Investigating factors that affect plant development.

<table>
<tr><th>Cognitive processes</th><th>Examples of scientific reasoning tasks</th></tr>
<tr><td colspan="2">1. Generating scientifically oriented questions</td></tr>
<tr><td rowspan="4"></td><td>Least complex: Students are given the research question: “How does the pH of the water used to water plants affect the plant development as reflected in stem length?”</td></tr>
<tr><td>Limited complexity: Given the research question—“Does the pH of the water used to water plants affect the plant development as reflected in the stem length?”—the teacher suggests students choose from pHs of 5, 6, 7, or 8. Students make the following revision to the research question: “How does water of pH 8 used to water plants affect the plant development as reflected in the stem length?”</td></tr>
<tr><td>More complex: Students make revisions to questions provided by the teacher. The teacher provides the following questions:
“How does the pH of the water used to water plants affect stem length?”
“How does the humidity of a plant’s environment affect leaf surface area?”
“How does the plant’s exposure to ultraviolet (UV) light affect leaf color?” and
“How does the plant’s exposure to salt water affect the number of flowers produced?”
The teacher then guides students in making changes to the question to narrow the focus to a particular pH, amount of humidity, exposure to UV light, and amount of salt in the water.</td></tr>
<tr><td>Most complex: The teacher’s role is limited to guiding students to consider what is safe, practical, and realistic for the investigation. Students generate their own research questions about factors that affect plant development—based on their own previous plant experiments and their literature research about plants and factors that influence plant development.</td></tr>
<tr><td colspan="2">2. Making predictions or posing preliminary hypotheses prior to conducting investigations</td></tr>
<tr><td rowspan="2"></td><td>Least complex: The teacher provides a prediction such as, “Adding water with a pH of 8 will cause stems to grow slower than if water of pH 7 is used.”</td></tr>
<tr><td>Limited complexity: The teacher asks students to choose from the following predictions:
“Adding water with a pH of 8 will cause stems to grow slower than if water of pH 7 is used,”
“Adding water with a pH of 8 will cause stems to grow faster than if water of pH 7 is used,” or
“Plant stems will grow at the same rate when water of pH 8 and pH 7 is added.”</td></tr>
</table>

	More complex: Students make their own predictions—such as, “Adding water with a pH of 8 will cause a lower flower production than if water of pH 7 is used”—without prior investigations in the lab or literature.
	Most complex: Students make predictions—such as “Adding water with a pH of 8 will produce flowers of a different color than if water with a pH of 7 is used”—based on their readings in the literature about the impact of salts on plant development.
3. Designing and conducting the research study	
Subprocesses	
Designing the procedure for the investigation	*Least complex:* Students are told, step-by-step, how to conduct their investigations. Their plants are chosen and delivered to them in soil and pots. The water solution is ready to add to the plants at a set pH. Students are told how to water the plants, and when and how often to add water. Students are told how many trials to conduct and how to make their observations and measurements.
	Limited complexity: Students make only one or two contributions to the procedure, such as how often to water the plants, how often to measure the stem length, or how to measure stem length.
	More complex: Students have more responsibility in designing numerous steps of their investigations such as how, when, and how often to water the plants, or how and when to measure the stem length.
	Most complex: Students determine what acid to use; how to make the pH 8 solution; how many experimental trials will be conducted; how they will make their measurements; what kind of plants they will use; and when, how, and how often they will water the plants.
Selecting dependent and independent variables	*Least complex:* The teacher chooses stem length as the dependent variable (DV) and water pH as the independent variable (IV).
	Limited complexity: Students choose to add sodium chloride (NaCl) to water (IV) and measure stem length (DV), but do not have any basis for these choices.
	More complex: Students choose to add NaCl to water (IV) and measure stem length (DV) because of their observations of the impact that adding salt to icy roads has on vegetation along the road.
	Most complex: Students make decisions to treat plants with a certain concentration of NaCl solution (IV) based on what they learn from the literature, concerning which salt is used on icy roads and the estimated salt concentration of the runoff. Based on the literature information, they decide to measure stem length for the dependent variable.
Considering experimental controls and conditions that need	*Least complex:* Students do not consider the importance of growing plants that have been treated with nonsalty water. or additional experiment conditions.
	Limited complexity: Students are told—without much explanation—that they will also be growing plants treated with nonsalty water, and that they need to control one or two other conditions, such as

to be controlled	room temperature and amount of light.
	More complex: Students are engaged in some teacher-led discussion about the need for growing plants treated with nonsalty water and the need to control conditions, such as room temperature, amount of light, amount of water, room humidity, and water temperature.
	Most complex: Students are engaged in thorough discussions and reflections regarding growing plants treated with nonsalty water and the variety of conditions that need to be controlled because they can influence the results.
Gathering and organizing data during the investigation	*Least complex:* Students investigating how leaf color changes when plants are watered with pH 8 water solution are given leaf color data collected by the teacher.
	Limited complexity: Students gather their own leaf color data, but are given blank tables in which to enter their data. They do not include other data formats.
	More complex: Students gather their own leaf color data, generate their own data tables, and—with some support from the teacher—create color drawings or photographs of the leaves.
	Most complex: With limited support from the teacher, students gather their own leaf color data, generate their own data tables, and create their own color drawings or photos of the leaves. They reflect on and discuss the optimal formats for representing experimental data and which formats best align with their investigations.
4. Explaining results	
Subprocesses	
Analyzing data using calculations, graphing, and statistical analyses; looking for anomalous data	*Least complex:* The teacher gives students a graph of stem lengths measured over the duration of the experiment.
	Limited complexity: Students are provided with a blank graph with axes on which to plot their stem lengths against time.
	More complex: Students develop their own graphs of stem lengths plotted against time. They have some support from the teacher in understanding how to design a graph and how to plot their data.
	Most complex: Students develop their own graphs, calculate the average rate of stem growth, conduct statistical analysis to determine if there is a difference in the stem growth rates for plants watered with salty and nonsalty water, and identify anomalous data with little to no support from the teacher.
Identifying the evidence from the analyzed data	*Least complex:* A pattern of stem growth is provided by the teacher.
	Limited complexity: The teacher provides strong direction for identifying evidence of a pattern in stem growth.
	More complex: The teacher guides the students as they identify evidence of a pattern in stem growth.
	Most complex: Students take most of the responsibility for identifying the evidence of a pattern in stem

	growth.
Providing explanations; noting unexpected findings; addressing accuracy of data, experimental errors, limitations, or flaws	*Least complex:* The teacher provides the explanation for the pattern of stem growth, and no attention is given to the data, unexpected findings, accuracy, errors, limitations, and flaws of the investigation.
	Limited complexity: The teacher strongly leads students through developing an explanation for the pattern for stem growth, and little attention is given to the data, unexpected findings, accuracy, errors, limitations, and flaws of the investigation.
	More complex: The teacher guides students through developing an explanation for the pattern of stem growth, unexpected findings, accuracy, errors, limitations, flaws of their investigations.
	Most complex: Students develop an explanation for the pattern of stem growth, unexpected findings, accuracy, errors, limitations, and flaws of their investigations—with little to no contributions from the teacher.
Connecting evidence with scientific knowledge	*Least complex:* The teacher and students do not connect the investigation findings to what scientists know about how pH affects plant development.
	Limited complexity: The teacher strongly leads students through connecting their findings to what scientists know about how pH affects plant development.
	More complex: The teacher guides students through connecting their findings to what scientists know about how pH affects plant development.
	Most complex: Students take most of the responsibility for connecting their findings to what scientists know about how pH affects plant development.
Posing and analyzing alternative explanations and predictions	*Least complex:* There is no attention given to multiple explanations for stem length changes based on the pH of the water.
	Limited complexity: The teacher strongly leads the students through considering alternative explanations to stem length changes based on water pH.
	More complex: The teacher guides students to think about other possible explanations for their water pH and stem length findings.
	Most complex: With little to no support from the teacher, students generate their own alternative explanations for their water pH and stem length findings. They use outside sources to analyze the viability of their alternative explanations.
Communicating and defending findings through discussion, presentations, and written reports	*Least complex:* Students do not talk to each other about their investigations, write about their investigations, or defend their water pH and stem length investigation findings.
	Limited complexity: The teacher strongly leads students through discussions or writing about their water pH and stem length investigations and defending their findings.
	More complex: Students are guided by the teacher to design presentations about their water pH and stem

	length investigations through discussions, presentations, and in writing.
	Most complex: Students take most of the responsibility for presenting the findings of their water pH and stem length investigations through discussions, presentations, or in writing. Presentations of findings include well-developed arguments for supporting the stem length findings.