while focusing on systems thinking (Damelin et al. 2017).

Identify and unpack the desired performance expectation

When designing an *NGSS*-aligned unit, it is important to identify and clarify the relevant PEs by unpacking the three dimensions in an iterative process. The initial step is to identify the desired PE. In this example, the unit was designed to last two to three weeks. Therefore, one PE was chosen: “MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem” (NGSS Lead States 2013). The unit focused on ocean acidification, as this topic holds opportunities for students to learn about meaningful issues such as CO_2 transfer between Earth’s spheres, environmental issues, and human involvement and its impact on the environment. Because the unit was designed to last two weeks, it focused on the flow of matter (carbon) between Earth’s spheres and did not include the cycling and flow of energy part of the PE (see Resources for draft materials for this unit).

Unpacking the PE required examining the grade band endpoint, elaborating on major ideas, defining boundary conditions, describing required prior

knowledge, and examining possible student challenges for each dimension. Major ideas of this PE include understanding the cycle of matter in ecosystems and that food webs are models that demonstrate how matter transfers between organisms in a system. By the end of grade 8, students are expected to know that an organism's survival depends on its interactions with living and nonliving factors in its environment. The assessment boundary for this PE, however, suggests that an understanding of matter transfer does not extend beyond understanding macroscopic interactions, and should not require using chemical reactions to describe the processes relevant to the investigated system. Prior knowledge included understanding photosynthesis, the particle nature of matter, and knowledge about ecosystems, food webs, and biodiversity. Several possible challenges were identified for each dimension. For example, students might not understand that CO_2 can naturally transfer between the atmosphere and the hydrosphere or the time scale for investigating the effect of changing ocean acidity.

Developing a driving question and identifying an anchoring phenomenon

Following the unpacking of the PE, we identified and developed a driving question and anchoring phenomenon for the unit. Formulating a good driving question is challenging and requires several meetings with teachers, students, and educational researchers. We chose "Why do fishermen need forests?" as the driving question for the unit. We chose this driving question because there is no simple or straightforward answer to it. To answer the question, students can construct several different models to explain their response, which should engage them in communicating, sharing, and critiquing each other's ideas. To fully answer this driving question, students must construct and revise a model of the carbon cycle that includes carbon absorption by plants, CO_2 emissions by factories and industries, CO_2 transfer between the air and the ocean, and carbon uptake by calcifying marine animals.

The anchoring phenomenon for the unit was the decreasing availability of oysters and lobsters in recent years, as described by fishermen in two short videos that are shown to students at the beginning of the unit. The videos are paused just before they present the concept of ocean acidification, so that the answer is not provided to students.

The teacher and students discuss why the decline of oysters and lobsters is an important problem. At the end of the unit, students view the entire videos after investigating the phenomenon themselves and learning about ocean acidification. Interviews with students and classroom observations indicated that students found the anchoring phenomenon relevant, because many of these students ate seafood or had relatives in the fishery industry.

Planning collaborative investigations to answer the driving question

After developing the driving question and identifying the anchoring phenomenon, the unit's sequence, lesson plans, and teacher and student materials were created. In designing the lessons for the unit, we carefully constructed learning goals that incorporated the three dimensions of the *NGSS* and build toward an understanding of the chosen PE. Although this part of the unit development process is not elaborated on in this article, we present and discuss three examples of tasks that were designed and incorporated into the unit. These tasks demonstrate how the investigations in the unit, carried out by students,

supported them in using evidence-based explanations to determine responses to the driving question. The unit's sequence of experiences provides students an opportunity to progress in their ability to create evidence-based explanations, continuously use this knowledge to further develop and revise their models, and build a complete and coherent answer to the driving question. For each activity, we provide information regarding the activity type, classroom setting, estimated time, and required equipment. Specific directions for each of the activities are provided in the ocean acidification unit link below.

Example task 1: How can CO_2 in the air transfer to water?

Activity type and classroom setting: Whole-class demonstration, small-group investigation, individual computer task

Learning goal: Students construct a model to explain how CO_2 from the air can transfer to water.

Brief description: Students observe how creating a CO_2-rich atmosphere above water containing a pH indicator will cause the water to change color as the CO_2 in the atmosphere transfers to the water below.

Estimated time: 2 hours

Required equipment: Computers with internet access, pH indicator, test tubes, baking soda, vinegar, straws, bicycle pump, rubber tubes, sparkling water

Safety information: Students must wear goggles and immediately inform their teacher of any spills. Students should not conduct the experiment near computers or other electrical equipment.

At the onset of the unit, students were asked to consider the possible involvement of CO_2 in the phenomenon of decreasing fishery catch. After seeing a teacher demonstration of how pH indicators work and how, when CO_2 is dissolved in water, the gas makes the water more acidic, students performed example task 1 to examine whether CO_2 can transfer into water just by being in the air above the water. Following this, students performed an investigation to examine whether CO_2 in the air can transfer into water. In this investigation, students mixed baking soda with vinegar in a test tube to produce CO_2. The CO_2 transferred through a rubber tube to a second test tube containing water and a pH indicator. Students observed the gradual change in acidity in the second test tube's water and discussed the diffusion of CO_2 between the air and the water.

Following this investigation, students started constructing their models, using the modeling tool, to answer the driving question, "Why do fishermen need forests?" In the following lessons of the unit, students continued to develop and revise their models, adding more variables as needed. The process of developing and revising the models continued as students collaborated with peers and the teacher by sharing and evaluating their models.

Example task 2: What do scientific data show us about the acidification of oceans?

Activity type and classroom setting: Individual computer task

Learning goal: Students analyze and interpret data to provide evidence for the relationship between atmospheric and oceanic CO_2 levels and the ocean's acidity level.

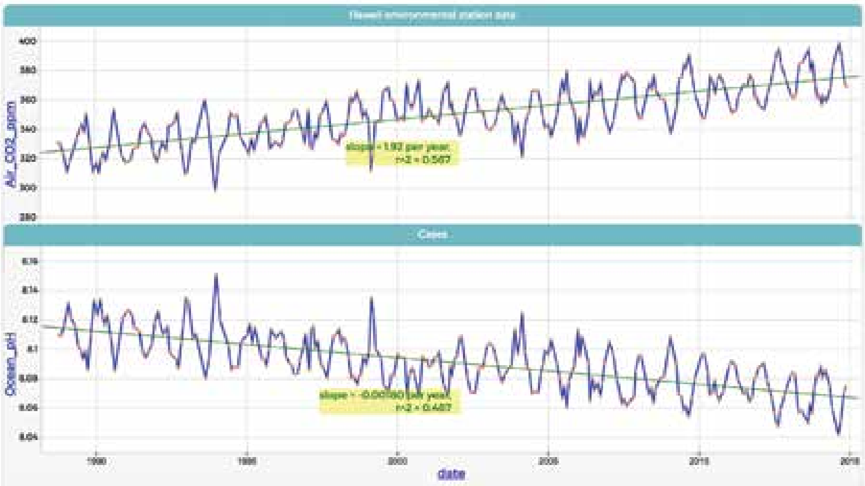
Brief description: Students use real-world data collected by the National Oceanic and Atmospheric Association to explore possible relationships between CO_2 in the air and ocean and how those relationships are related to ocean pH.

Estimated time: 40 minutes

Required equipment: Computers with internet access, Hawaii environmental research data set (see Resources)

An important feature of the SageModeler modeling tool is that it provides students with opportunities to use scientific data sets to test their models. A tutorial video for using SageModeler is provided within the software. This allows students to engage in authentic science and develop an appreciation and understanding of the scientific process. In the ocean acidification unit, a large data set of oceanic and atmospheric CO_2 concentrations and pH levels was integrated into the tool as a numeric chart. Environmental researchers in Hawaii collected these data over several years, indicating the gradual and steady increase in CO_2 concentrations and the sea's decreasing pH level (see Resources). Students used these data to create graphs and compared them to graphs of data generated by their models. This feedback on the behavior of their model could then be used to revise the models to better match real-world phenomena. Using scientific data allows students to observe that data is often messy and confusing; however, patterns and trends can still be clearly seen. In the Hawaii environmental station data, patterns such as periodic seasonal increase and decrease of atmospheric CO_2 (caused by plants' increased CO_2 uptake during spring and summer), events of CO_2 changes, and an overall trend of rising CO_2 concentration throughout the years could be found by graphing the real-world data. Figure 1 provides an illustration of the Hawaii station data graphs that students can produce.

FIGURE 1: Example of possible student-created graphs using the Hawaii environmental station data



Example task 3: How does ocean acidification affect marine species?

Activity type and classroom setting: Small-group, online investigation

Learning goal: Students perform an investigation to determine possible effects of ocean acidification on marine organisms.

Brief description: Students research how a change in pH affects various species.

Estimated time: 1 hour

FIGURE 2: Example of a student activity sheet for investigating the possible effect of ocean acidification on marine species

Pteropods (sea snails)

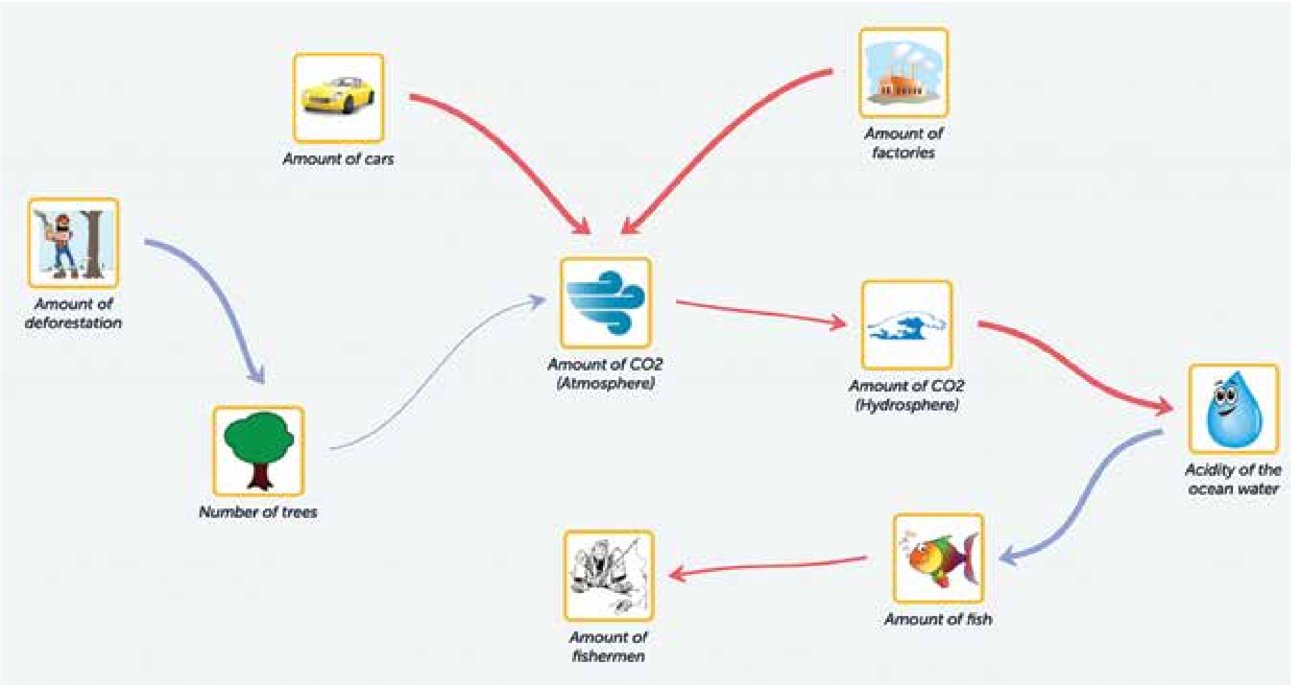
NOAA

This is a pteropod, also known as "sea butterfly." It is a tiny snail that serves as a basic food source for many ocean species, ranging from tiny krill to whales.

In this activity, you will search for information about pteropods and answer several questions based on the information you find. Following this, you will present your discoveries to the rest of the class.

1. Describe pteropods in your own words. Discuss their structure, what they do, and where they can be found.
2. Describe some of the other species that depend on pteropods. What would happen to these species if there were changes in the pteropod population?
3. Can you find information about the effect of ocean acidification on the pteropod population? What do the data indicate? How can you explain this?
4. Cite the data sources on which you have based your answers.

FIGURE 3: Example of a student's final model for the driving question "Why do fishermen need forests?" using SageModeler (red arrows represent increasing effect; blue arrows represent decreasing effect; width of arrows represent the degree of effect)



Required equipment: Computers with internet access, group activity sheets (see Resources for a link to the ocean acidification unit)

During the last part of the unit, students conducted an online inquiry investigation that involved gathering information about the possible effects of ocean acidification on populations of marine species, such as phytoplankton, corals, sea snails, and oysters. Students collected data on the food webs that each species is part of, examined data on possible damage to the species due to ocean acidification, and studied how these interactions may affect human behavior. One of the tasks included an example of marine species that may benefit from the increasing CO_2 levels (seaweeds), which can promote a more engaging debate among students. The investigation was done in small groups, and students were guided by basic information about each marine species and questions they would explore and discuss by performing an online inquiry (see Figure 2 for an example of one activity sheet).

The teacher supported students during the activity, directing them to appropriate websites and information sources and encouraging them to consider various issues involved in the ecosystem, such as biodiversity and human impacts related to the species under study and its food web. Upon completion of the activity, each group presented its findings to the rest of the class and shared and discussed ideas about the possible consequences of continued ocean acidification. After this, students revised their models once again to include the possible effects of ocean acidification on marine species, biodiversity, and fishermen. At this point, the models should be usable to answer the driving question that included variables linking forests to fishermen. Figure 3 provides an example of a student's final model of the ocean acidification unit.

These examples demonstrate how the tasks in the ocean acidification unit progress to provide students with opportunities to investigate and create responses to the driving question using their newly acquired knowledge. Having done so, students build their ability to meet and understand the desired PE by investigating the cycling of CO_2 and focusing on marine ecosystems affected by ocean acidification.

Conclusion

This article describes the features of PBL and focuses on the important role that a meaningful driving question and engaging anchoring phenomenon play in promoting students' learning, eliciting a sense of wonderment, and providing coherence to the curricular unit. Choosing a driving question for the unit is not trivial. It should inspire student curiosity and be feasible, worthwhile, sustainable, contextualized, and ethical. Alongside the driving question, the anchoring phenomenon should provide students with a relevant context and an engaging real-life experience to help them see the value of the driving question. The experiences of students as they investigate the driving question should build toward the three-dimensional learning goals of the unit.

PBL units drive student learning by guiding students to answer important questions, such as the driving question discussed here, helping them build usable knowledge of the three-dimensional components of the PE. Teachers and practitioners can benefit from these curriculum design ideas by considering a driving question to develop science lessons and designing curricular materials that are coherent, engaging, and support student exploration of phenomena. ●

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RESOURCES

Hawaii CO2 concentration and pH level data—*http://hahana.soest.hawaii.edu/hot/products/products.html*

SageModeler curricular units, including ocean acidification unit—*https://learn.concord.org/building-models*

SageModeler software—*https://concord.org/sagemodeler*

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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 expectation listed below.

Standard

MS-LS2-3 Ecosystems: Interactions, Energy, and Dynamics
www.nextgenscience.org/pe/ms-ls2-3-ecosystems-interactions-energy-and-dynamics

Performance Expectation

MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Developing and Using Models	Students construct, revise, use, and share models to explain the flow of CO_2 between Earth's spheres and the possible effect of Ocean Acidification on marine biodiversity.
Disciplinary Core Idea	
LS2.B: Cycle of matter and energy transfer in ecosystems • Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem.	Students investigate how transfer of CO_2 to the oceans can cause Ocean Acidification, which may endanger calcifying marine species and affect many food webs and the biodiversity of marine ecosystems.
Crosscutting Concept	
Energy and Matter	Students explore how changing the balance of the natural occurring Carbon cycle can have environmental effect that may damage food webs in marine ecosystems.