“Learning to explain phenomena and solve problems is the central reason students engage in the three dimensions of the NGSS.”

Why use a Driving Question Board?

• Keeps the focus on figuring out phenomena
• Reflects the curiosity inherent in authentic scientific inquiry
• Invites and organizes students’ ideas and questions
• Reminds the teacher to connect activities to questions about the phenomena
• Makes learning more meaningful
Carbon TIME Plants unit

How do plants grow, move, and function?

Our Ideas
- Plants breathe in CO₂ and out O₂.
- Pigments absorb sunlight energy for the plant to use.
- Plants need water, sun, and air to grow.
- Plants need water & nutrients from the soil to grow.
- Leaves have tiny mouths (stomata) for breathing & veins for moving water and nutrients.
- Plant cells have cell walls.

Our Questions
- How does air help a plant grow?
- What do plants use water for?
- What happens to plants in the dark?
- How do plants use CO₂ to grow?
- Do plants perform cellular respiration (like animals)?
- What is photosynthesis?
- How do plants convert light energy into chemical energy?

What We Figured Out
- Plants take in CO₂ in the light & give off CO₂ in the dark.
- Photosynthesis converts carbon dioxide and water into glucose and oxygen.
- Plants use the chemical energy stored in glucose from photosynthesis to get energy through the process of cellular respiration.
- Cellular respiration converts glucose and oxygen into carbon dioxide and water.
- The chemical reactions of cellular respiration and photosynthesis are the reverse of each other.
Driving Question Board (DQB)

What is it?

A driving question board (DQB) is a large bulletin board dedicated for students to write and discuss their initial ideas and questions about the phenomenon.

- First, a driving question is presented or developed as a class based on a phenomenon related to the unit.
- Students will post ideas and questions using sticky notes or index cards. Each activity in the unit should be connected to the ideas and questions on the board.
- The activities’ investigations will generate new questions, evidence, short summaries, and/or key learning that is added to the board. In the end students connect all the pieces to solve the overall question for the unit.

Why?

- Opportunity for students to feel invested in their own learning.
- Makes the lessons in the unit accessible for all academic levels of students.
- Demonstrates that questions are important for learning.
- Questions drive the learning! Students often are hesitant to ask questions in case they are perceived as unintelligent. DQB’s dispel that myth.
- Helps to organize the unit and keep the lessons connected and focused on the phenomenon.
- Promotes authentic assessment and serves as formative assessment throughout the unit.

Learn More

Enhancing Science Kits with the Driving Question Board article from NSTA’s Science & Children, 2012

What is the Driving Question Board in IQWST? Video from ActivateLearning

Using a Driving Question Board to Figure out Phenomenon by Wendy R. Johnson PhD

Search Driving Question Boards on Twitter and Instagram for real classroom pictures (and add your own. Use #DQB or #DrivingQuestionBoard.)
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 CO₂ 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 CO₂ 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, CO₂ emissions by factories and industries, CO₂ 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.
Adding a visual reminder to enhance a project-based-learning unit

ISRAEL TOUITOU, STEPHEN BARRY, TOM BIELIK, BARBARA SCHNEIDER, AND JOSEPH KRAJCIK

Project-based learning (PBL) is an instructional approach to science teaching that supports the Next Generation Science Standards (Krajcik 2015; NGSS Lead States 2013). In a PBL lesson, students design and solve real-world problems or explain scientific phenomena. Students using a PBL model learn and retain more than those not using PBL (Krajcik and Shin 2014). PBL classrooms have six key features:

- aligning with measurable learning goals,
- focusing on finding solutions to meaningful questions or problems,
- exploring phenomena using science practices,
- engaging in collaborative activities to find solutions to the driving question,
- using learning tools and other scaffolds to support students’ learning, and
- creating tangible artifacts that address the driving question.
At the core of PBL is the open-ended driving question. The driving question guides all learning tasks inside and outside the classroom, supports and inspires students’ curiosity while learning more about the phenomena being explored, and culminates in the creation of a final artifact.

An anchoring phenomenon gives context to the driving question. The driving question and anchoring phenomenon also provide students with opportunities to ask their own questions—which makes the learning process more engaging and relevant for the students (Weizman, Shwartz, and Fortus 2008).

Driving questions can be integrated into the curricular materials at different levels. For example, a broad driving question can provide the stable core investigation for a whole unit. Alternatively, a driving question can either span several days of explorations or merely provide a foundation for a single lesson, such as in a less complex, very specific investigation with a narrow focus.

The driving question board
The driving question board (DQB) serves as a visual organizer for PBL units (Weizman, Schwartz, and Fortus 2008). Teachers use the DQB to display the driving question to remind students of the goal of the unit’s investigations. Students write their own questions and comments about the driving question, the phenomena, or anything that arises from subsequent investigations on the DQB. Using sticky notes for this means students’ questions, categories, and groupings can be easily added, revised, or moved as more information is acquired during the unit.

Investigations are then completed to give students the experiential data and evidence needed to answer their questions, draw preliminary conclusions, and synthesize enough information to move closer to answering the driving question.

The activity summary board
This article introduces an additional tool, the activity summary board (ASB) (Figure 1). The ASB is a classroom organizational tool that summarizes what students do and figure out in the classroom as they take on the role of scientist or engineer to make sense of the phenomenon or problem. The ASB augments the DQB: Student questions that have been investigated and answered are physically removed from the DQB and then placed on the “Question” side of the ASB (Figure 1). Thus, the ASB provides a visual representation of the students’ progress in making sense of the phenomenon.

FIGURE 1
The unit moves from (left to right) the driving question board (DQB) through unit investigations to the activity summary board (ASB).

FIGURE 2
Question formulation technique
(Adapted from Rothstein and Santana 2014).

Part 1:
- Ask as many questions as you can.
- Don’t stop to judge, discuss, or answer any questions.
- Write down every question exactly as stated.
- Change any statements into questions.

Part 2:
- Categorize questions.
- Prioritize questions.
- Reflect.
Sample physics unit
A two-week physics unit in a classroom of one of the authors illustrates use of the DQB and the ASB. The unit focused on studying and explaining electric motors and was co-developed by science education researchers and physics teachers collaborating as part of an NSF-funded project. The aim of the project was to investigate optimal learning moments in a science class using PBL-based, NGSS-aligned curriculum units while measuring:

- student engagement and other affective states, and
- student learning during classroom instruction (Schneider et al. 2016)

Introducing the driving question
The unit began with the teacher introducing phenomena related to electric cars. Students were shown two short videos of engineers discussing the advantages and disadvantages of electric car technology (see “On the web”).

Then, in a classroom discussion, students debated whether electric cars would become common during their lifetimes. Students discussed current models of electric cars and brought up barriers to consumer adoption of the technology, including initial expense, limited range of the vehicles before battery recharging is needed, and the time needed for recharging.

Students agreed that the driving range between charges would have to be increased if electric cars were to ever replace cars with internal combustion engines. The teacher then guided the discussion to how scientists and engineers might overcome such challenges. This eventually led to the teacher writing the driving question for the unit on the board: “How can I make the ‘best’ (most efficient) electric motor?”

Developing the driving question board
Once the unit’s driving question was established, students experimented in groups of three or four with small DC toy motors to help them develop their initial questions and ideas. Students connected a toy electric motor to a battery and tried to pick up various loads of paper clips attached to a string wound around the shaft of the motor.

During the experiment, students made observations and asked their peers and teacher about the operation of their toy motor using a “question formulation technique” (Figure 2 and student handout under “On the web”). Students’ questions included: “Why does the motor get warm?” “Is there a maximum number of paper clips the motor can lift?” and “Why is the paper clip attracted to the motor casing?” The teacher did not evaluate the questions at this stage, only reminded students to think about the driving question: “How can I make the ‘best’ (most efficient) electric motor?”

To get students to ask questions more closely addressing the driving question, the teacher provided the following guiding questions: “What do you know about motors?” and “What do you need to know about motors to answer the driving question?” The student groups worked to form as many questions about the phenomenon and driving question as possible. Later, some of these questions were answered through student investigations, which helped them develop an answer to the unit’s driving question.

The teacher asked the groups to place their top four questions on individual sticky notes that could be added to the DQB along with the driving question. As the groups shared their top questions with the class, the teacher asked them to propose categories for their questions. For example, a group that asked, “How do you measure efficiency?” proposed placing this question under a category titled “Efficiency.” Another group suggested the category “Energy” for one of their questions: “How does electricity make the car move?” Another group asked “How can we reduce friction in the car?” and suggested this be placed in the “Efficiency” category, explaining that reducing friction would help improve overall efficiency. The discussion on which category to place each question also helped other groups better understand what was meant by “efficiency.” The students placed their questions on sticky notes on the DQB sorted into the categories they created.

Using the driving question board
Once the teacher and students had co-created the DQB, the questions helped guide instruction throughout the unit. Important questions that did not initially appear on the DQB were added later as the unit progressed, based on guidance from the teacher and as students’ activities changed their thinking. Students thereby revised their initial impressions on their own, rather than having a concept introduced by the teacher before any hands-on exploration.

For example, students needed to discuss magnets, coils, and wires to answer the driving question, even though specific questions related to those topics did not at first appear on the DQB. The teacher placed a more general question on the DQB: “What’s inside an electric motor?” This led students to think about the inner workings of an electric motor and to ask: “Why is there so much wire in a motor?”
Questions that arose during students’ investigations were added to the DQB, which in turn led to further investigation. This process of figuring out, or sense making, is quintessential to PBL in the classroom. Promoting this type of student autonomy by asking and investigating student questions can increase overall engagement and create an atmosphere in which students actively participate in the lessons.

**Transitioning to the activity summary board**

Refining the questions on the DQB advanced the unit and encouraged students to move toward an explanatory model to investigate and respond to the driving question. To track their progress, the teacher moved the sticky notes with students’ questions to the ASB and listed the particular investigation the class performed to help answer each question. Also written on the ASB was a summary of the big ideas or takeaways that students discovered in their investigations, as well as several student-drawn models (Figure 3).

This growing body of knowledge on the ASB helped to engage students with the material. Students realized the importance of exploring their questions to generate the big ideas needed to address the driving question. Figure 4 (p. 34) shows an example of an ASB taken from the unit on electric motors.

At the end of the unit, students were able to use the acquired knowledge and practices to answer the driving question: “How can I make the “best” (most efficient) electric motor?” Students created a detailed model of the energy flow in the motor and used that to change their motor design to increase efficiency. The detailed model as well as the revised motor design served as the unit’s tangible product and was used for formative assessment of students’ learning.

**PBL helps educators engage students in science and engineering practices, integrating disciplinary core ideas and crosscutting concepts to solve real-world problems and make sense of phenomena.**

**Benefits of PBL**

PBL helps educators engage students in science and engineering practices, integrating disciplinary core ideas and crosscutting concepts to solve real-world problems and make sense of phenomena. Using one of the key features of PBL—the driving question—along with the driving question board and activity summary board, the teacher can scaffold subsequent investigations using a visual reminder of the unit’s goal and progress made over several lessons.

Moving students’ questions from the DQB to the ASB tracks students’ learning throughout the unit, giving them a sense of ownership of the figuring-out process at the core of PBL and inquiry-based science.

**ON THE WEB**

Student handout: www.nsta.org/highschool/connections.aspx

Videos on electric car technology: www.youtube.com/watch?v=QVgBESEIpJ, www.youtube.com/watch?v=PvtnrYODISw

**REFERENCES**

FIGURE 4

The activity summary board (ASB).

<table>
<thead>
<tr>
<th>Student question</th>
<th>Classroom activity/investigation</th>
<th>Big ideas from the activity/investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is inside of an electric motor?</td>
<td>Take apart a toy motor.</td>
<td>Components include magnets, coil of wire, metal plates, axle, and power supply.</td>
</tr>
<tr>
<td>How does a motor work?</td>
<td>Build a simple homopolar motor.</td>
<td>Electromagnetism—something happens when electric current goes through a coil of wire.</td>
</tr>
<tr>
<td>Why is there so much wire in the toy motor?</td>
<td>Explore the magnetic fields around a coil of wire.</td>
<td>Electricity flowing through a coil of wire creates a magnetic field.</td>
</tr>
<tr>
<td>Why is the wire used in the toy motor so thin?</td>
<td>Interaction between a coil of wire and stationary magnet mounted on a toy car.</td>
<td>More loops in the coil of wire creates a stronger field. Change the polarity of the coil by changing the direction of electron flow.</td>
</tr>
<tr>
<td>How do electromagnets create movement?</td>
<td>Build models of the interaction of magnetic fields between coil of wire and stationary magnets.</td>
<td>Interaction between the magnetic fields will allow the coil to rotate. The more loops in the coil, the stronger the magnet.</td>
</tr>
<tr>
<td>What factors affect a motor’s efficiency?</td>
<td>Measuring energy inputs and outputs of a system.</td>
<td>% efficiency = useful output/total input x100</td>
</tr>
<tr>
<td>How could I reduce friction?</td>
<td>Build an electric motor.</td>
<td>Some motors work better than others. Why?</td>
</tr>
<tr>
<td>Why did the motor get hot?</td>
<td>Build explanatory models to make predictions.</td>
<td>Models can be used to help explain phenomena.</td>
</tr>
</tbody>
</table>


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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 expectations listed below.

### Standards

**HS-PS2 Motion and Stability: Forces and Interactions**

**HS-PS3 Energy**

### Performance Expectations

**HS-PS2-5.** Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

**HS-PS3-1.** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

**HS-PS3-3.** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

### DIMENSIONS CLASSROOM CONNECTIONS

<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>CLASSROOM CONNECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning and Carrying Out Investigations</strong></td>
<td>Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.</td>
</tr>
<tr>
<td>Students carry out investigations to determine the cause-effect relationship between a coil of wire and stationary magnets.</td>
<td></td>
</tr>
</tbody>
</table>

| **Using Mathematics and Computational Thinking** | Create a computational model or simulation of a phenomenon, designed device, process, or system. |
| Students use formulas for potential energy and kinetic energy and work to create a formula to measure efficiency of their motor. This calculation is entered into a spreadsheet so that they can easily explore the efficiency of many motors built in class. |

| **Constructing Explanations and Designing Solutions** | Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. |
| Students complete investigations to develop an understanding of how a motor works. They use this understanding to design and build an electric motor and compare its efficiency to the motors their classmates build. |

### Disciplinary Core Ideas

**PS2.B: Types of Interactions**

Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

Students explore the interaction between magnets and an electric field to construct an explanation of how an electric motor works.

**PS3.B: Conservation of Energy and Energy Transfer**

Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

Students use the idea of conservation of energy so that they can create a mathematical model of the efficiency of the motor that they build.

### Crosscutting Concept

**Energy and Matter**

Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Students use the idea of energy flow to model the energy flow into the motor, within the motor, and out of the motor to understand what efficiency is and how it can be improved.