Using Understanding by Design to Make the Standards Come Alive

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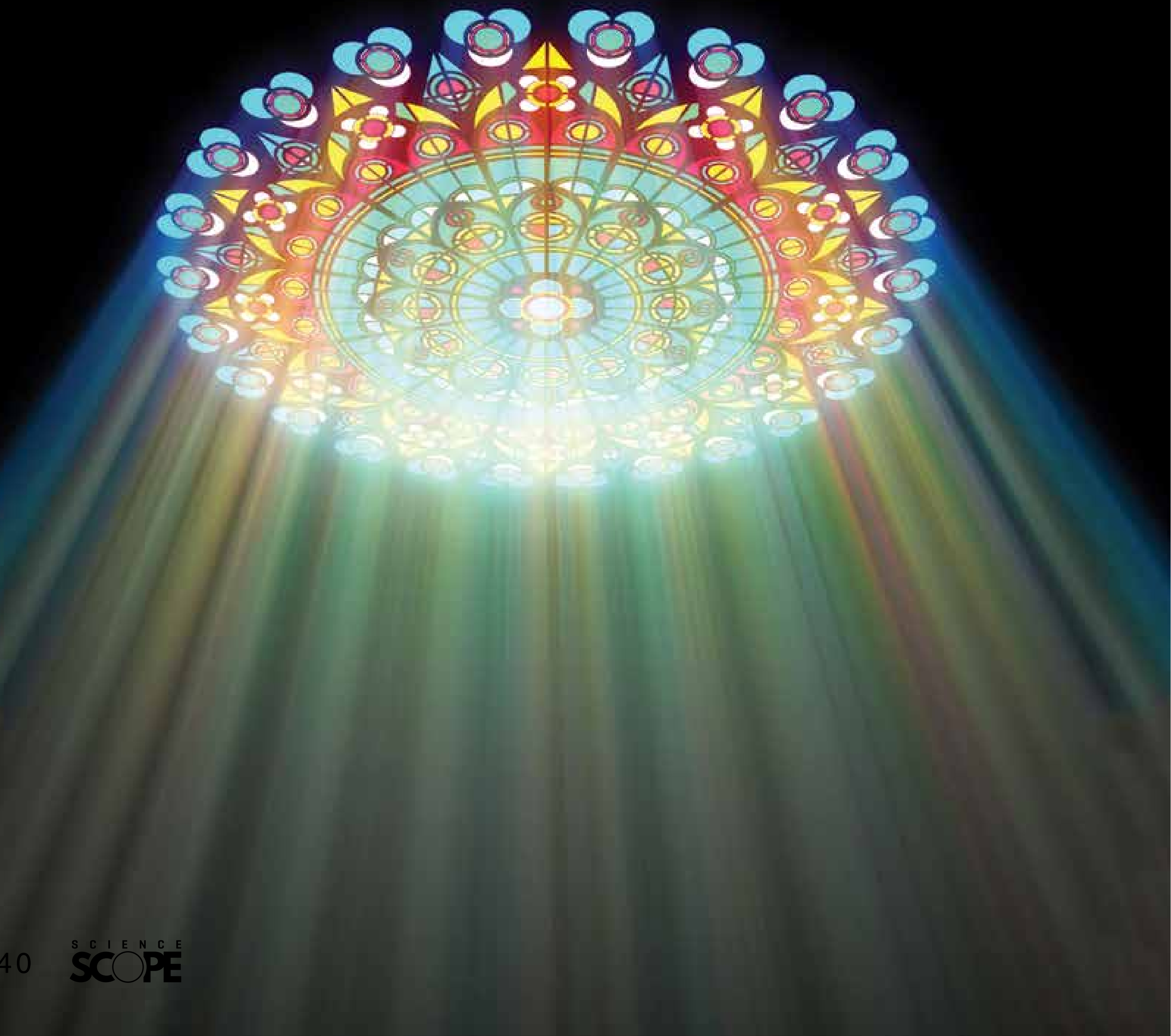


The *Next Generation Science Standards* (NGSS Lead States 2013) present a modern framework for science education. Its three-dimensional construct calls for teachers to favor depth over breadth, while engaging students in "doing" science, not just learning science facts. To avoid the familiar problem of curricula that are a mile wide and an inch deep, the Standards call for framing teaching around disciplinary core ("big") ideas, science and engineering practices, and crosscutting concepts. This construct aligns with the recommendation of curriculum experts (e.g., Wiggins and McTighe 2005; Wiggins and McTighe 2011) that educators should move away from trying to cover volumes of factual material and instead prioritize their curriculum around a smaller number of conceptually more critical, transferable ideas.

As well developed as they may be, the *NGSS* are not curriculum. It is the job of teachers and curriculum teams to use the Standards as the basis for designing the specific pathway for teaching and learning. In this article, we will explore the use of Understanding by Design (UbD), a widely used curriculum development framework, for honoring the intentions of the *NGSS*. We will also examine an instructional sequence called *explore-before-explain* teaching and provide an example of how to incorporate it into a unit using the UbD framework.

Three stages of backward design

The UbD framework offers a three-stage curriculum unit design process based on the idea that teaching is a means to an end, and curriculum planning precedes instruction. The most successful teaching begins with clarity about desired learning outcomes (Stage 1) as well as about the evidence that will show that the targeted learning has occurred (Stage 2). Daily lessons that describe the planned teaching and learning activities are *then* developed (Stage 3). A critical factor in a quality unit plan is alignment—all three stages clearly aligned, not only to standards, but also to one another. What follows is a description of the three UbD phases and explore-before-explain teaching (aligns with Stage 3) as well as how UbD plays out in practice for teaching middle school students about how light behaves when it encounters different mediums (NGSS Lead States 2013).

Stage 1: Identify desired results

This first stage in the design process calls for clarity about instructional priorities. Curricular planners target the learning goals for a unit that identifies what they want learners to know, understand, and be able to do. In science, this means framing lessons around phenomena that are understandable through data-based experiences. UbD emphasizes that units should focus on transfer goals that specify what students should *be able to do* with their learning in the long run. Then, teachers identify the "big ideas" they want their students to come to understand as a result of the unit. The essential concepts frame their companion essential questions—open-ended, thought-provoking questions meant to engage students in meaning-making. Finally, more specific knowledge and skill objectives (termed *acquisition*) are iden-

CONTENT AREA

Physical Science

GRADE LEVEL

6–8

BIG IDEA/UNIT

Students develop a model to describe that waves are reflected, absorbed, or transmitted through various materials.

ESSENTIAL PRE-EXISTING KNOWLEDGE

Properties of different materials influence how we see different objects.

TIME REQUIRED

50 minutes

COST

$15

SAFETY

Safety googles; see other cautions in article.

tified in Stage 1. Thus, Stage 1 includes three levels (transfer, meaning, and acquisition) that promote deep conceptual understanding.

Stage 2: Determine acceptable evidence

Stage 2 of backward design encourages teachers to think like assessors *before* planning lessons and learning activities in Stage 3. In other words, think about the assessment evidence that will reveal the extent to which students have attained the learning goals targeted in Stage 1. Traditional tests, quizzes, and skill checks can assess students' acquisition of science knowledge and proficiency in basic skills. However, UbD proposes that conceptual understanding requires more robust evidence, obtained through the performance assessments that ask students to *apply* (i.e., transfer) their learning to new situations and *explain* the meaning(s) they have made. We recommend that the performance tasks be set in meaningful and authentic contexts (e.g., linked to phenomena) whenever possible.

Stage 2 of UbD embodies a fundamental *if–then* proposition: the primary goal of modern education (and the *NGSS*) is to equip students to be able to transfer their learning to new situations, *then* you should design curriculum backward from authentic performances of transfer, not from long lists of discrete topics or skills to "cover." In curriculum planning, this means giving priority to experiences that allow students to construct evidence-based claims. Here is where knowing the evidence-statements of the *NGSS* can play a powerful role in helping teachers hone in on the most essential scientific ideas.

Stage 3: Plan learning experiences and instruction

Stage 3 is where day-to-day lesson planning occurs. We have found that when teachers have established clear learning goals in Stage 1 and have carefully considered the needed assessment evidence in Stage 2, their teaching and learning plan is sharpened. More specifically, the various types of learning goals identified in Stage 1—acquisition of knowledge and skills, understanding of big ideas, and transfer—inform the selection of appropriate instructional strategies, learning experiences, and roles for teachers (e.g., direct instructor/modeler, facilitator, and coach).

One of the big ideas in UbD is that understanding must be "earned" by the learner. In other words, students need to actively strive to make (or construct) meaning to come to understand core ideas, crosscutting concepts, and the application of the practices.

FIGURE 1: Stage 1 of the UbD unit template: Desired results.

<table>
<tr><th>Established goals</th><th colspan="2">Transfer</th></tr>
<tr><td rowspan="5">Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various material (NGSS Lead States 2013; MS-PS4-2).</td><td colspan="2">Students will be able to independently use their learning to . . .
Use models to explain and predict how light travels between different transparent materials.</td></tr>
<tr><th colspan="2">Meaning</th></tr>
<tr><td>Understandings
Students will understand that . . .
• Models can be used to explain and predict how light travels.
• The properties of materials will help explain whether light is reflected, absorbed, or transmitted.</td><td>Essential questions
Students will keep considering . .
• What factors affect how light travels?
• How do different materials influence whether light is absorbed, transmitted, or reflected?</td></tr>
<tr><th colspan="2">Acquisition</th></tr>
<tr><td>Students will know . . .
• Transmitted light travels through a material.
• Reflected light bounces off a material and is what is seen.
• Absorbed light is captured by a material.
• Refracted light appears bent because it changes speed and direction as it travels from one transparent material to another.</td><td>Students will be skilled at . . .
• Constructing evidence-based claims.
• Constructing models that illustrate that explain and predict science phenomenon.</td></tr>
</table>

As teachers develop their learning plan in Stage 3, they are encouraged to think about ways of involving their learners in meaning-making. In this regard, we highlight the importance of the instructional sequence used to teach science. More specifically, we recommend an explore-before-explain approach to engage in meaning making, giving students first-hand experiences with phenomena.

Explore-before-explain as a lesson planning approach

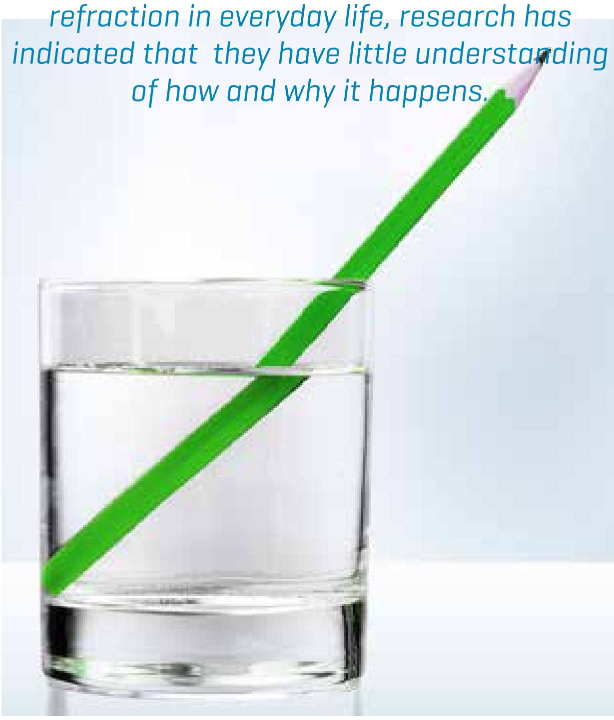
Explore-before-explain learning highlights a unique synergy between explorations and explanations, and it recognizes that explorations need to come first. Students' prior knowledge and experiences are the foundation on which new conceptual understandings are built. Explore-before-explain teaching begins by eliciting students' ideas about scientific phenomena in light of their life experiences. This initial step engages students' inherent curiosity, invites their ideas, and sets the context for later learning related to the desired understandings. Starting new lessons of study with students' thoughts and experiences helps to create a storyline that makes learning meaningful and aligns with how students learn science best (Bransford, Brown, and Cocking 2000).

Teachers can employ a variety of resources and strategies for engaging and eliciting students' ideas and experiences at the start of new learning. Teachers can use formative assessment probes to assess students' prior experiences using the excellent set developed by Page Keeley and colleagues (Keeley, Eberle, and Farrin 2005), or they can create prompts, making use of the extensive AAAS database of science topics linked to the *NGSS* (see Online Resources).

Teachers can also invite students to make *predictions* about demonstrations and observed phenomena. Neurologist and teacher Judy Willis contends that prediction is one of the highest yield instructional strategies because it focuses the brain's attention and sets up a "need to know" (McTighe and Willis 2019). If a prediction is successful, it validates prior knowledge and sound reasoning. If the prediction is incorrect, the brain wants to find out why and seeks an explanation. A related strategy involves the use of *discrepant events* that are counterintuitive or unexpected to capture students' interest and engage them in trying to "make sense" of the surprising or unanticipated phenomena they observed.

Students' ideas should lead directly to firsthand experiences with data that provide evidence that can be used when developing an evidence-based claim. While students' evidence-based claims are essential for the organization of new knowledge, they are not always sufficient to ensure deep conceptual understanding. Explaining the scientific principles and the reasoning *why* the evidence supports a claim cultivates a more sophisticated understanding. Explanations are necessary because some scientific principles are inherently abstract and inaccessible through hands-on explorations. For example, subatomic ideas and many microscopic phenomena are not easily investigated in classroom settings. Furthermore, it would be inefficient and unnecessary to try to get students to learn abstract scientific principles (that took scientists hundreds of years to formulate) using a solely discovery-based approach. The key point is that explanations are time- and experience-sensitive and should answer *why* and *how* questions, especially ones that students generate in their attempts to make meaning.

*The word **refraction** describes the phenomenon of light rays bending as they pass from one material to another. Although many students experience the property of refraction in everyday life, research has indicated that they have little understanding of how and why it happens.*



Putting it all together

The three stages of UbD can provide educators with a practical framework for developing curriculum units that honor the *NGSS*. To illustrate the process, we used UbD to design a unit for teaching about the properties of materials and light (NGSS Lead States 2013). The model lesson aims to explain why objects appear differently underwater versus out in the open. If you have experienced this phenomenon, it is because light rays are influenced by different substances (such as air and water) depending on physical properties. The word *refraction* describes the phenomenon of light rays bending as they pass from one material to another. Although many students experience the property of refraction in everyday life, research has indicated that they have little understanding of how and why it happens (Driver et al. 1994).

Stage 1 of UbD

As shown in Figure 1, we connected the practices in conjunction with core concepts—specifically, linking the understandings about analyzing and interpreting data and systems and systems models as the basis for students to construct explanations (science and engineering practices [SEPs] and crosscutting concepts [CCs]) about what happens to light when it shines on an object and the path light travels as between different transparent materials. The transfer and meaning-making goals integrate content and process to develop and deepen students' understandings, while the

FIGURE 2: Stage 2 of the UbD unit template: Evidence.

NGSS coding	Evaluative criteria	Assessment evidence
Analyzing and interrupting data	• Evidence-based claims are logical and reflect observations and collected data • Developing models	**Performance task(s)** • Based on observations and provided data, students construct an evidence-based claim. • Students use models to explain and predict how different mediums influence light.
Constructing explanations	Answers are: • accurate	**Supplemental evidence** Test(s) of knowledge of: • Test predictions about how objects appear when light passes through different transparent materials.

acquisition goals target the essential information and skills as necessary "building blocks." Such an integration of core content, crosscutting concepts, and practices is precisely what the *NGSS* calls for.

Stage 2 of UbD

As shown in Figure 2, the focus is on measurable ways to assess students and could serve as evidence of conceptual understanding. The assessment standards sought to determine student understanding and emerged seamlessly from the essential learning goals (all three levels: transfer, meaning, acquisition). First, based on students' experiences, they should be able to construct claims-evidence-reasoning (C-E-R) statements and be able to explain how different materials influence light as well as explicitly knowing that scientific models both explain and predict sophisticated understanding. In sum, all three levels of desired learning goals were directly related to assessment to aid and evaluate transfer learning.

Stage 3 of UbD

The learning plan for this unit applied an explore-before-explain lesson sequence to immediately engage students in light of the desired learning goals identified in Stage 1 and the planned assessments in Stage 2 (Brown 2013; see link to full *Science Scope* article in Supplemental Materials). Teachers can help elicit students' ideas about the behavior of light by asking them to think about how different mediums influence how objects appear that includes: (1) a test tube filled nearly to the top with water submerged in a 50 ml beaker filled with water, and (2) a test tube filled almost to the top with cooking oil in a 50 ml beaker of cooking oil (Wesson-brand cooking oil works well for the demonstration). The prediction activity was purposefully selected so that students could think and reason about the characteristics of different materials compared with one another to situate their firsthand experiences. Ask students to draw a model that includes how they think light rays will travel; student drawing should explain how the object will look. This exploration helps give students a background to anchor learning for which they may not have had prior experiences.

During the Explore phase, teachers can get students excited by unveiling each of the setups at approximately the same time. *Teachers need to review with students two safety precautions when performing the demonstration.* First, all participants need to wear indirectly vented chemical-splash goggles. Second, all spills must be cleaned immediately to prevent slip-and-fall accidents. One way to ensure engagement is by having multiple setups for students to observe. For example, the teacher can bring the setups to three different stations in the room. Students must remain seated so everyone can see the demonstration. This will allow all students to observe the demonstration and prevent disruptions.

Many students are surprised by how much the submerged portion of the water-filled test tube in the beaker of water is magnified compared with the unsubmerged section of the test tube (see Online Resources for link to the YouTube video "test tube with water in a beaker with water"). At this point, have students revise their models so that they explain how light travels.

When the second setup is revealed, the energy, enthusiasm, and interest in the room quickly reach a new height (see Online Resources for link to the YouTube video "test tube with oil placed in a beaker with oil"). Students' eyes widen and their jaws drop, and they are completely shocked by the results, which are that the test tube seems to disappear or becomes invisible. It is rare for a single student to have an accurate prediction. Again, students revise their model to support their observations.

Next, students use data that includes the refractive indexes of air (1.0), water (1.33), corn oil (1.47) and Pyrex glass (1.47). This data helps them construct evidence-based claims and understanding of the scientific reasoning behind the disappearing test tube demonstration. As a result of the Pyrex glass and test tube having the same refractive index, the speed and direction of light does not change from one medium to another so students perceive no boundary (e.g., the test tube) that exists between the two materials. Having students construct evidence-based reasoning aligns with Stages 1 and 2 of the UbD framework.

Note: In this article, we have presented a brief description of a learning plan for this unit. A more detailed version, including samples of student work, is available in *Science Scope* (Brown 2013; see link to full article in Supplemental Materials).

Conclusion

The *NGSS* calls for the fusion of *content* based on "big ideas" (via core ideas and CCs) with the *processes* of science (science and engineering practices)—by design. Understanding by Design offers a practical and proven curriculum-planning framework through which teachers can enact the vision of the *NGSS* by targeting understandings and transfer goals in Stage 1 and specifying the needed assessment evidence in Stage 2. Then, by following the explore-before-explain instructional sequence in Stage 3, teachers honor learners' background knowledge, capitalize on their inherent curiosity, and actively engage them in making meaning through experiential learning. The understandings that students construct from direct experiences are powerful and enduring; they embody the *NGSS* call for learners to be "doing" science. ●

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ONLINE RESOURCES

AAAS: Science assessment—*http://assessment.aaas.org/topics*

Test tube with water in a beaker with water—*https://youtu.be/3N6_UkJQZ6o*

Test tube with oil placed in a beaker with oil—*https://youtu.be/jFXXvhc3zSc*

SUPPLEMENTAL MATERIALS

Science Scope article by Patrick Brown—*https://www.nsta.org/online-connections-science-scope*

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