Methods and Strategies

Getting a Grip

A framework for designing and adapting elementary school science investigations

By Eve Manz

eimanz@bu.edu

Eve Manz (eimanz@bu.edu) is an assistant professor at Boston University Wheelock College of Education & Human Development in Boston, MA.

Mrs. W.'s third-grade students had been studying a "wild" area behind their school, a small trapezoid that the school custodian did not mow (Figure 1). Students had figured out that seeds had traveled into the backyard in various ways. They were now wondering if the shade cast by the school wall and two Magnolia trees mattered for the growth of plants.

Mrs. W introduced the Wisconsin Fast Plant (see Internet Resources), telling students, "We're going to do an investigation to see if it matters for this seed whether it lands in a place with more or less light." She showed students a light box **(See Resources)** and asked, "What do you think that this is going to act like?" Students readily identified that the light box acted as the Sun, providing light for growth. Mrs. W. helped students identify how parts of the setup (a wicking system to keep the plants moist; fertilizer pellets) represented aspects of the outdoor system. Fertilizer pellets were placed in a small dixie cup, then tipped into the soil by students. Students used spoons and toothpicks to move soil.

Mrs. W. then asked partners to figure out how they could use the setup to investigate the plant's light needs. Students' ideas included comparing plants grown in a light box with a light on as compared to off, with different hours of light/day, and with a screen blocking light as compared to no screen (Figure 2). After discussing ideas, the class designed an investigation comparing plants in three conditions: "sun," where the light was always on, "shade," with the light always off, and "sun and shade," with 7 hours of light per day to represent areas of the backyard where light shifted over the day. Students discussed whether the "shade" box should have all the light blocked by a dark cloth and agreed that it should not, since some light could get into the backyard's shady areas.

In this example, students develop an investigation to help them understand a complex system, and in doing so develop their understandings of plants' needs and life cycles (see Connecting to the NGSS on p. XX; Please note that this investigation was taught in a state that had not yet adopted NGSS and, therefore, plants' needs and life cycles were addressed in the third grade curriculum.) Experiments and other empirical investigations are, at heart, tools that scientists use to represent phenomena that are difficult to observe, measure, and compare: they are ways to "get a grip" on the world (Lehrer and Schauble 2012; Manz, 2015). In contrast, in elementary science classrooms, we often simplify investigations and provide step-by-step instructions telling students what to see so that they reach a desired conclusion. In this article, I share a framework for rethinking the classroom investigation. I describe how this framework (1) better represents how scientists use investigations and (2) supports opportunities for elementary students to engage in argumentation, explanation, and planning and carrying out investigations. I then discuss strategies that teachers can use to design or adapt investigations by implementing the framework.

Safety Sidebar

The outdoors area, which students visited regularly, was fenced and gated. Before visiting the outside area, Mrs W and her students discussed guidelines for safety, for example, staying in the backyard area, staying on paths, and not picking or breaking parts off plants before checking in with an adult. Mrs. W regularly discussed and reinforced these guidelines.

The Investigations Framework

The Investigations Framework (Figure 3) focuses on four components of scientific activity: a *complex phenomenon* (the backyard setting with different plants in different places), the *empirical investigation* (Fast Plants in different light conditions), *observations and evidence* (noticing and comparing attributes, organizing data) and an *explanation* (different plants are successful in different light conditions). We can think of the arrows as "transitions" between these components, in the sense that scientists have to do work to move from one component to another. These transitions can support rich discussion in elementary classrooms.

The first two arrows represent the work that scientists do to generate evidence: they must decide how to represent a phenomenon to generate an informative comparison, determine what is worth paying attention to, and find ways to describe and measure attributes so that outcomes can be compared and agreed on by other scientists. In the Fast Plants Investigation, rather than introducing a plant growth experiment and asking, "Do plants need light?" we introduced the investigation as a way to help students test their ideas about plant growth in the backyard. We made space for students to consider how to represent the system in an investigation (how to represent shade) and develop an informative comparison (three conditions, same moisture).

We also helped students to think about what to count as evidence (e.g., height, color, or seedpods) and allowed them to come to different conclusions based on different kinds of evidence (Figure 4). The plants grown in the light box that received light for seven hours a day stayed green and grew relatively tall but did not produce seedpods; the plants in the "sun" condition turned brown and crunchy but produced copious seedpods. Students had to consider which evidence mattered given their interest in explaining where plants were growing in the backyard. As student disagreements became evident, we introduced read-alouds and discussed the life cycles of plants, unpacking how reproduction allows plants to make more of their own kind and grow more and more over time in a particular area. Doing so allowed students to understand why seedpods were an important measure of success.

Figure 3 also represents two transitions scientists navigate as they move from evidence to an explanation. One of these transitions involves well-described practices such as analyzing and interpreting data and drawing an evidence-based conclusion about the investigation (McNeill and Martin 2011; Zembal-Saul, McNeill, and Hershberger 2013). Figure 3 also highlights another important transition: moving from the investigation-based conclusion to an explanation of a complex phenomenon that the investigation likely did not perfectly represent.

During the Fast Plants investigation, students came to agree that the plants in the sun condition were most successful because they produced seeds and would make more of their own kind. However, not all plants need continuous light inches from their leaves to reproduce and grow in a particular area. And not all plants reproduce within 40 days. The plants that we had been studying in the backyard were found in different conditions. Some produced seeds and turned brown in the fall; some (like the Magnolia trees) never turned brown.

How would we help students make sense of these discrepancies and develop a more powerful and general explanation? Mrs. W. introduced a new claim:

"I think the just right amount of light for all plants in the backyard is sun. So when we go outside, I think we will find no plants in the shade, some plants in the sun and shade, and lots and lots of plants in the areas that always get sun."

Several students disagreed, arguing, "No, the strawberry's not really in a place in the sun" and "Because when you go in the Wild Backyard there are some." Students then began to generate reasons for the differences. Steven argued, "the light box doesn't have as much sun as the sun, we're just pretending it does."

As they continued conversations in small groups, several students noted that the experiment used only Wisconsin Fast Plants, while there were many kinds of plants outdoors. Azhad (all students' names are pseudonyms) argued, "we have two different plants…some are MADE to live in the shade." Mrs. W. asked him to voice this idea in the ensuing whole-class conversation, invited response, and introduced a read-aloud (see Resources) about the structures that allow plants to live in different conditions. Eventually, students agreed that different plants can be successful given different amounts of light. They returned to the backyard in the spring to understand which plants were successful in which light conditions. In addition, they used what they had learned about the much shorter Fast Plants life cycle to consider how the plants they saw in the backyard had changed over the course of the school year. They were now able to see seasonal changes as part of the outdoor plants' life cycles, rather than evidence that the plants were not getting what they needed.

In this investigation, students were supported to consider how to move between a complex phenomenon, an empirical investigation, evidence, and explanations. This work supported rich opportunities for argumentation and explanation. Because students focused on different forms of evidence, they initially disagreed with each other about how much light was best for Fast Plants, establishing a need to reason about evidence, a practice that can be harder to invoke in elementary classrooms (Zembal-Saul, McNeill, and Hershberger 2013). Disagreements and surprises also established a need for students to develop explanations; for example, to consider why plants in the backyard did well with less light than Fast Plants. Over the course of the seven-week investigation, the classroom was full of lively discussions about what to do and conclude (ELA CCSS.ELA-LITERACY.SL.3.1).

Using the Investigations Framework to Design or Adapt Investigations

The Fast Plants example above illustrates how the Investigations Framework can support students to more deeply consider questions about how to design an investigation, what to use as evidence, and what to conclude. Below, I describe design and teaching strategies drawn from this work. I use examples from both the Fast Plants investigation and a Landforms investigation conducted in a second grade classroom. The Landforms investigation allowed students to explore ideas about how wind and water shape land (NGSS DCI ESS2.A). Students first examined pictures of storms occurring in familiar landscapes and make predictions about what might happen to the land. They examined different earth materials (rocks, sand, and soil) that they had conjectured were present in the landscapes and discussed whether they thought that wind and water could move these materials. In small groups, they designed ways to use a straw and a squirt bottle to compare how the earth materials moved and determined what data to collect. Finally, they wrote down their claims and evidence and presented their findings to their classmates, then discussed as a class how their investigations helped them understand how wind and water shape landscapes such as the ones they examined before conducting the investigation. Table 1 in the supplementary materials provides concrete examples of these strategies. These strategies can be adapted for different classrooms, content areas, and student learning goals.

1. Anchor investigations to a rich phenomenon

Rather than posing a general question (Do plants need light to grow?), consider what phenomena your classroom investigation can help students explore. Before introducing the investigation, give students ample time to experience the phenomenon and to share their initial explanations. If you are placing cars on ramps with different surfaces, consider examining a sledding scenario. If you are using compost columns, begin with a rotting log. Phenomena not only engage students and motivate investigation questions but also enrich students' thinking and argumentation during the investigation because students have more resources to think with. When chosen to be both rich and accessible to students, phenomena function as a strategy for equity, in that they allow all students access to sense-making, and for formative assessment, in that asking students to engage with the phenomenon and develop tentative explanations will allow you to see what students are paying attention to, what partial explanations they are bringing to instruction, and what they don't yet understand about the conceptual content under study. This will allow you to tune your investigation to students' ideas and provide appropriate support throughout the investigation. (See Resources for sources of phenomena.) Unpack the transitions needed to move from the phenomenon to the explanation you hope students will develop.

Any investigation involves the transitions identified in Figure 3. Someone (the curriculum developer, teacher, students) makes choices about what to represent, what to count as evidence, and what the investigation can explain. Identifying these choices will help you understand where students may need support and where you might incorporate opportunities for sense-making, explanation, and argumentation. Key questions that emerge during the transitions in Figure 3 include:

Phenomenon to Investigation

- *What to represent and how:* Do we represent shade with a screen blocking light, a light that is turned off, or a totally black box? Why are we spraying a spray bottle to represent water shaping land rather than pouring water?
- *How to understand differences in the values of variables:* Often, classroom investigations involve scaling down variables that are too large to examine in the real world. For example, testing wind and water shaping land inside the classroom will involve significantly weaker forces of wind and water and significantly smaller amounts of land materials than used outside.

Investigation to Evidence:

- *What to use as evidence:* It is often taken for granted that students understand what to look at and why. We have found that it isn't always entirely clear why a particular form of evidence is being considered, and that allowing students to generate different forms of evidence generally leads to rich discussion. For example, is color evidence of plant success? Is floating evidence of the movement of earth materials due to water?
- *How to define and measure attributes:* This is another easy-to-overlook but generative aspect of investigations. Seeing takes scientific knowledge; debating how to see attributes in the same way involves students in building scientific understanding. It can be productive for students to discuss how to define plants dying, what to count as a seedpod, or how to agree on whether rocks moved "a little" or "far."

Evidence to Explanation:

- *What can and can't be concluded about the world:* Due to choices about representation and scale, there is generally a discrepancy between what can be concluded from an investigation and how the world works. In the Fast Plants investigation, students needed to grapple with the differences in the kind of plant and timing of the life cycle of the plant chosen for the investigation, as compared to plants in the backyard. In the landforms investigation, we might ask: if the rocks in our landforms investigation did not move when sprayed, how do large rocks move to new places or change shape over time?

3. Determine how to productively engage students in navigating transitions
   There are several teaching strategies for discussing transitions. In any investigation, you might use a combination of these strategies to provide support and focus students' decision-making on the questions richest for argumentation and explanation. The strategies you choose to use will depend on what discussions are most productive given the core ideas you are addressing and how much support your students need.

- *Explain or provide information so that a transition makes sense to students*. There some decisions that are necessary for the success of the investigation (e.g., using a setup that allows Fast Plants to flourish). In these cases, you might determine these parts of an investigation, but take the time to help students understand what they represent; for example, as Mrs. W. unpacked how the light box, wicking system, and fertilizer pellets represented parts of the backyard system. You can begin by asking students what these parts of an investigation represent, to assess how they are connecting the investigation to explaining a larger phenomenon, then provide appropriate support as needed.
- *Allow students to make different decisions to generate variability in claims and evidence.* When students can make different decisions (e.g., about how to represent a phenomenon or what to use as evidence), they will often reach different conclusions. As they recognize that their conclusions don't agree, they will more naturally question each other about differences in methods, supporting opportunities for deeper discussion, for example about what the best evidence of plant success is.
- *Use structured discussion strategies.* Sometimes, we need to implement more scaffolded and time-efficient strategies than allowing students to invent and compare different methods. One such strategy is for the teacher to *propose an idea that is so outrageous the*

students find fault with it, therefore leading to a need to consider what to do or conclude. For example, a teacher can propose a conclusion that generalizes problematically from the investigation (e.g., that the backyard should only have plants in sunny areas). Another strategy is to *present two distinct choices* for students to discuss; for example, whether we should make the shade box entirely dark or allow some light to get in. These strategies can be particularly useful when your class is new to designing investigations, or if you see that a student or small group is struggling to develop a plan and you need to provide additional support to those individuals.

4. Add assessment questions focused on students' understandings of the transitions to your formative and summative assessment probes.
   As you move around the room and facilitate discussion, consider asking students questions such as "What are you paying to attention to to know…? Why is that important?" or "So the rocks did not move when you blew on them. Does that mean wind can't move rocks?" In your summative assessment, consider asking students to justify the choices that class made or to critique a fictional student conducting and drawing conclusions from a similar experiment.

Conclusion

The transitions between phenomena, investigations, evidence, and explanations are central to scientists' work, but are often left out of, or made invisible in, elementary science investigations. Strategically incorporating these transitions in your classroom provides students a new window into science, supports exciting opportunities for explanation and argumentation, and involves your students in deeper thinking about important science content.

NSTA Connection

Download assessment materials at www.nstaorg/SC0419.

2-LS2 Ecosystems: Interactions, Energy, and Dynamics http://www.nextgenscience.org/dci-arrangement/2-ls2-ecosystems-interactions-energy-and-dynamics 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 expectation listed below.	
Performance Expectation	Connections to Classroom Activity *Students:*
2-LS2-1. Plan and conduct and investigation to determine if plants need sunlight and water to grow	• collaboratively plan an investigation to understand whether amount of sunlight matters for a plant's growth.
Science and Engineering Practices	
Planning and carrying out investigations Constructing Explanations and Designing Solutions Engaging in argument from evidence	• collaboratively design a controlled experiment to compare the growth of plants in different light conditions • discuss what to consider as evidence of plant success • support claims with evidence and examine why different students have reached different conclusions based on evidence • explain why the plants in a wild backyard area are found in different light conditions than predicted by the investigation
Disciplinary Core Idea	
2-LS2.A. Interdependent Relationships in Ecosystems	• determine that all plants need light to grow and reproduce but that different plants can grow and reproduce in different light conditions
Crosscutting Concept	

Cause and Effect Scale, Proportion, and Quantity	• explore how varying the amount of light that plants receive affects their growth • Move from thinking about light and shade as categorical to developing a conception of amount of light described by intensity and duration

Connections to the *Common Core State Standards* (NGAC and CCSSO 2010):

ELA CCSS.ELA-LITERACY.SL.3.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on *grade [level] topics and texts*, building on others' ideas and expressing their own clearly.	• engage in rich discussions in which they question, agree, and disagree with each other and the teacher.
Mathematics	

Acknowledgements

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Resources

Burnie, David. *Plant*. London, UK: DK Publishing [Note: We selected pages most relevant to structures and strategies that allow plants to live in different places: Creepers and Climbers, Meat Eaters, Surviving About the Snowline].

Wisconsin Fast PlantsTM Growing Instructions. https://fastplants.org/pdf/growing_instructions.pdf [Note: Carolina Biological Company also provides growing instructions and is a good source for Fast Plants materials]

Phenomena for NGSS. https://www.ngssphenomena.com

Light box for growing Wisconsin Fast Plants: https://www.carolina.com/wisconsin-fast-plants-supplies/plant-light-house-with-cfl/159004.pr

References

Lehrer, R., and L. Schauble. 2012. Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education 96* (4): 701-724.

Manz, E. (2015). Resistance and the development of scientific practice: Designing the Mangle into science instruction. *Cognition and Instruction*, *33*(2), 89–124.

McNeill, K.L., and D.M. Martin. 2011. Claims, evidence, and reasoning. *Science and Children 48* (8): 52.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. www.nextgenscience.org.

Zembal-Saul, C., K.L. McNeill, and K. Hershberger. 2013. *What's Your Evidence?: Engaging K-5 Students in Constructing Explanations in Science*. Boston, MA: Pearson Education.

Figures and Supplementary Tables

FIGURE 1.

The wild backyard

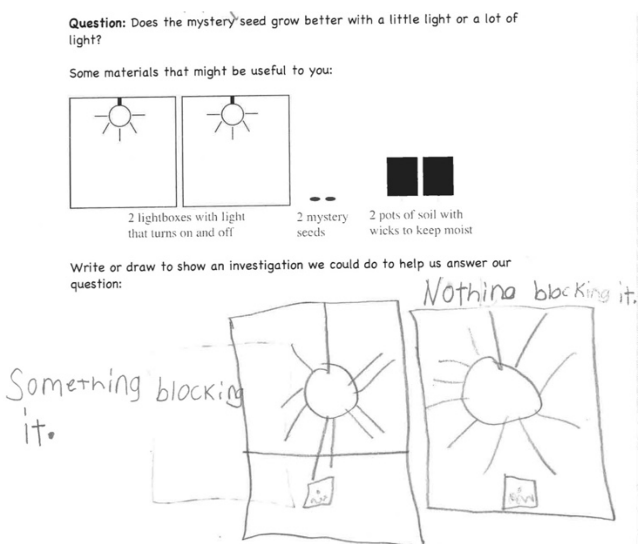


FIGURE 2

An example investigation planning sheet

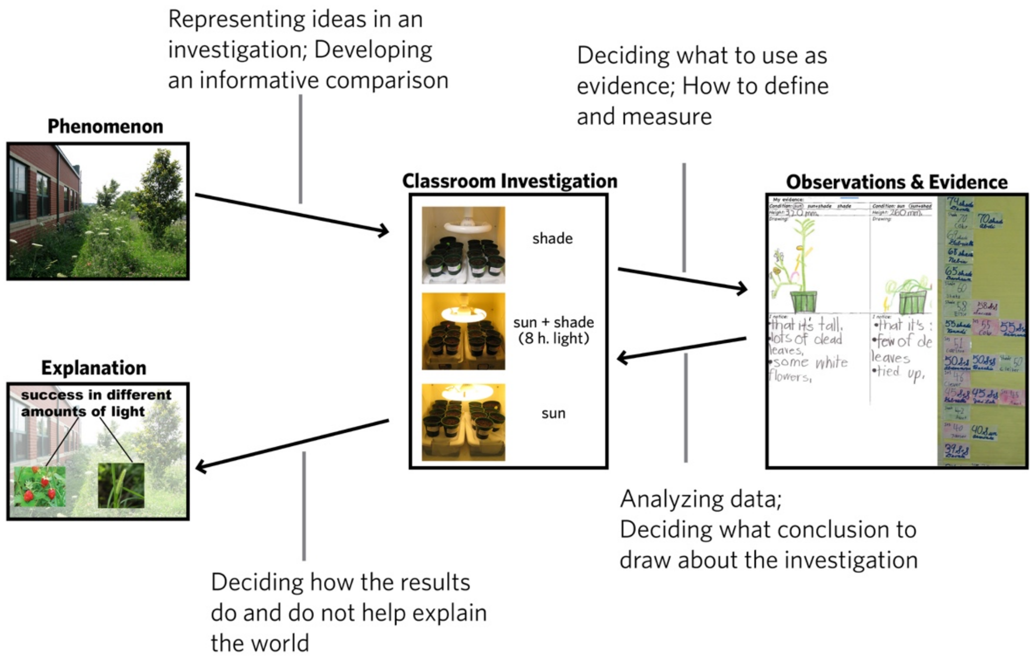
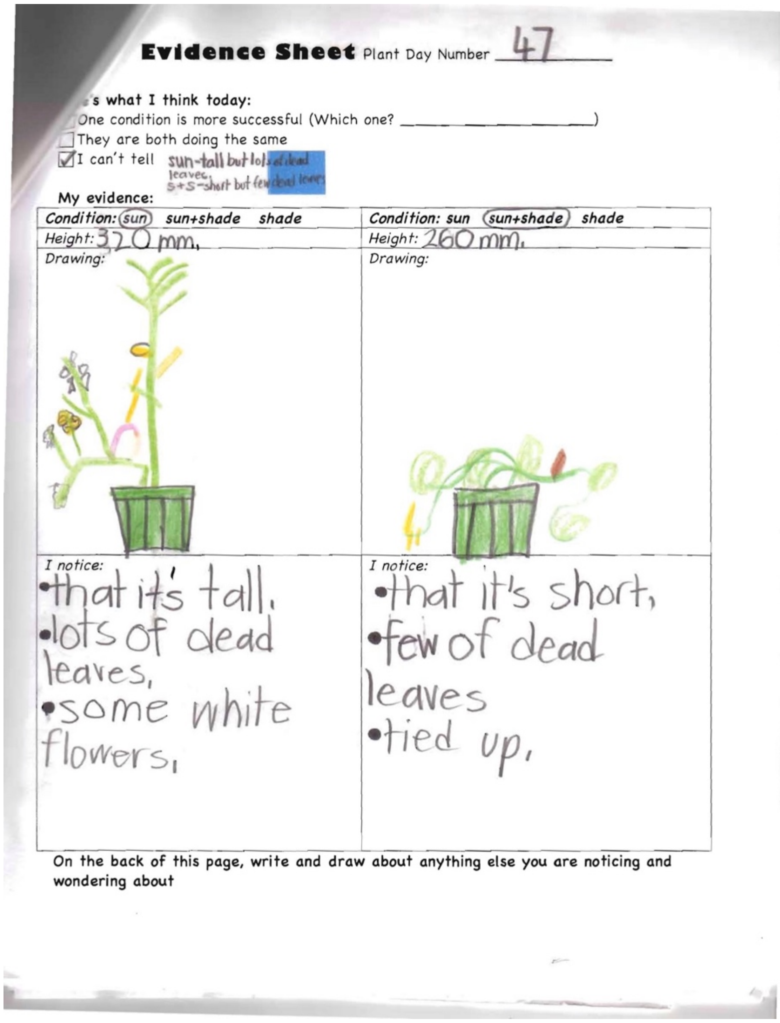


FIGURE 3

The investigations framework



Evidence Sheet Plant Day Number 47

's what I think today:

- [ ] One condition is more successful (Which one? ____________)
- [ ] They are both doing the same
- [x] I can't tell sun-tall but lots of dead leaves, s+s-short but few dead leaves

My evidence:

Condition: (sun) sun+shade shade	Condition: sun (sun+shade) shade
Height: 320 mm,	Height: 260 mm,
Drawing:	Drawing:
I notice: •that it's tall, •lots of dead leaves, •some white flowers,	I notice: •that it's short, •few of dead leaves •tied up,

On the back of this page, write and draw about anything else you are noticing and wondering about

FIGURE 4

An example student evidence sheet

TABLE 1.

Supplementary materials: Examples of how teaching strategies were used for each transition in the Fast Plants and Landforms investigations.

Transition	Fast Plants Decisions	Example Strategies	Landforms Decisions	Example Strategies
Phenomenon to Investigation	- How to represent sun and shade - What different parts of the setup represent (wicking system, fertilizer) - Why it is important to keep other aspects of the system constant	The teacher provided the setup and mapped each part to the backyard system. Students brainstormed, discussed, and reached consensus on how to represent shade.	- How to represent wind and water shaping land - How to develop a fair test using materials - How to arrange earth materials (in a petri dish vs. in a mound)	The teacher presented the straw and spray bottle and asked how these could be used to represent wind and water. Students worked in groups of four to use the materials to design a test, then conducted the test.
Investigation to Evidence	- What to use as evidence (height, health, seedpods) - How to define attributes to see them the same way (healthy, seedpod)	Students used different forms of evidence and came to different conclusions.	- What to use as evidence (floating, a hole in the materials, traveling) - How to measure and record distance materials travel	Students used different forms of evidence and came to different conclusions.
Evidence to Conclusion about Investigation	- How to compare data across the class's plants - What conclusion to draw about where the fast plants did best - When in the life span of the plant we can draw a conclusion	Students combined data, invented and compared different data representations, and drew a joint conclusion from the displays.	- What conclusion to draw about whether materials move and how easily	Students and teacher developed consensus tests of different mechanisms (wind, rain, and a pool of water or river) and agreed on the conclusions from those tests.
Investigation Conclusion to Explanation	- How to extrapolate from the experiment to multiple generations of plants - Whether we can draw a conclusion about the backyard based on one kind of plant - Whether the conditions in the experiment represented the backyard	The teacher introduced an outrageous claim to spur discussion of the backyard and a return to examine plant success in the backyard.	- How to generalize to greater amount of force from wind and water - How to generalize to different amounts and sizes of earth materials being moved (e.g., large boulders, beachside cliffs).	The teacher showed photos and videos of phenomena and asked students to apply what they learned in the investigation to explain those phenomena, pointing out differences (e.g., this big boulder moved, the pebbles in our investigation did not).