Ms. Hawthorne is a long-time seventh-grade science teacher who is teaching sixth grade for the first time. She is excited about the opportunity to teach a new grade, but a bit nervous about some of the material. Her first unit of the year is thermal energy and energy transfer. Nervous about teaching this new content, she looks for curricular resources available at her school and finds an energy transfer unit that she thinks might work because it says it targets the two performance expectations she has prioritized: MS-PS1-4 and MS-PS3-4. The unit introduces students to important terms like conduction, convection, and radiation; has them experience demos and labs that illustrate how those kinds of energy transfers happen; and ends with asking students to apply their learning by building an insulated cup that resists energy transfers.
As she reads the materials, Ms. Hawthorne is excited about the opportunities it will provide students to build their understanding of energy types and transfer, process that information, and apply it to a different context. When she begins to teach the unit, however, she starts to feel a bit uneasy. She is unclear how much her students are actually engaging in science practices or using the crosscutting concepts. Ms. Hawthorne begins wondering if this is really supporting her students in reaching the Next Generation Science Standards, but she isn’t sure what exactly is off or how to improve the materials for her students.

The story of Ms. Hawthorne is based on our experience teaching and working with teachers. The Next Generation Science Standards (NGSS; NGSS Lead States 2013) were first released in 2013, but eight years later many teachers still do not have access to curricular materials that truly meet the ambitious vision of these standards. Many curriculum publishers claim to be aligned with the NGSS, but those claims do not always hold up to analysis, or they may rely on using NGSS terminology instead of designing materials to reflect the goals of the standards (Achieve 2018). This can be especially problematic for teachers who are provided a curriculum that might not be well designed for the NGSS and need to consider how to make it work better for their students.

Key features of the NGSS

To help with this challenge, we suggest focusing on four key features of NGSS instructional design. In previous research, we have found that these key features can help highlight important ways curriculum and instruction might—or might not—be aligned with the NGSS (Lowell, Cherbow, and McNeill 2021). This lens can also help us consider ways we could modify existing curricular materials to make them more NGSS designed. The four key features we suggest are: phenomenon based, three dimensional, student centered, and coherent from the student perspective (Lowell, Cherbow, and McNeill 2021). Figure 1 has a brief description of each of these key features.

A phenomenon is a specific, observable event that students can experience either directly or through the use of video and/or audio representations (Lowell and McNeill 2019). What makes instruction phenomenon based, however, is that the phenomenon is introduced at the beginning and used to drive students’ learning of science concepts rather than simply being used as a hook or example of a science concept (Inouye, Houseal, and Gunshenan 2020). Choosing phenomena that are relevant to students or draw on their cultural and personal knowledge can be particularly powerful in engaging and supporting students whose experiences, backgrounds, or cultures are less often represented in traditional science classrooms (Lee 2020).

The idea that science education should consist of three equally important dimensions—disciplinary core ideas, science and engineering practices, and crosscutting concepts—is foundational to the NGSS (National Research Council 2012). For a curriculum to be truly three dimensional, it must not simply have a core idea, practice, and concept present, but rather integrate them together. Students should come to an understanding of a core idea through the use of a practice that informs or is informed by a crosscutting concept.

### FIGURE 1: Key features of the NGSS.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phenomenon based</strong></td>
<td>Student learning is driven by figuring out a natural or constructed phenomenon.</td>
</tr>
<tr>
<td><strong>Three dimensional</strong></td>
<td>Students come to an understanding of a core idea through the use of a practice that informs or is informed by a crosscutting concept.</td>
</tr>
<tr>
<td><strong>Student centered</strong></td>
<td>Students are the primary ones doing and talking about science ideas. Students actively co-construct understanding with the support of the teacher.</td>
</tr>
<tr>
<td><strong>Coherent from the student perspective</strong></td>
<td>Students connect learning activities with each other over time to understand why they are doing each activity to figure out a phenomenon.</td>
</tr>
</tbody>
</table>
The NGSS is built around the idea that students are doing science, not just learning about what scientists have done (Schwarz, Passmore, and Reiser 2017). Research has also shown that students learn when they engage in meaningful, well-structured talk about science ideas (Brown 2019). Student talk is particularly beneficial for multilingual students who develop their science understandings and language abilities when they can use both everyday and formal language (González-Howard, Andersen, and Pérez 2021). These ideas are what we mean when we say student centered: Students should be the primary ones doing and talking about the science, rather than mostly listening to the teacher or reading a textbook that explains the science ideas to them.

For something to be coherent from the student perspective, the sequence of learning activities should make sense to students and be driven by questions that arise from their investigation of the phenomenon. Often lessons are built to make sense to people who already understand the science, not to learners who are developing their understanding (National Academies of Sciences, Engineering, and Medicine

**FIGURE 2:** Rubric for evaluating the key features of the NGSS.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Not designed for NGSS</th>
<th>Somewhat designed for NGSS</th>
<th>More designed for NGSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenomenon based</td>
<td>Teacher focuses on skills or content without a connected, relevant phenomenon OR students do not engage with phenomenon introduced in class.</td>
<td>Phenomenon used as hook or example for students to work with but not as a driver of goals or activities.</td>
<td>The goals and activities of the lessons are focused on figuring out a conceptually rich phenomenon.</td>
</tr>
<tr>
<td>Three dimensional</td>
<td>Students learn about a DCI without engaging in practices or CCCs OR students develop components of a practice or CCC without learning about an idea.</td>
<td>Students develop components of a SEP or CCC and learn about a DCI. These may or may not be integrated.</td>
<td>Practices and/or CCCs are used to figure out DCIs and/or CCCs.</td>
</tr>
<tr>
<td>Student centered</td>
<td>Lessons are mostly students receiving information (via teacher talk, reading and/or videos) rather than constructing or making sense of ideas.</td>
<td>Students engage in hands-on activities, but almost all cognitive work has already been done by teacher OR students discuss ideas but teacher maintains primary control over discussion flow and connections.</td>
<td>Students are actively constructing their understanding during lessons OR students discuss ideas as a group with little direct control by the teacher.</td>
</tr>
<tr>
<td>Coherent from the student perspective</td>
<td>There is no attempt to connect lessons to past or future lessons.</td>
<td>The teacher plays the main role in connecting lessons to past and future lessons.</td>
<td>Students are the primary ones making sense of how lessons are connected to past or future lessons.</td>
</tr>
</tbody>
</table>

Note: DCIs = disciplinary core ideas; CCCs = crosscutting concepts; SEPs = science and engineering practices.
Instead, students, with the help of the teacher of course, should be connecting lessons from one to the next by discussing what they have already figured out about the phenomenon of interest and what they need to continue working on together (Reiser, Novak, and McGill 2017).

These four key features can help teachers to pinpoint what is successful about a curriculum they have and consider how to modify materials so they are more aligned with the NGSS. To help operationalize these features, we have constructed a simple rubric for each feature. The rubric, which is shown in Figure 2, can be used by individual and/or groups of teachers to turn a critical eye on their materials and consider how to adapt them to each of the key features. This rubric could be used in individual lesson planning or unit-level planning to guide teachers in determining where adjustments might be needed.

Applying the key features: A thermal energy example

Let’s return to Ms. Hawthorne and this thermal energy unit to see how the key features can help us consider ways in which it can be better designed for the NGSS. For this unit, Ms. Hawthorne was targeting the following performance expectations: (1) develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed (MS-PS1-4) and (2) plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample (MS-PS3-4).

A traditional approach to these standards might begin with having students learn about the definitions of heat and energy, watch simulations of particles of materials at various temperatures to see how they have different amounts of energy, and then turn to how energy is transferred from one substance to another. Using examples from everyday life such as refrigerators or teapots, students might be introduced to terms like conduction, convection, and radiation. They might use food-colored water of different temperatures to create a convection cell to visualize these ideas. Finally, a traditional unit might ask students to apply these ideas with an engineering challenge like designing and building an insulated cup.

On the surface, there is a lot to like about this unit outline. It involves students engaging in core ideas about the particulate nature of matter and the flow of energy. There are also multiple opportunities for students to apply their knowledge with real materials and engage in some engineering-design thinking at the end. When we look at it through the lens of the four key features, however, it becomes clear where it falls short in terms of actually preparing students to meet these performance expectations. In addition, the key features are useful to highlight ways the unit might be modified to better support students to achieve these goals. Next, we talk about each of these features specifically and summarize some potential differences in Figure 3, which shows how the key features are applied to the specific thermal energy example.

Phenomenon based

The traditional unit has examples of thermal energy in real life (teapot, refrigerator, insulated cup), but these examples are not used as phenomena to figure out. They are presented as ways to explain or illustrate the core ideas, but students are not asked to do anything with these examples other than know how they work.

To make this lesson more phenomenon based, Ms. Hawthorne could use one of the real-life examples, such as the insulated cup, to anchor the unit. For example, in the OpenSciEd thermal energy unit, students begin to figure out how insulated cups keep things cold by developing models and asking questions such as “how can containers keep stuff from warming up and cooling down?” (OpenSciEd 2019). As they go through the unit, if each new topic were in service of figuring out how the insulated cup worked, Ms. Hawthorne could help students figure out this natural phenomenon rather than simply use it as an example of terms they have been taught.
Three dimensional

The traditional unit can struggle to incorporate three-dimensional learning because of the lack of science and engineering practices (SEPs). If students are mostly learning new terms and seeing them applied, they are less likely to be doing the science practices. Similarly, teapots and refrigerators might be examples of systems of energy transfer, but presenting them does not mean students are using systems thinking as a crosscutting concept (CCC) to help them better understand energy movement.

To make this unit more three dimensional, Ms. Hawthorne could incorporate the SEPs as she asks students to figure out the anchoring phenomenon. In terms of science practices, when Ms. Hawthorne introduces the cup, she could have students ask questions about why it works and develop initial models to help explain their thinking and highlight where they need more information. This use of modeling and explanation connects well with the Math and English Language Arts Common Core standards (Cheuk 2013). Developing models supports students in considering how systems are represented, and constructing explanations requires students to effectively collect and use evidence to support their claim. These are two examples of how the science and engineering practices also support students in developing their math and English Language Arts skills. Throughout the unit, Ms. Hawthorne could have students use one of the CCCs, systems thinking, to help them reflect on how energy might or might not move through a cup, which would help them to understand the various ways that energy moves while considering how the components of the cup work together to limit that movement of energy. Basing the unit on figuring out a phenomenon makes it much easier to ask students to authentically engage in both the SEPs and CCCs.

Student centered

In the traditional unit, students might engage in whole-class discussion while the teacher asks questions focused on students repeating back information they have just heard. This structure limits the students’ cognitive work to processing and recalling information rather than building ideas together like scientists do. Lessons might include some hands-on activities, such as students rubbing their hands to-
gether to see that friction creates heat, but often those activities tell students what to do to demonstrate an idea rather than give them opportunities to make decisions about what to investigate and how.

To make more student-centered lessons, Ms. Hawthorne could ask students to share their ideas and questions about an anchoring phenomenon like the insulated cup to help construct a shared need to engage in investigations. She could also have students discuss the results from various investigations before giving the “right” answer so that students have an opportunity to use investigations to construct understanding rather than to confirm ideas they had already been told. Of course, there are certain core ideas she wants her students to understand, but when she allows students to ask questions that guide investigations, the ideas are more likely to come from the students’ thinking rather than simply using talk and activities to get students to better remember something the teacher has told them.

**Coherence from the student perspective**

In traditional units, the teacher is often the primary connector of past and future lessons. For example, lessons might begin with asking students to discuss prior knowledge or have the teacher foreshadow concepts in the lesson, but these moves do not help students logically connect one lesson to the next. As a result, students might not understand why they need to know information from a lesson or how it helps to explain a phenomenon or solve a problem.

To make lessons more coherent from the student perspective, Ms. Hawthorne could end class with students discussing what they learned in that lesson, how it helps them answer the questions they had about the anchoring phenomenon, and what questions still

---

**FIGURE 3:** Example of a traditional versus an NGSS-designed approach.

<table>
<thead>
<tr>
<th>Feature</th>
<th>A more traditional approach</th>
<th>A more NGSS-designed approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenomenon based</td>
<td>Real-world examples are used to illustrate concepts but not to anchor the lesson. Students are not “figuring out” the phenomena throughout the lesson.</td>
<td>An anchoring phenomenon such as the insulated cup motivates students’ sensemaking throughout the unit as they try to figure out how the phenomenon works or happens.</td>
</tr>
<tr>
<td>Three dimensional</td>
<td>Students are mostly learning vocabulary words or seeing examples of the SEPs or CCCs without actually doing that work themselves.</td>
<td>Students use SEPs such as asking questions, modeling, or carrying out investigations and CCCs such as systems thinking to figure out core ideas as they make sense of the anchoring phenomenon.</td>
</tr>
<tr>
<td>Student centered</td>
<td>Student talk is limited to closed questions that require students to repeat back information they learned in the lesson. Students complete hands-on activities but do not make decisions about what they should do to get a desired outcome.</td>
<td>Students engage in hands-on investigations to help them explore and make sense of ideas rather than confirm ideas already told to them. Students co-construct ideas from these investigations with each other and the teacher, using SEPs and CCCs to help them.</td>
</tr>
<tr>
<td>Coherent from the student perspective</td>
<td>Lessons are mostly independent of each other or the teacher explains how students’ previous work might be helpful in the next lesson.</td>
<td>Students use models and questions from one lesson to guide their thinking throughout the unit. Students ask questions at the end of a lesson to help them understand why they would need to do future investigations in the following lessons.</td>
</tr>
</tbody>
</table>

Note: CCCs = crosscutting concepts, SEPs = science and engineering practices.
remain. For example, if students end the lesson curious about what characteristics of the cup help to keep things cold, Ms. Hawthorne could have students conduct an investigation during the next lesson to answer that question. Another possible way to help students see how each lesson connects to the others is returning to a shared model of the anchoring phenomenon. If students begin the unit modeling what they think is happening, they can regularly return to and update this model to maintain motivation and keep track of information they need to build their own insulated cup at the end of the unit. These moves allow Ms. Hawthorne’s students to see how their ideas build over time and why they are doing each new learning activity.

Conclusion

We are now eight years removed from the publication of the NGSS and in a tricky place in science education. There are some very strong materials currently being released, such as OpenSciEd, whose Thermal Energy unit we used as a model throughout these examples (OpenSciEd 2019). Unfortunately, many others don’t quite hit the mark, and classroom teachers are often left to figure out how to make them work for their students. These four key features can help teachers to analyze curricular materials, modify them to make them better fit the NGSS, and/or ensure modifications to strong materials (such as replacing a phenomenon with a locally relevant one) are still in line with the NGSS. By thinking about how a unit or lesson is phenomenon based, three dimensional, student centered, and coherent to students, we can focus on creating and adapting lessons that help our students actually do the science learning that the NGSS asks for.

REFERENCES


Benjamin R. Lowell (benjamin.lowell@bc.edu) is a former high school chemistry teacher and a doctoral candidate in science education at Boston College Lynch School of Education and Human Development in Chestnut Hill, Massachusetts. Hannah McGowan (hmcgowan@mcacec.org) is a middle school science teacher at Mother Caroline Academy and Education Center in Dorchester, Massachusetts.