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BOARD ON SCIENCE EDUCATION

Science and Engineering for Grades 6-12: Investigation and Design at the Center

Study Sponsors: Amgen Foundation and Carnegie Corporation of New York

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Webinar on Instruction
March 7, 2019

The **Board on Science Education** and the **National Academy of Engineering ran this study.**

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Committee Charge

- Review research on science investigation and engineering design for middle and high school students conducted since publication of *America's Lab Report* (National Research Council, 2006)
    - o Review will include research and evaluations of innovative approaches, such as computer modeling or use of large on-line data sets that have become more widely available since publication of the original report.

- Provide guidance for designing and implementing science investigation and engineering design for middle and high school students taking into account the new vision for science education embodied in the *Framework for K-12 Science Education* (National Research Council, 2012) and standards based upon it.

Report Chapters

- K-12 Science Education Past and Present
- Learning and Motivation
- How Students Engage with Investigation and Design
- How Teachers Support Investigation and Design
- Instructional Resources for Supporting Investigation and Design
- Preparing and Supporting Teachers to Facilitate Investigation
- Space, Time, and Resources
- The Education System and Investigation and Design
- Conclusions, Recommendations, and Research Questions

POLL

Students should do science investigation or engineering design in class in order to demonstrate that their knowledge of science.

Strongly Agree Agree Disagree Strongly Disagree

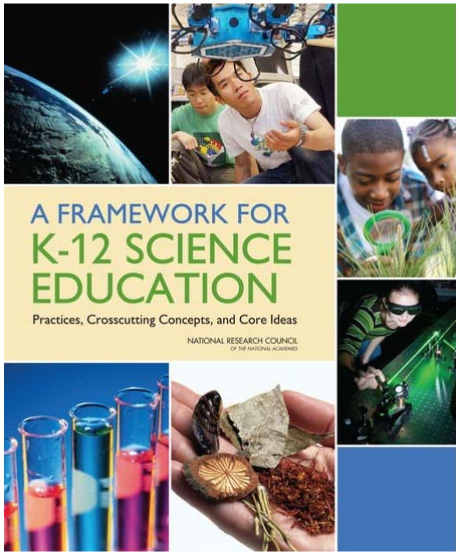
Students should do science investigation or engineering design in class in order to make sense of the world around them.

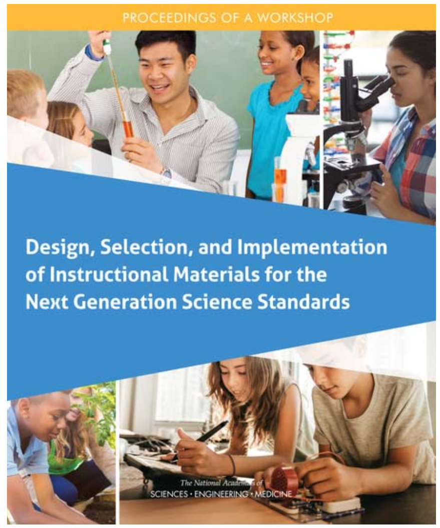
Strongly Agree Agree Disagree Strongly Disagree

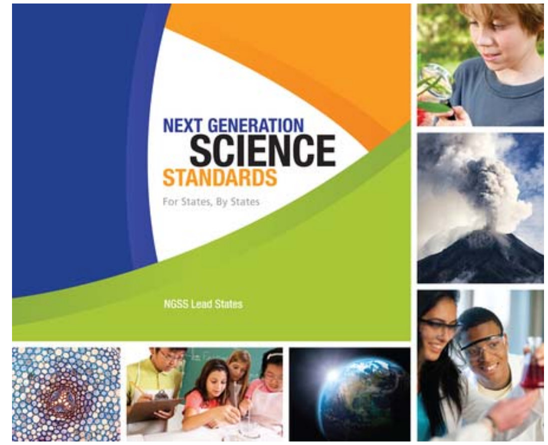
Students should participate in science investigation or engineering design in class in order to get them interested in science.

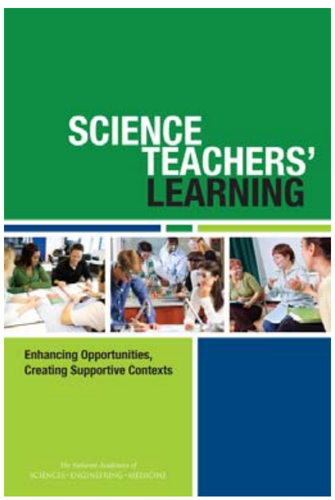
Strongly Agree Agree Disagree Strongly Disagree

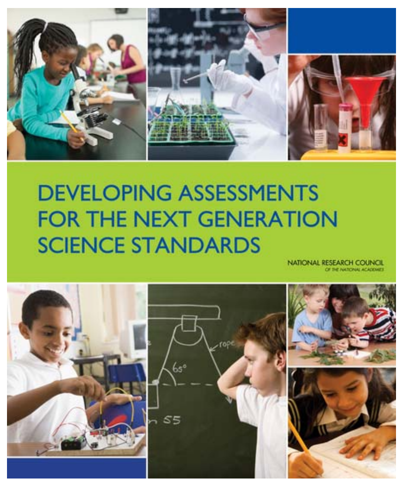
Context of our Study

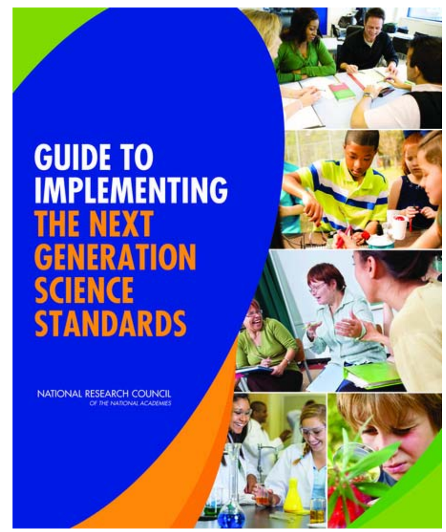












Investigation and Design at the Center

- Science investigation and engineering design should be at the CENTER of teaching and learning science. Teachers need to build classes around students investigating phenomena and designing solutions.

- In these classes, students work to make sense of the causes of phenomena or solve challenges in a way that uses all three dimensions of the *Framework* in concert and with increasing depth and sophistication, making connections between ideas and concepts.
  - For example, students **design a solution** (a practice) for a device (crosscutting concept: structure & function) that collects plastics that have made their way to a local waterway and are **causing** native marine life to die prematurely (crosscutting concept: cause/effect).

The Power of Investigation and Design

Teachers can use students' curiosity to motivate learning by choosing phenomena and design challenges that are interesting and engaging to students, including those that are locally and/or culturally relevant.

Science investigation and engineering design entail a dramatic shift in the classroom dynamic. Students ask questions, participate in discussions, create artifacts and models to show their reasoning, and continuously reflect and revise their thinking. Teachers guide, frame, and facilitate the learning environment to allow student engagement and learning.

Inclusive pedagogies can support the learning of all students by situating differences as assets, building on students' identities and life experiences.

Instruction for Investigation and Design

Centering classes on science investigation and engineering design means that teachers provide multiple opportunities for students to demonstrate their reasoning and show understanding of scientific explanations about the natural world. Providing opportunities for teachers to observe student learning and embed assessment into the flow of learning experiences allows students as well as teachers to reflect on learning.

Instructional resources are key to facilitating the careful sequencing of phenomena and design challenges across units and grade levels in order to increase coherence as students become increasingly sophisticated science and engineering learners.

RECOMMENDATION 1:
Investigation and Design is Central

- Teachers arrange their instruction around phenomena or design projects.

- Administrators support teachers by providing
  - Instructional resources
  - Sustained professional learning experiences
  - Opportunities for teachers to work collaboratively to design learning sequences that are interesting and relevant
  - Time to learn about inclusive pedagogies

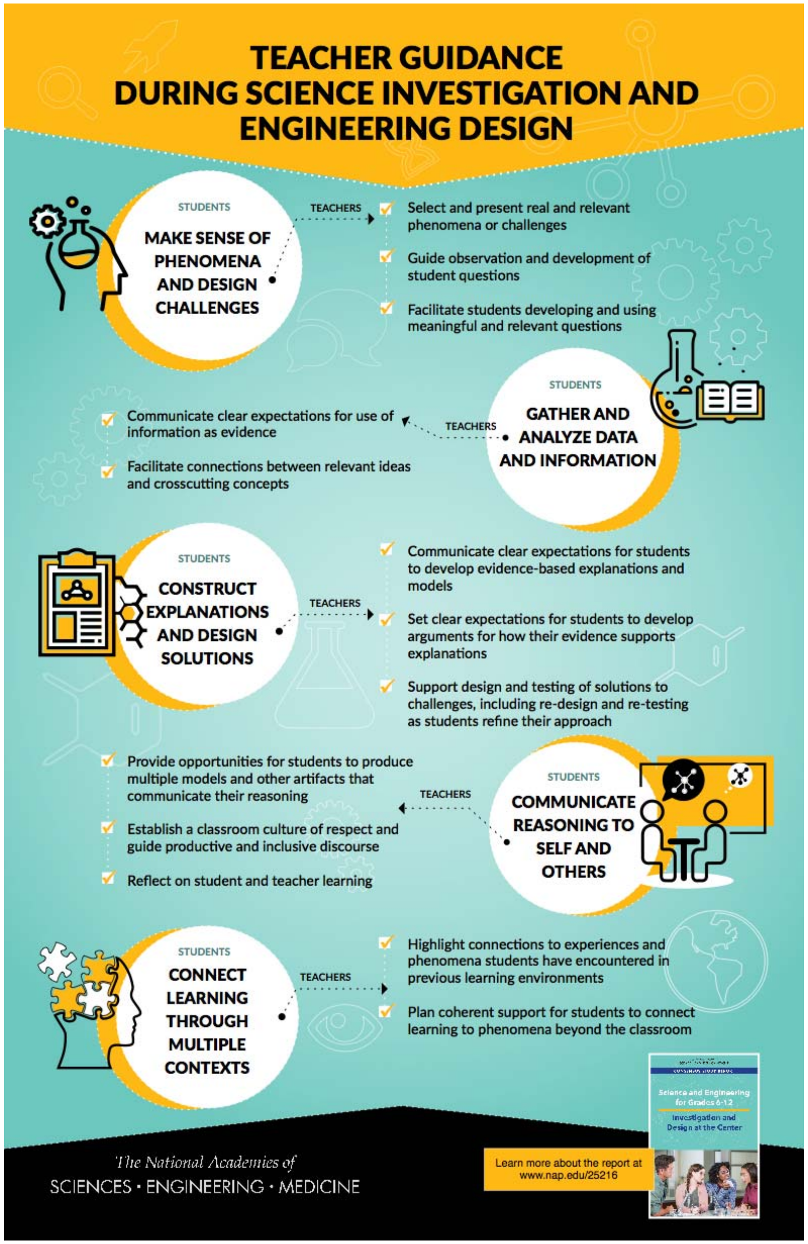
RECOMMENDATION 2: Three-dimensional science and engineering performances

- Teachers monitor learning via ongoing, embedded, and post-instruction assessment
- Teachers use formative assessment tasks and discourse strategies
- Students share, develop and revise their ideas
- Teachers use evidence from formative assessment to guide instructional choices

RECOMMENDATION 3: Instructional resources consistent with the *Framework* and knowledge about how students learn

- Teams of teachers and designers of instructional resources
  - Develop coherent sequences of lessons
  - Include information on strategies and options to increase relevance to students' backgrounds, cultures, and place

- Administrators provide access to
  - High-quality instructional resources
  - Space
  - Equipment
  - Supplies

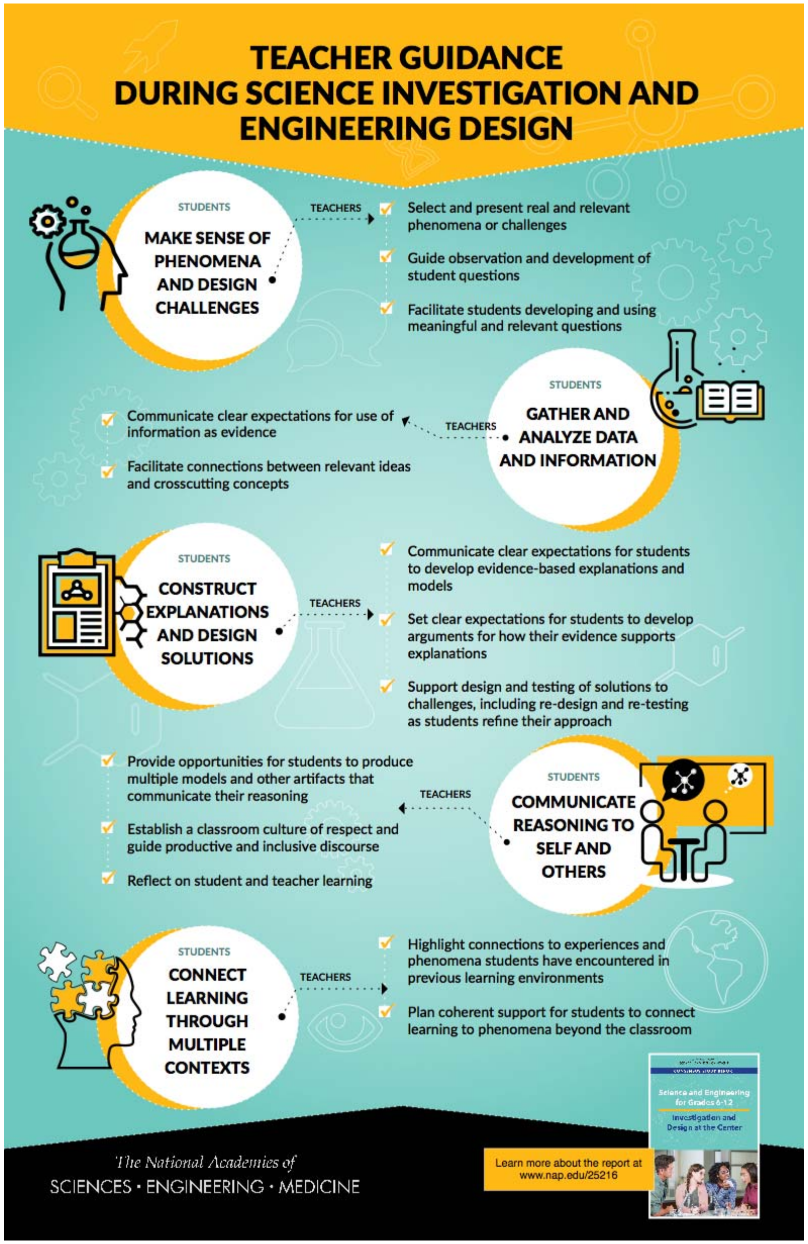


Teacher Guidance

The full Interactive Infographic is available at

https://www.nap.edu/resource/25216/interactive/

Questions?



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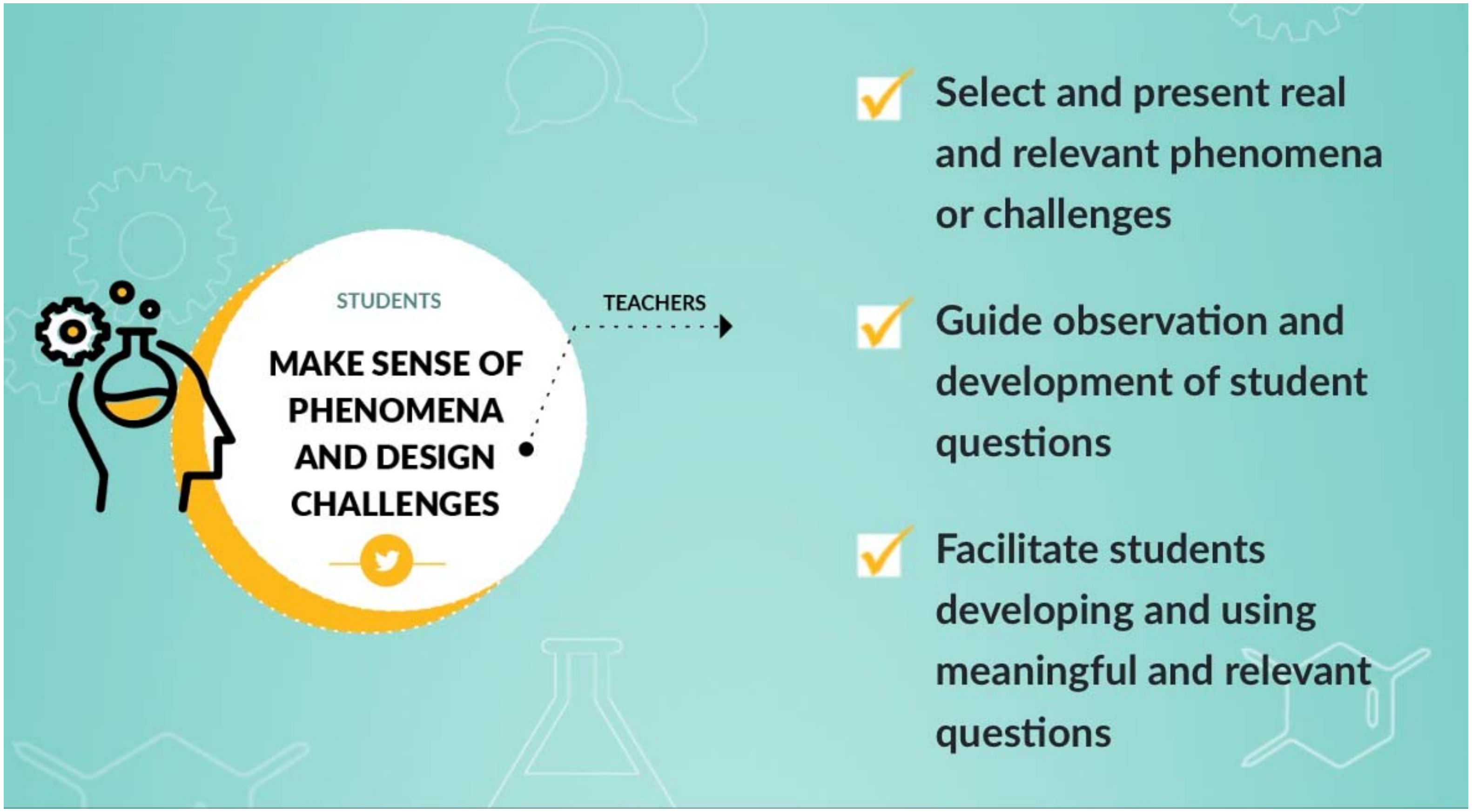
Make Sense of Phenomena and Design Challenges



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Make Sense of Phenomena and Design Challenges

Phenomena that students will find interesting/ relevant/relatable/compelling – developing a need to know.

Phenomena need to be complex to engage learners in using all three knowledge dimensions - DCIs, CCC, scientific practices

How students develop and use questions – have them experience phenomena and based on that experience ask questions!

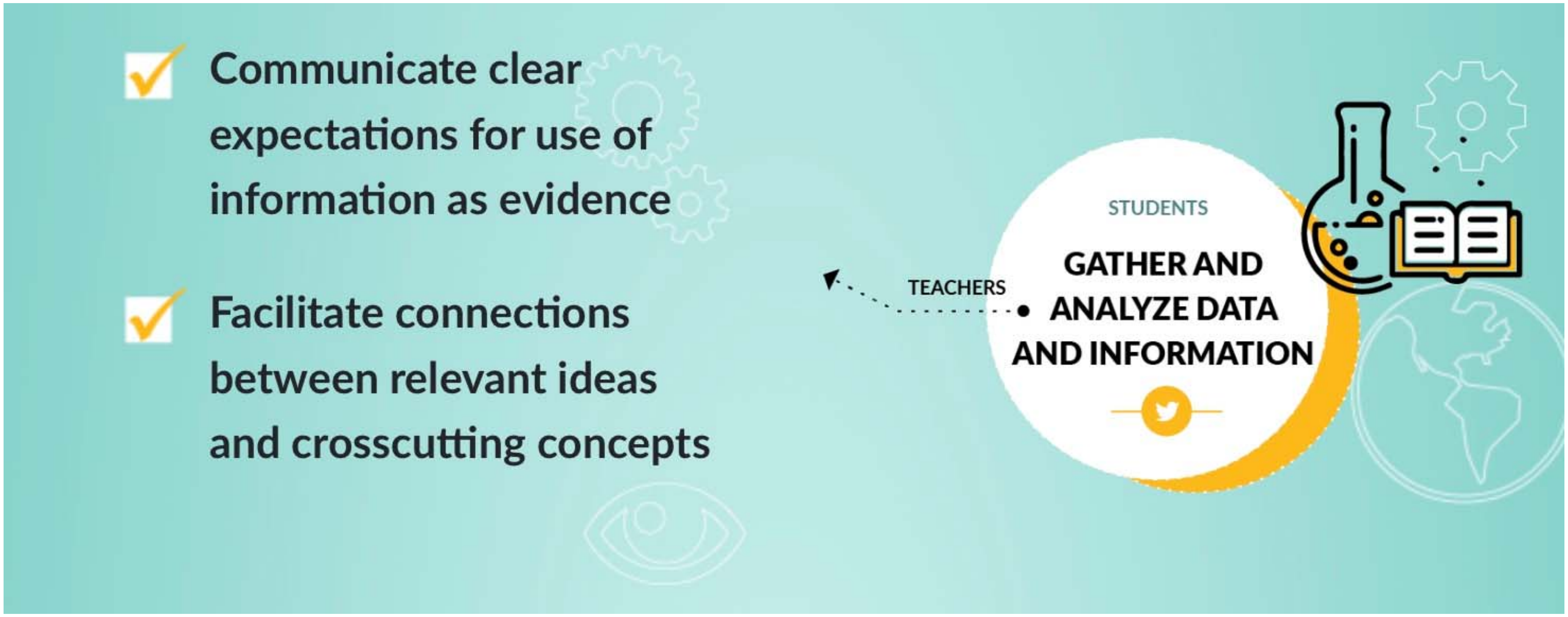
Possible compelling and complex phenomena:

Why can you eat some substances like table salt (NaCl) but the components (Sodium and Chlorine) are toxic?

How can I design a vehicle to be safer for a passenger during a collision?

How healthy is our stream for fresh water organisms? How do our actions on land impact the stream and the organism that live in it?

Gather and Analyze Data and Information



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Gather and Analyze Data and Information

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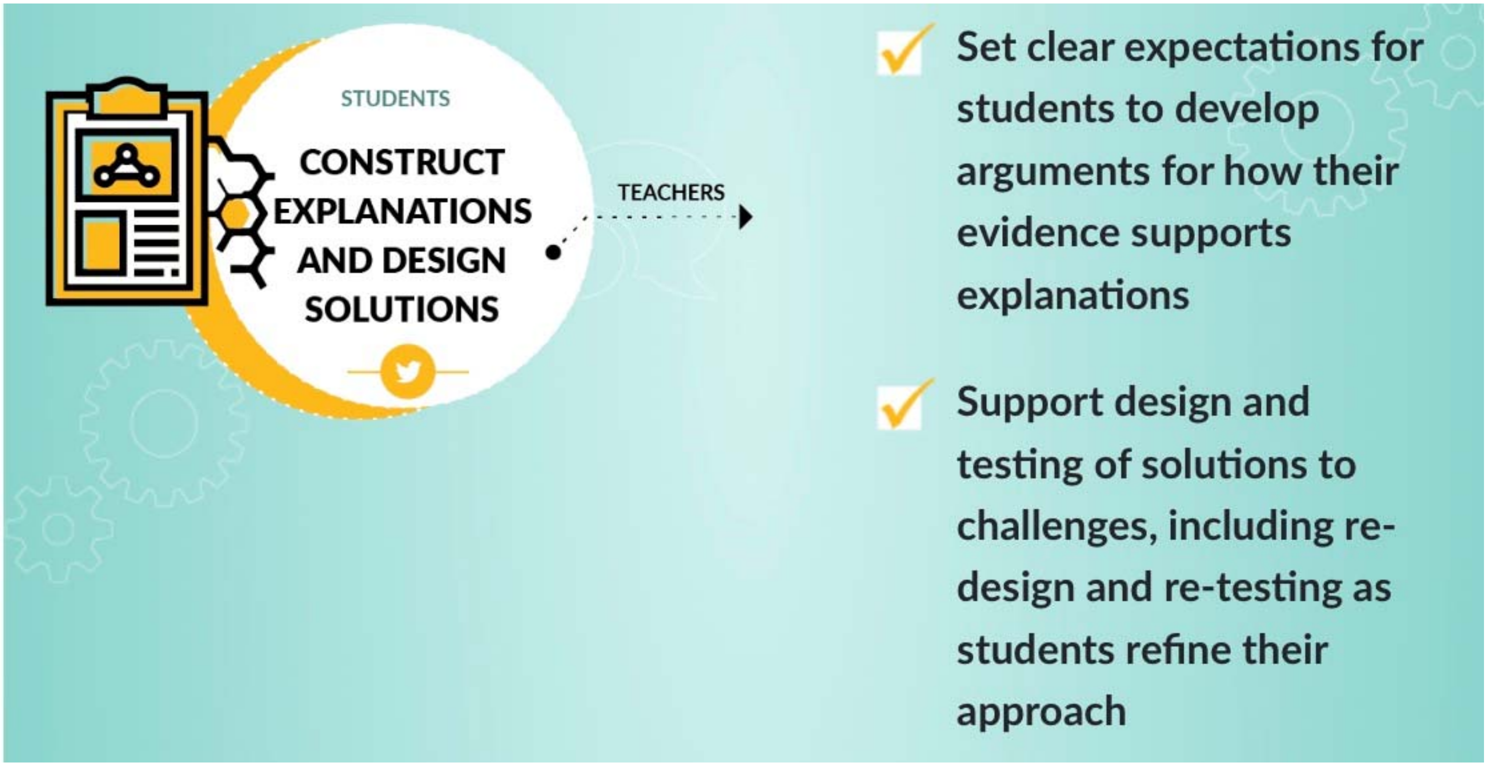
Construct Explanations and Design Solutions



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Construct Explanations and Design Solutions

Use Evidence

- Is it sufficient?
- It is appropriate?
- Can stem from qualitative and quantitative data

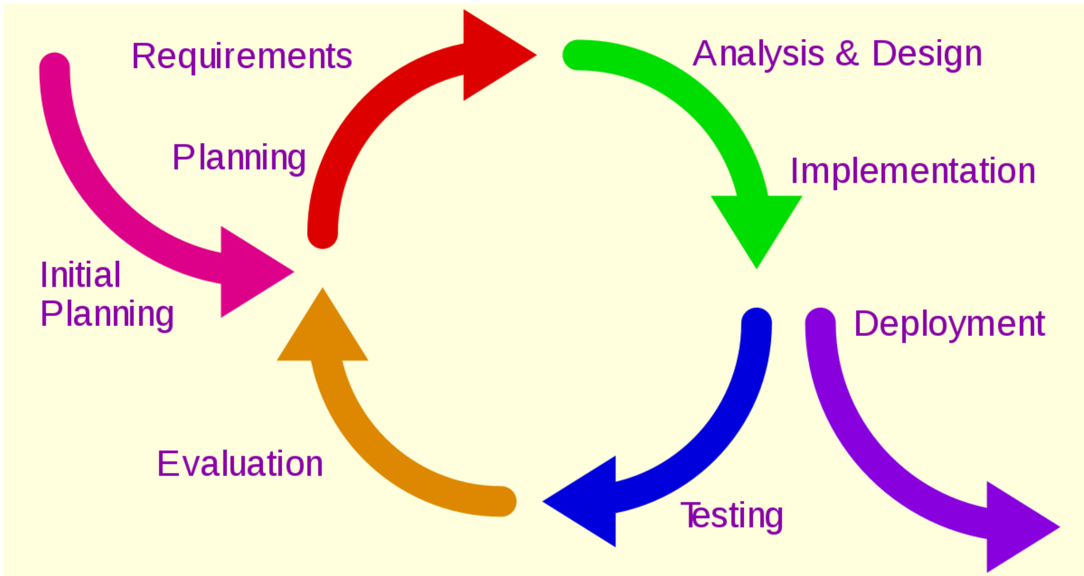
Develop Arguments

- What is the most appropriate claim?
- Does the claim fit the evidence?

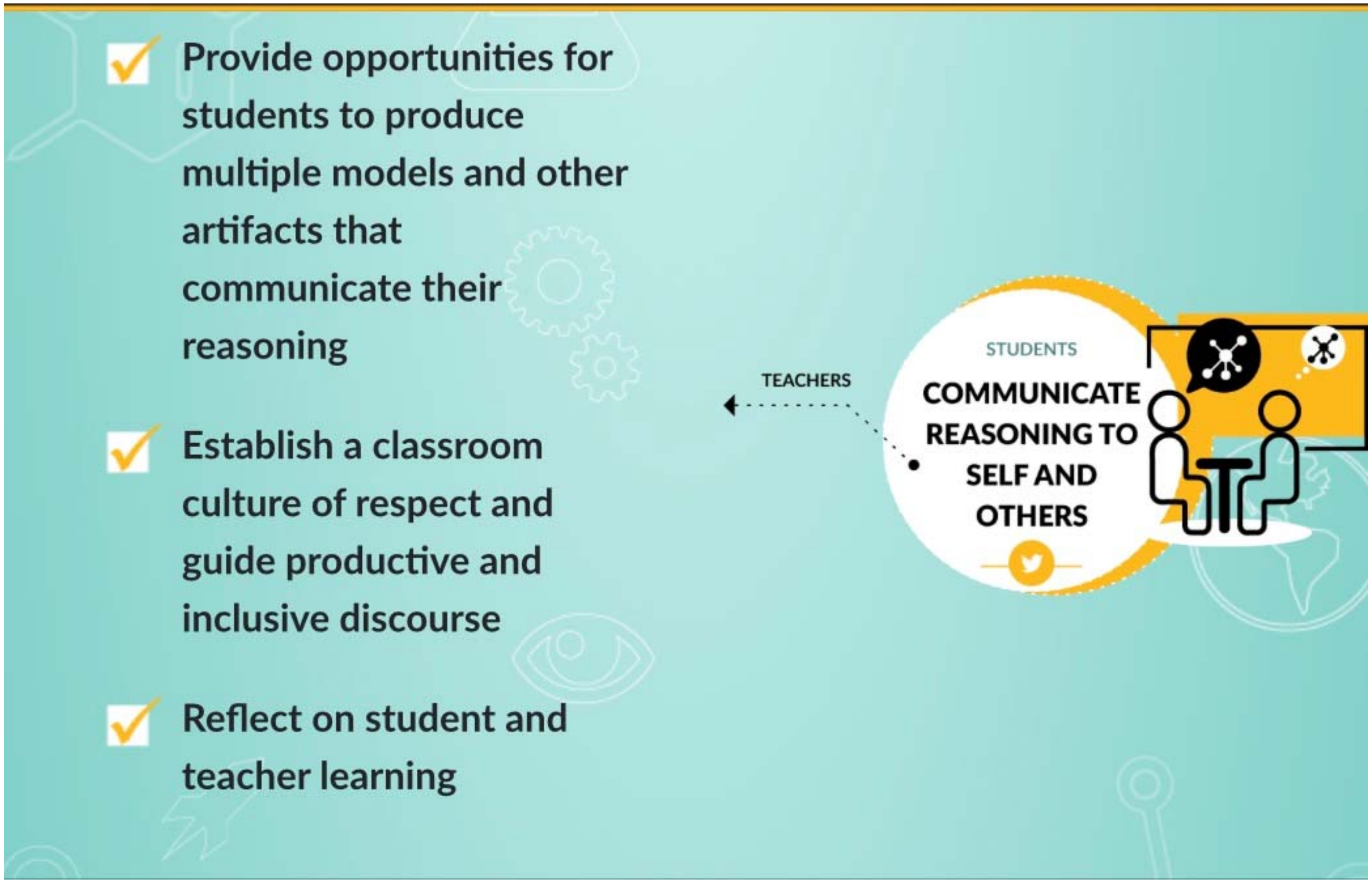
Construct Explanations and Design Solutions

Design and Test Solutions

- Criteria and Constraints
- Iterative cycles of testing and redesign



Communicate Reasoning to Self and Others



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Communicate Reasoning to Self and Others

- Discourse
- Talk Moves
- Eliciting and Support
- Inclusive Discussions
- Using Student Ideas t

Resources for Teacher Guidance

TABLE 5-2 Talk Moves

Talk Move	Purpose	Example
Marking: "That's an important point."	Pointing out to students what a student has said that is important given the teacher's current academic purposes	"Did everyone hear what Marisol just said? She made a comparison between this phenomenon and something she experienced with her family last summer. That's important because it shows that we're connecting what we're doing in school to what's happening in our everyday lives."
Challenging Students: "What do YOU think?"	Promoting academically rigorous conversation by challenging students and turning the responsibility for reasoning back to students	"That's a great question, Kwame. What does everyone else think?" "That's an interesting idea, is there a way we could possibly test it to see if it's true?" "Can you give an example?" "Does your explanation fit with other science ideas, like [state science concept]?"
Linking Contributions: "Who wants to add on . . . ?"	Helping students link their contributions to the ongoing conversation	"Who disagrees with Arjun?" "Who else wants to add on to what she just said?"

BOX 5-5
Eliciting and Supporting Student Ideas with Talk Moves

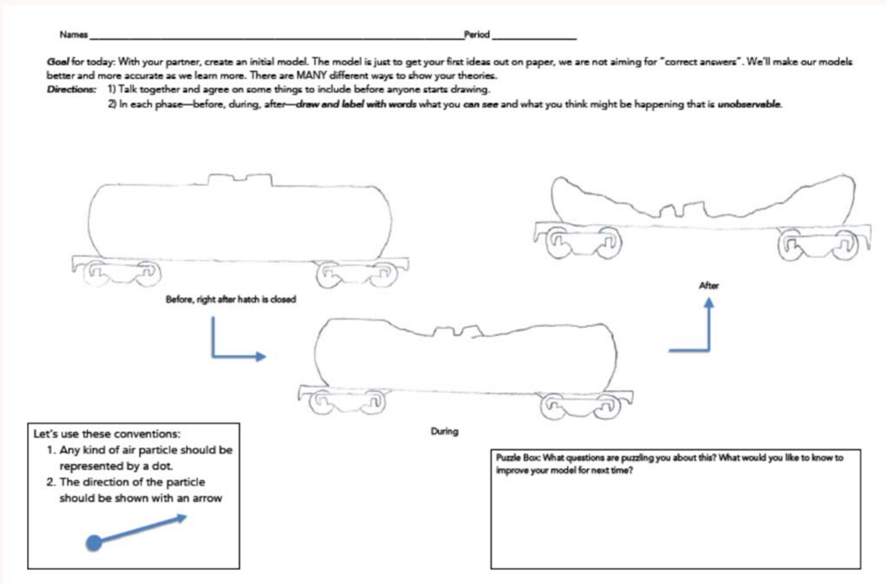
As part of the lesson described above on the tanker, students worked in small groups, having conversations in which they shared their ideas about what might have happened. After a few minutes of students talking and drawing their ideas, Bethany circulated to small groups, using talk moves to draw out and refine students' ideas and encouraging them to connect their drawings back to the phenomenon of the crushing tanker. An excerpt of the conversations is reprinted here.

Student: So we said that if it was like regular air in the beginning, this is air on the outside, and this is the air on the inside, and then when the steam, it was like bouncing the molecules . . . and then, um, what did we say? It's complicated.
Bethany: Because this looks empty now, is this empty?
Student: Well, I mean maybe it has some air in it.
Bethany: Because this is, they steam cleaned it, they closed all the valves . . .
Student: Oh so inside . . .
Bethany: So nothing can get in or out. So there still has to be something in here, what's in here?
Student: Just some air . . .
Bethany: What happened to the steam?
Student: It went out when it exploded.
Student: It didn't explode!
Student: I mean imploded 'cuz it like you know it broke, so now there's holes all over it so steam got out.
Bethany: So let's assume that it didn't break, that it just crushed. So like you know, ah . . .

Communicate Reasoning to Self and Others

- Artifacts and representations
  - models
  - written reports
  - videos
  - blogs
  - computer programs
  - presentations

Communicate Reasoning to Self and Others



Names ________________________________ Period __________

Goal for today: With your partner, create an initial model. The model is just to get your first ideas out on paper, we are not aiming for "correct answers". We'll make our models better and more accurate as we learn more. There are MANY different ways to show your theories.

Directions: 1) Talk together and agree on some things to include before anyone starts drawing.
2) In each phase—before, during, after—***draw and label with words*** what you ***can see*** and what you think might be happening that is ***unobservable.***

Before, right after hatch is closed

During

After

Let's use these conventions:
1. Any kind of air particle should be represented by a dot.
2. The direction of the particle should be shown with an arrow

Puzzle Box: What questions are puzzling you about this? What would you like to know to improve your model for next time?

FIGURE 5-1 Initial template for student work on tanker explosion.
SOURCE: Windschitl, Thompson, and Braaten (2018, p. 123).

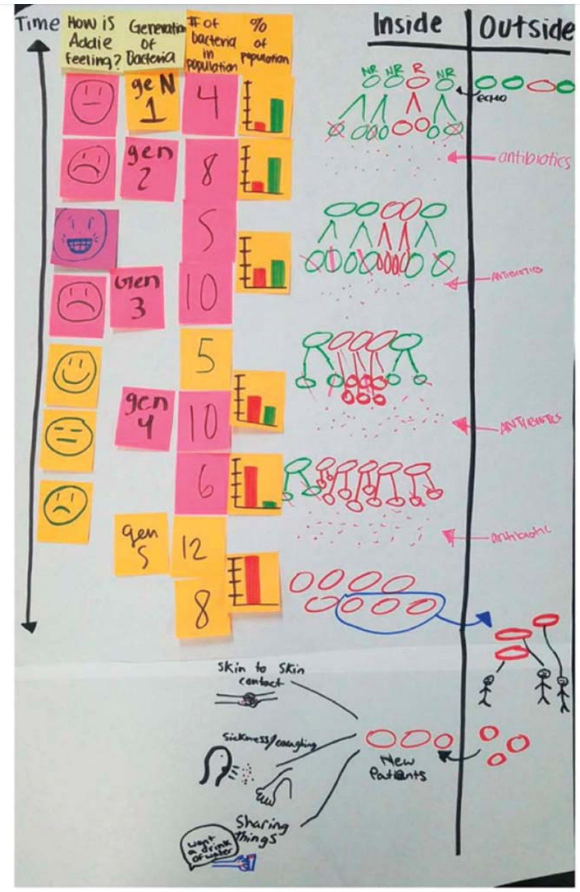
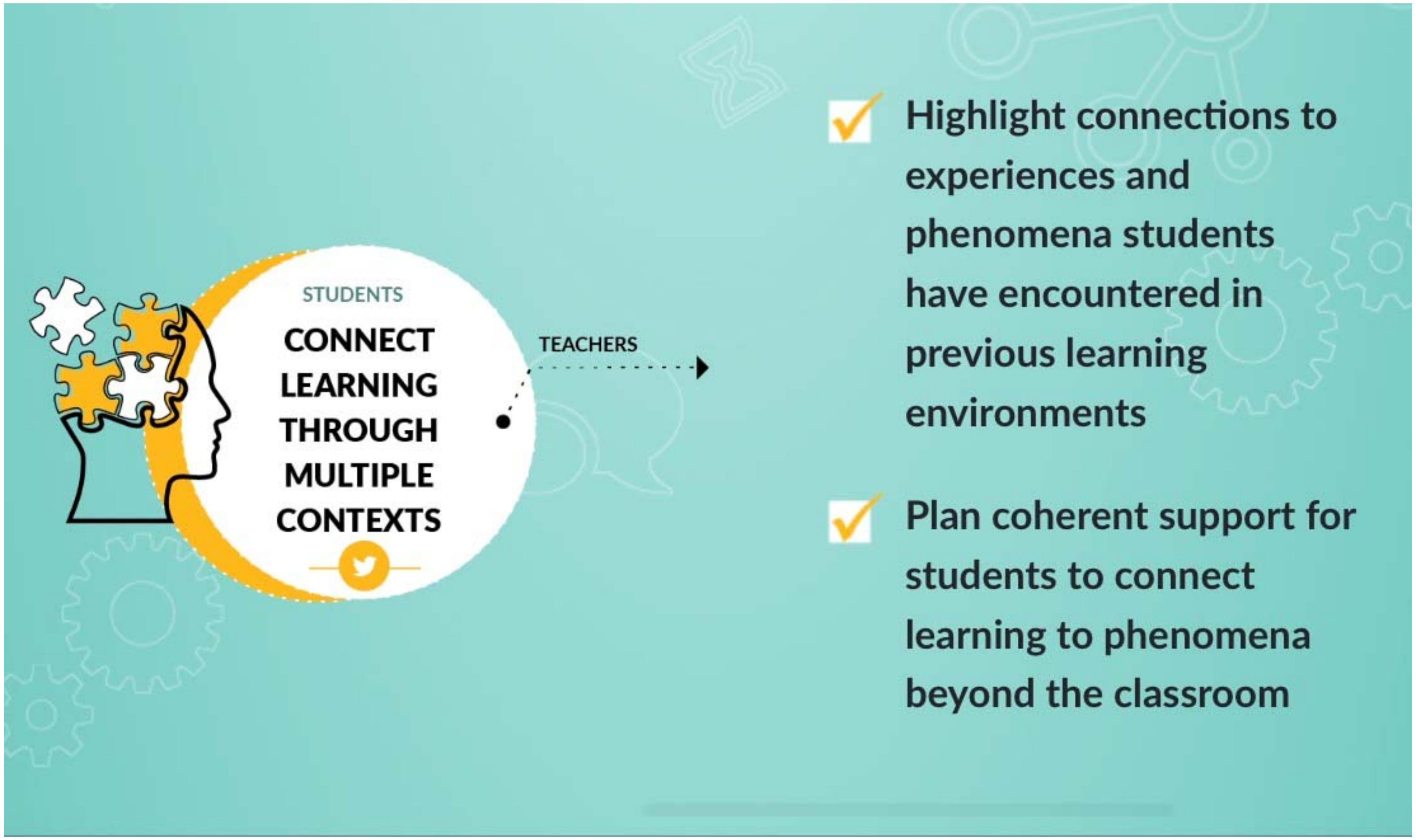


FIGURE 4-3 A small group's revised model to explain how Addie's condition changed as the bacteria changed within her.
NOTE: The model is organized into how Addie is feeling, the generation of bacteria, size of the resistant (R) and nonresistant (NR) bacteria population, and what is happening inside and outside Addie's body.
SOURCE: Reiser and Penuel (2017)

Connect Learning Through Multiple Contexts



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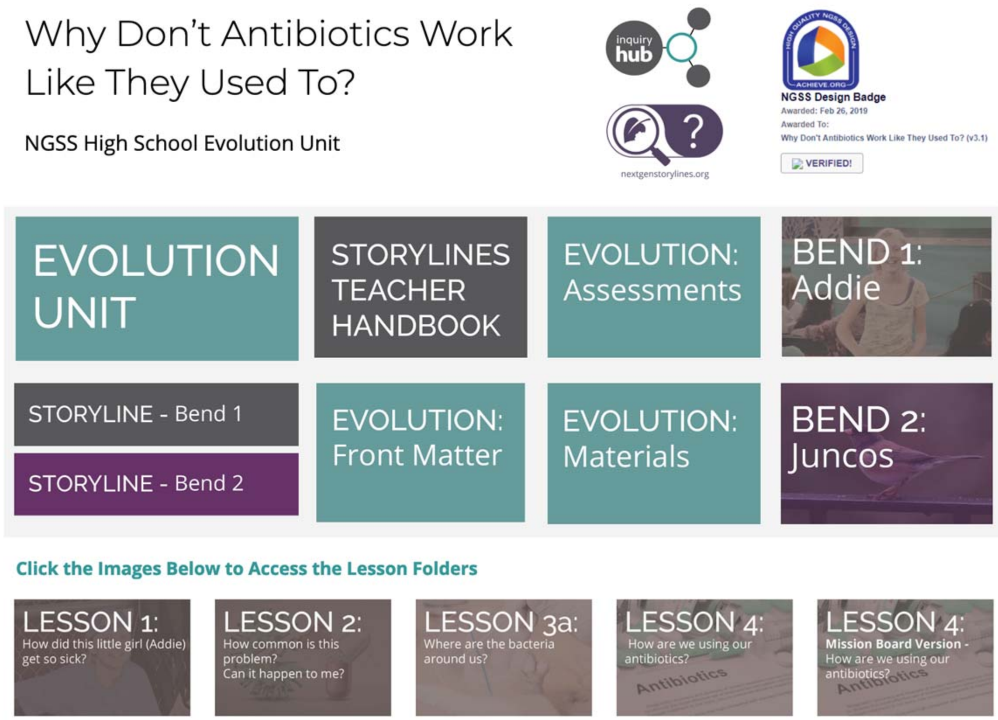
Connect Learning Through Multiple Contexts

Coherent curricula

A **storyline** is a coherent sequence of lessons, in which each step is driven by students' questions that arise from their interactions with phenomena (NGSS Storylines, 2017)



Inclusive Pedagogies

BOX 4-2
Growing Strawberries

Teresa, a high school student working on an engineering design project, attempted to address several factors she had learned at school as she tried to grow strawberries in a community garden. She and several of the other Hispanic youth working on the design project had many previous experiences growing home gardens, including many vegetables and fruit such as cucumbers, jalapenos, watermelon, cilantro, green chili, pumpkins, beans, garlic, raspberries, and strawberries. She and the other students working in her group had all had the experience where plants had not grown as they had expected. They tried out controlled experiments to diagnose and develop solutions to this problem. Some students noted that their family goat "basically ate all the garden," and others identified soil erosion, inadequate sunlight, infertile soil, and freezing temperatures.

Teresa described her own testing process as she tried growing strawberries over the course of several years: "If it doesn't turn out, then I go back in my mind and be like 'What was the part that I'm missing? Or what did I do wrong?'" One year she gave two different fertilizers to the plants to observe how each fertilizer affected their growth. However, during that same year, the plants were located in the path of rainwater that came out of a gutter. It seemed that the eroding soil, and not the fertilizer, was keeping the strawberries from growing, so she moved the strawberry plants to another part of her yard. However, despite her trying to use different kinds of fertilizers, the plants still were not growing as she expected. Teresa reflected on other possible causes for the plants' failure to grow and thrive, including the "bugs in the garden" that she had seen. Based on these experiences, she used pesticides on the strawberry plants in a later season, but then a family member ran over them with a car by accident. She noted that this inadvertent error limited her ability to conclude whether the pesticides had an influence on the growth of the strawberries. Throughout this process, while working in her home garden, Teresa had sought to design valid experiments in which she isolated single variables, made observations, developed tentative conjectures in regards to causation, re-

Leveraging student experiences to support their science learning

(Wilson-Lopez et al., 2018)

Inclusive Pedagogies

BOX 5-1
Design Challenge Topics

Christopher G. Wright (Drexel University) studies the interrelationship between engineering competencies and identities for African American males. Focusing on what Nasir and Hand (2008) referred to as "practice-linked identities," Wright works to identify real-world design challenges that could potentially engage this student demographic, while providing authentic opportunities to participate in engineering and science practices. This work can lead to an understanding of the ways in which learning contexts could potentially support the learning and identities of students who have been historically marginalized within STEM communities.

Wright has worked with middle school students to understand the relationship between learning and identity in these contexts. The complexity in this work is avoiding the essentializing of students by boiling them down to common stereotypes and assumptions in what might interest them, but to truly understand what it means to engage students by incorporating aspects of their lived experiences and community capital. Considering students' competencies and identities, teachers may consider a more expansive learning space where students can participate in and reconstruct meanings for their own engagement in learning engineering and scientific competencies. Wright suggests that teachers identify the kinds of engineering challenges (e.g. particular human problems, and engineering practices in order to address student interests, participation, engagement, and identity development).

In a recent pilot study, Wright has worked with middle school students to explore the question, *What role do engineers play in the design and analysis of sneakers?* In addressing this question, students explore why different types of sneakers are used in a variety of common sports, study how engineers analyze the needs of athletes, and explore how engineers engage in the design of sneakers in order to meet athletes' needs. Students have opportunities to analyze foot movement in a variety of different sports and develop design criteria for individual sports and/or athletes.

SOURCE: Adapted from material presented to the committee by Christopher Wright on July 24, 2017.

- ***Concept Project**: Bioengineering and Shoe Design (kinds of challenges)*
- What role do engineers play in the analysis & design of sneakers?

Upcoming Webinar

Professional Learning for Investigation and Design
March 28 at 1pm EDT

More Information and registration links for the webinar can be found at
nas.edu/Science-Investigation-and-Design