There I was, standing in the middle of my lab room while students were quietly toiling away at their stations. It was my third year of teaching, and I was at the top of my game. I knew it all, able to answer any question asked by a parent, student, teacher, or even an administrator. I was a great teacher! After all, my kids were quietly working in the lab—painstakingly following my every instruction without a word of discussion. But as my chest swelled with pride, I had an “aha” moment of concern.

I realized why my students were so silent. They weren’t learning a thing, other than how to mindlessly follow directions. Mine was more of an assembly line than a science classroom. Today, three years later, my students have become more inquisitive as I take us deeper into the Next Generation Science Standards (NGSS Lead States 2013).

A new way of teaching science

The NGSS were developed by teachers, scientists, and leaders in science and science education from around the country and are endorsed by the National Science Teachers Association (NSTA), a partner in the development of the NGSS. The hardest part of incorporating them into your classroom is simply getting started. Making sense of the NGSS can be difficult at first, but with practice and a few pointers, you’ll find these standards immensely helpful. Extensive resources for navigating the NGSS, including readers’ guides and archived web seminars, can be found at a special NSTA website (see “On the web”). This article should help, too, offering an example of how to modify a lab to align with the NGSS.

It was during a lab exploring the laws of thermodynamics that I realized that my students weren’t performing an inquiry but only following directions. They were told to use our Styrofoam cup calorimeter sets to collect data that would allow them to calculate the transfer of thermal energy of a system after a heated piece of metal had been put into cool water. When they finished collecting data, the students were instructed to solve for the heat energy using \( Q = mc\Delta T \) (heat equals mass \( m \) \times specific heat capacity \( c \) \times temperature change). Nearly every student came up with a reasonable answer but was tight lipped when it was time for follow-up discussion. They had completed the task without comprehending the “what” and “why” of the science content and processes.

To address this embarrassing classroom situation, it was time to start implementing the NGSS with its various performance expectations, scientific and engineering practices, disciplinary core ideas, and crosscutting concepts.
NGSS and Common Core State Standards connections.

Next Generation Science Standards: HS-PS3

Energy performance expectation

HS-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Science and engineering practices
Planning and Carrying Out Investigations: Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence; 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. (HS-PS3-4)

Disciplinary core ideas

PS3.B: Conservation of Energy and Energy Transfer: Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4)

Crosscutting concepts

Systems and System Models: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)

Common Core State Standards

WHST.9-12.7 Reason abstractly and quantitatively. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-4)

MP.2 Reason abstractly and quantitatively. (HS-PS3-4)

and MP.4 Model with mathematics. (HS-PS3-4)

Performance expectations

The first step to understanding the NGSS is to look at how the standards are organized. Consider, for example, HS-PS3: Energy. Within it are several performance expectations, including HS-PS3-4, which proposes that students who demonstrate understanding can “Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics)” (Figure 1). My original investigation did an excellent job of demonstrating the second law of thermodynamics (the entropy of an isolated system never decreases), but that’s all it did. By creating a performance expectation (PE) that explicitly uses the verbs “plan and conduct,” the NGSS have transferred the action from the teacher to the student, while also connecting this PE to an essential scientific and engineering practice: Planning and Carrying Out Investigations. After exploring these standards, it was clear that my curriculum and lesson plans needed an overhaul.

Overhauling the curriculum

I teamed up with a science professor at a local college to transition my curriculum to incorporate an interactive and student-centered approach. Previously, my classroom activities and teaching revolved around lesson plans and units of study, which mostly followed book chapters. Under the NGSS, I view these same activities and teaching methods as mini-units. The focus has turned from the small details of a lesson to the overall idea the lesson is trying to impart, what the NGSS refer to as disciplinary core ideas and crosscutting concepts. These mini-units are implemented over a longer period than typical lessons and try to create a deeper understanding for students. This is accomplished by emphasizing one of the three dimensions of the NGSS: scientific and engineering practices.

The mini-units allow the disciplinary core ideas to be integrated and the crosscutting concepts to be contextualized as students engage in authentic scientific practices and ultimately prepare to meet the performance expectation. For example, when students plan and carry out an experiment with multiple variables, they learn to identify system boundaries, inputs, and outputs. When an evidence-based conclusion is written based upon student-centered data collected from their own investigations, students can uncover the overarching crosscutting concepts related to the disciplinary core ideas. They also engage in the scientific practice of Obtaining, Evaluating, and Communicating Information.

Each mini-unit is ultimately based on a performance expectation and includes a number of different lessons that incorporate the 5E model, because the implementation and learning of all aspects of the NGSS—or even a single performance expectation—often cannot be accomplished in a sin-
FIGURE 2

Does your lesson align with the NGSS?

<table>
<thead>
<tr>
<th>Question to ask</th>
<th>Yes</th>
<th>No</th>
<th>If no, what can be changed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the activity engage students in at least one of the eight scientific and engineering practices of the NGSS? 1. Asking questions (for science) and defining problems (for engineering) 2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Constructing explanations (for science) and designing solutions (for engineering) 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information</td>
<td></td>
<td></td>
<td>Recast the lesson to use one or more of these practices.</td>
</tr>
<tr>
<td>Does the final goal of the lesson reflect a performance expectation?</td>
<td></td>
<td></td>
<td>Rewrite the directions so that students plan an investigation and produce and create something.</td>
</tr>
<tr>
<td>Does the developmental sequence of activities reflect the performance expectation?</td>
<td></td>
<td></td>
<td>Reorder existing activities so that students can develop performances and skills in a logical manner.</td>
</tr>
<tr>
<td>Is understanding a disciplinary core idea achieved in the lesson?</td>
<td></td>
<td></td>
<td>Place the disciplinary core idea in the activities’ “explain” step.</td>
</tr>
<tr>
<td>Does the lesson relate a disciplinary core idea to one or more crosscutting concepts?</td>
<td></td>
<td></td>
<td>Develop a checklist or two-column graphic organizer to align crosscutting concepts with a disciplinary core idea.</td>
</tr>
<tr>
<td>Do the students determine what procedures to use?</td>
<td></td>
<td></td>
<td>Modify existing directions to be more student-centered.</td>
</tr>
</tbody>
</table>

Single activity. Similar to the process described by Bybee (2013), we implemented the 5E model over the course of an entire mini-unit rather than a single lesson.

For example, mini-units can include a lesson that engages a student and another lesson that may separately allow the student to explore the topic. By extending the 5E model across a mini-unit, students are presented with a more intriguing and cohesive curriculum. Each individual lesson within the mini-unit can still follow the 5E model, but conceptually the entire mini-unit allows the broad concepts of the performance expectation to be met.

Rather than completely reinvent the wheel, it’s often better to adapt current lessons to the NGSS approach. We developed Figure 2 to help. When evaluating current lessons, ask the questions in the left column of Figure 2 sequentially. If the answer to most of the questions is “yes,” then the lesson is NGSS centered. If “no,” then the lesson may need modification. Once these questions are answered, modify the activities and lessons over time to better align with the NGSS, following a 5E-lesson plan format.

**Engage**

Using Figure 2, we determined that the earlier energy lab was nowhere near NGSS-ready. For example, while the PE states that students should “plan and conduct” the investigation, the students were merely following and conducting. So, we developed a mini-unit for HS-PS3-4: Conservation of Energy and Energy Transfer. It involved an introduction day with discussion and video clips to engage students in reviewing their understanding of energy and the first law of thermodynamics (conservation of energy). Students were then ready to learn about the second law of thermodynamics (the entropy of an isolated system never decreases) by conducting an investigation in class.
**Thermal energy transfer format**

**Research question:**
What happens to the energy in a system when two materials of different temperatures are put together?

**Purpose:**
To plan and carry out an investigation to answer the research question described above. To do this, you will need to further refine (or broaden) the question being investigated, develop a procedure to collect data that can be used as evidence in answering the problem, and construct an explanation using the evidence you collect to provide an answer to the research question.

**Materials:**
Please list all of the materials you use in the experiment.

**Guidelines and background:**
1. Q = mcΔT (students should arrive at this concept behind this equation in a previous activity rather than being given to them).
2. Make sure your experiment follows proper lab safety protocols. Your teacher must approve all safety procedures, but you are on your own to design and carry out this investigation.
3. If you need more materials, equipment, or tools than are at your lab station, please ask the teacher.

**Procedure:**
Please state your procedure and design. Include all variables, both inputs and outputs, and trials. Be sure to include a written description of the boundaries and initial conditions of the system.

**Data:**
Create a data table that includes all independent and dependent variables. These data will be used to refine the experimental design if needed.

**Conclusions:**
Discuss what your data mean. What did you learn about the transfer of thermal energy? Are there any trends in the data? How did the data influence your experimental design? What scientific and engineering decisions did you make? Discuss the accuracy of the data and the limitations of the precision of the data.

**Extension:**
Where else can you find energy transfer in your home or at school? Do these examples show the same principles of energy transfer? Why or why not?

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**Explore**
The following day we presented students a problem to solve: Can you plan and conduct an experiment based upon multiple trials and conditions to determine the heat flow between different materials at different temperatures? The goal over the next few days would be to design an experiment that would provide evidence that when a student placed a heated piece of metal into cool water, a quantifiable amount of thermal energy would be transferred from the metal to the water. When addressing the PE of this standard, it was important to provide students different liquids (water, oil) and different types of metal (bronze, aluminum, lead, and nickel). Other variables were added as determined by the students.

**Safety note:** One possible approach involves students heating water to high temperatures (near 100°C) and transferring a hot piece of metal from the hot water (or other appropriate liquid) into a container with cooler water. Students should wear appropriate safety goggles and lab aprons while following appropriate behavioral procedures. In addition, the students should use insulated gloves when transferring the heated piece of metal using tongs. A heating plate is preferable and safer to use for heating the liquid than an open flame. For safety concerns, all student procedures should be approved by the teacher in advance.

After presenting students with the task, we gave them a format (Figure 3) that helped them organize and focus their investigation. At this point—working in groups of two to four—students began to explore the tools (e.g., thermometers, heating plate, different size beakers and containers, graduated cylinders, and tongs) at their lab stations. To help, I provided the students with some materials (e.g., pieces of different types of matter such as wood, metal, and plastic) they might need, but teachers could also choose to allow students to propose all materials.

It was the students’ job to plan this investigation, so we offered no instructions. This required more time but gave students a better
understanding of the material. Although students spent an extra two or three days on this concept compared to students in previous years, by allowing students more freedom and independence, the lab became their own. Most of the student groups developed a procedure that was effective, often similar to the original “cookbook” procedure, and they took pride in it. Students modified variables in various ways: Some altered the insulated container, the type of liquid, the amount of liquid, and the initial temperature of the metal or water. This approach also gives students experience with engineering practices—another focus of the NGSS—as they decide about materials, amounts, time, and other constraints and carry out multiple iterations (if time allows).

**Explain**
The day after the students planned and carried out their experiments, they discussed the results and used the data that they collected to develop an explanation that heat—regardless of the type of liquid or metal being tested—tended to dissipate toward a uniform distribution, thereby uncovering the second law of thermodynamics on their own. Students then wrote up their lab reports and shared them with the class. The conclusion section of the lab had particular guidelines that required students not only provide reasoning for their group’s procedures but also to explain how their data did or did not provide evidence for answering the original question and support the first law (conservation of energy) and second law (the entropy of an isolated system never decreases) of thermodynamics. Students collaborated within their groups to develop their discussions, which focused on what data they collected, how they used the data to support answering the question, the engineering decisions they made, and what science content related to energy transfer.

This was followed by a presentation of the disciplinary core ideas so that the correct content could be reinforced and related to student work.

**Elaborate**
Part of the lab write-up was a section that asked students to provide concrete, real-world examples of what they had just learned. Students had to find and describe a practical example of the concept of energy transfer to a working system (e.g., refrigerator, car engine, ocean current, or convection oven).

The traditional “specific heat” activity is to determine the heat transfer from a warm piece of metal to a measured amount of water by recording the initial and final temperatures of the metal and water. This simulates what food scientists do with a calorimeter to determine food “calories” (kilocalories). Variations and extensions of this activity include using unknown (to students) metals to determine their specific heat capacity, and using different liquids for heat transfer.

**Evaluate**
To determine if students understood the concept of energy transfer, we posed the following challenge a week later: “Design an experiment to determine the specific heat capacity of an unknown metal found in a meteorite that has fallen from space. Include the procedure and variable you would use to determine the specific heat.”

**Conclusion**
What was previously a one-day cookbook lab became an extensive three- to four-day mini-unit that involved students in figuring out the second law of thermodynamics. Such changes address the intention of the NGSS to not only increase student achievement but also provide a better understanding of the nature of science. With adjustments, many current lesson plans can be transformed into a much more sophisticated set of lessons we call an NGSS mini-unit.

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**On the web**
The National Science Teachers Association NGSS@NSTA hub: 
http://ngss.nsta.org

**References**