Prompts for Integrating Crosscutting Concepts Into Assessment and Instruction

The new vision for science education features a three dimensional view of learning that involves: science and engineering practices, crosscutting concepts, and disciplinary core ideas. Many educators already incorporate crosscutting concepts into their teaching, but may still be looking for ways to amplify these concepts or to make them more explicit for their students, including in their classroom assessments.

This set of prompts is intended to help teachers elicit student understanding of crosscutting concepts in the context of investigating phenomena or solving problems.

These prompts should be used as part of a multi-component extended task. They should not be used in isolation, and the blanks provided are intended to be filled using the content of the scenario presented at the beginning of the multi-component task. The prompts can be open-ended, as shown below. They can also be turned into multiple-choice questions. These prompts were developed using the Framework for K-12 Science Education and Appendix G of the Next Generation Science Standards, along with relevant learning sciences research.

These prompts are currently being tested or evaluated in the field. We request you send feedback and information about how you have used the prompt to william dot penuel at colorado dot edu.

Please note that some prompts may not be suitable for students in early grades, while others may be low-level for high school students. Designers should consult the learning progressions in Appendix G of the NGSS to choose a prompt that is appropriate for different grade level bands.

Our team has also created a similar tool to help educators create tasks that incorporate the science and engineering practices into their teaching, found at stemteachingtools.org/brief/30. You can learn how to develop 3D formative assessments here: http://tinyurl.com/3Dassessmentdevelopment

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Crosscutting Concept: Patterns

A Framework for K-12 Science Education description of **patterns:** Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

Ask after presenting students with data from an experimental study focused on isolating causal variables as part of the scenario:

- What patterns do you observe in the data presented above in the [table, chart, graph, model output]?
- Are there ways you can use mathematics to summarize the data that might help you see patterns in the data more clearly, to determine whether________ causes ________?
- What does the pattern of data you see allow you to conclude from the experiment?
- Does the pattern in the data support the conclusion that ________ is caused by ________? Why or why not?
- Are there any other data that are needed to test whether ________ causes ________?
- How does the pattern of data at the ________ scale help you explain [phenomenon at different scale]?

Ask after presenting students with observational data as part of the scenario:

- What patterns do you observe in the data presented above in the [table, chart, graph, model output]?
- What does the pattern of data you see allow you to conclude about ________?
- Does the pattern in the data support the conclusion that ________ is related to ________? Why or why not?
- What mathematical representations of the data could help you identify patterns in the data?
- What observations could you ask next, to help explain the pattern in the data?
- What kind of mathematical function best fits the pattern of data you see?
- For bivariate data: How strong is the correlation between x and y? (Calculate correlation coefficient)

Ask when time is a variable:

- How is________ changing over time?
- What do you predict will happen to [variable] in the future? Use the pattern you see in the data to justify your answer.
- How is the rate of change changing over time? How could you represent that rate of change mathematically?

Ask when asking students to classify (e.g., physical objects, organisms) presented as part of the scenario:

- What are some similarities and differences among the ________ above?
- What is one way you could classify or group these ________, to create groups of ________that are similar to each other? Describe the attributes (characteristics) you are using to classify the ________.

    - Follow up question: To which of your groups would a ________ with the following characteristics belong: ________, ________, and ________.

- How similar or different are [objects or organisms that are similar at macroscopic scale] at the microscopic scale?
- How similar or different are [objects or organisms that are similar at microscopic scale] at the macroscopic scale?

After presenting students with data on performance of a designed object or system:

- What patterns do you observe in the data presented above in the [table, chart, graph, model output]?
- Are there mathematical summaries of the data that could help you describe more clearly the success or failure of the designed system?
- What does the pattern of data you see allow you to conclude from the test of the system?
- *If the pattern of data is indicative of failure:* On the basis of the patterns you see, what appears to be the cause of failure in the system?

Crosscutting Concept: Cause and Effect

A Framework for K-12 Science Education description of **cause and effect:** Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

When drawing conclusions from a simple investigation, ask students:

- How do the patterns in the data allow you to decide whether ________ caused ________?
- What caused the patterns you observed?
  - Follow up question: How do you know that ________ caused ________?
- Does the fact that that the data showed that ________ always happened [after/whenever] ________ occurred mean that ________ causes ________? Why or why not?
  - Follow up question: How can you test whether ________ caused ________ to happen?
- What do you predict would happen if [extrapolate to new, related situation]?

When seeking to elicit whether students understand the ***underlying mechanism*** *involving something that is not part of the surface situation presented in the scenario, ask students:*

- What [properties, entities, or rules] that aren't described explains what you see happening [in the scenario]?
- What would you predict in [present new situation involving same mechanism] would happen? How is the situation similar to or different from [the presented scenario]?

When a system or situation presented in the scenario involves ***complex or relational causality*** *(e.g., as in ecosystems and co-evolution), ask students:*

- Draw a diagram that shows how changes to one component of the system affects components that are not directly connected to that component.
- What do you predict would happen if [change to one component of complex system] to [component that has an indirect, rather than direct, connection to the first component]?
- How do ________ and ________ affect ________?
- How do ________ and ________ affect each other over time?
- What feedback loops are causing this system to be in [balance/equilibrium]?
- How can a small change to ________ have a big effect on ________?

When the system or situation involves ***probabilistic but not deterministic causality****, ask students:*

- What is the probability that ________ caused ________? How do you know?
- If ________ causes ________, why can't we know for sure what will happen when ________?
- Does knowing [the level or value of cause] allow you to predict [the level or value of effect] with certainty? Why or why not?

When seeking to elicit students' skill in ***evaluating causal claims****, ask students:*

- Is [claim that states a causal relationship or a claim that states a correlational relationship] a causal claim? If so, what makes it a causal claim? If not, why not?

- What evidence presented in the scenario supports the claim that ________ causes ________?
- Can the study design provide evidence as to whether ________ causes ________? Explain why or why not.
- Is the evidence presented sufficient to conclude that ________ caused ________? If not, what additional evidence is needed?

When analyzing ***causes of failure in a designed system****, ask students:*

- Draw a diagram of the system, showing what is causing the pattern of failure observed in the test of the system.
- Design a test to figure out what is causing the failure of the system, given the data presented.

Crosscutting Concept: Scale, Proportion, and Quantity

A Framework for K-12 Science Education description of **scale, proport on, and quant ty**: In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

*When eliciting understanding of **quantity and proportion** presented as data in the scenario, ask students:*

- How long is ________?
- How much does ________ weigh?
- What is the temperature of ________?
- What is the volume of ________?
- How could you compare how much of [property or characteristic] these two different ______ presented in the scenario have?
- What would make a good measure of [property, characteristic, or process] to investigate the phenomenon presented in the scenario? Why is that a good measure?
- What is the ratio of ________ and ________ in the data presented?
- How do the ratios of ________ and ________ at [Time 1/Sample 1] and [Time 2/Sample 2] compare?
- What is the proportion of ________ that are ________?
- How do the proportion of ________ that are ________at [Time 1/Sample 1] and [Time 2/Sample 2] compare?
- Is the relationship between ________ and ________ linear or exponential, or something altogether different? How does the pattern in the data support your conclusion?
- What equation could be written to express the relationship between quantities of ________ and quantities of ________? Explain your answer.
- On the basis of the data you have, what do you predict would be the effect of a change in ________ on ________?

*When eliciting students' understanding of **scale**, ask students:*

- Is the model presented at a [smaller/larger/the same] scale than the phenomenon as you might observe it directly?

Does the model describe processes that are [faster/slower/the same speed*]* than the phenomenon as you might observe it directly?

- What scale should be used to investigate the mechanisms at work in this system? Why is that the right scale for this system?
- What scale of a model would allow you to gain insight into ________?
- What scale of a model would allow you to test the design of ________ in the classroom?

*When eliciting students' ability to **change scales** to investigate phenomena that are too large or small to see, or too long or short to observe directly, ask students:*

- Why could [people in the scenario] see ________ when they observed it [under a microscope/with a telescope], but not when they looked just with their eyes?
- How could we test whether ________ is changing, even though it looks like it is not?
- Which of the patterns presented in the scenario do you think could be observed at a [faster/slower, smaller/larger] scale? Why?

Crosscutting Concept: Systems and System Models

A Framework for K-12 Science Education description of **systems and system models**: Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

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*When eliciting information about the **components and interactions** of systems and system models, ask students:*

- What are the key parts of the [a natural object, designed object, or organism described in the scenario]?
- Draw the parts of the system described in the scenario.
- How do the parts of [a natural object, designed object, or organism described in the scenario] work together?
- Draw a picture that shows how the parts of the system described in the scenario work together.
- What can the parts of [a natural object, designed object, or organism described in the scenario] do together, that the individual parts cannot do alone?
- How do the different components of the system interact?
- What would happen in this system if you increased [component of the system]?
- What would happen in this system if you decreased [component of the system]?
- How do you think [component] would respond to [change in another component of the system]?

*When eliciting information about the **boundaries** of systems and system models, ask students:*

- What is the boundary of the system described in [the scenario]?
- What are the consequences of drawing the boundary of the system around ________ as opposed to ________ in a model?
- Draw a boundary to indicate what is inside and outside of the system.
- Can the system be physically isolated, in order to study it?
- Are their sub-systems in this system that can be isolated for analysis? If so, what are they?
- How does [subsystem A] relate to [subsystem B]?

When there are feedback loops presented in the scenario, ask students:

- For homeostatic systems: What feedback loops make this system stable?
- What feedback loops make this system unstable?
- How do positive feedback loops in this system affect how it functions?
- How do negative feedback loops in this system affect how it functions?
- For chaotic systems: How do feedback loops in this system make the system's behavior unpredictable?

*When eliciting information about the **flow and cycling of energy, matter, and information**, ask students:*

- What energy flows into the system?
- What energy flows out of the system?

- What matter cycles into the system?
- What matter cycles out of the system?
- How does energy flow within the system?
- How does matter cycle within the system?
- How does information flow within the system?
- What information is flowing into the system?
- What information is flowing out of the system?
- Draw a picture that shows how energy is flowing into, within, and out of the system.
- Draw a picture that shows how matter is cycling into, within, and out of the system.
- Draw a picture that shows how information is flowing into, within, and out of the system.

*When the model is of a **complex** system, ask students:*

- What properties emerge from interaction of components in the system that can't be seen just by looking at the interactions?
- How does [emergent property] of the system affect interactions in the system, once [that emergent property] emerges?

*When the model is of a **designed** system, ask students:*

- Create a set of instructions for building [system] that another child can follow.
- If you could control X in the system would it stop Y? Why or why not?
- How could you test whether this system satisfies the design constraints described in the scenario?

When eliciting understanding of the limitations, assumptions, and approximations of system models, ask students:

- What part of the system does the model show? Why are these parts shown?
- What parts of the system are not shown in the model? Why are these parts not shown?
- What are the key assumptions of the model?
- How do the assumptions affect the reliability of the model?
- What is estimated, rather than observed directly, in the model?
- How do estimates affect the precision of the model?
- Could you use the model to reliably predict ________________?
- Could you use the model to precisely estimate what would happen if ________________?

Crosscutting Concept: Energy and Matter: Flows, Cycles and Conservation

A Framework for K-12 Science Education description of **energy and matter:** Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

When making observations of simple systems where materials are broken apart or reassembled:

- What happens to ________ when you put it together with ________?
- Is there more, less, or the same of ________ when you combine it with ________?
- What kinds of material is [assembled object] made of?

When eliciting understanding of how energy transfers drive the cycling of matter within and between systems:

- How does the flow of energy between ________ and ________ drive the cycling of matter in the ___ system?
- How does the flow of energy between ________ and ________ drive the cycling of matter between ________ and ________?

When eliciting understanding of the cycling of matter, ask students: (Scale: The movement question can be answered at the atomic-molecular, cellular, or macroscopic scale.)

- Where is matter coming from that enters [this system]?
- What happens to matter as it moves within [this system]?
- Where does matter go that leaves [this system]?
- Draw a picture showing the the stocks and flows of matter in [this system].
- Where are the molecules moving in [this system]?
- What evidence is there that matter is conserved in this cycle?

When eliciting understanding of changes to matter, ask students: (Scale: The chemical change question is always answered at the atomic-molecular scale.)

- How are atoms in molecules being rearranged into different molecules?
- What molecules are carbon atoms in before and after the chemical change?
- What substance are the carbon atoms part of before and after the chemical change?
- What other molecules are involved?
- What evidence is there that matter is conserved in these changes?

When eliciting understanding of energy change, ask students: (Scale: These energy questions can be answered at the atomic-molecular, cellular, or macroscopic scales.)

- How is energy coming into this system?
- How is energy going out of this system?
- What forms of energy are involved in this system?
- What energy transformations take place during the chemical change?
- How much energy is needed to [make something happen]?
- What energy is entering, staying, and leaving [the system]?
- Draw a picture showing the stocks and flows of matter in [this system].
- Where does the ________ get its energy?
- What evidence is there that energy is being conserved in this system?

Crosscutting Concept: Structure and Function

A Framework for K-12 Science Education description of **structure and function:** The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

After presenting students with observational data as part of the scenario:

- What structures are present in ________? What function does each structure have in (scenario)? How do you think each structure behave?
- What is the relationship between the structure and its function?
- Why does the shape of ________ matter for its function? What other properties of the structure might allow it to have certain behaviors?

Ask after presenting students with a model as part of the scenario:

- What are the substructures shown in the model? For each substructure, how does it behave in the model? What properties does it have? What is its function in the model?
- Describe the organization of substructures and how the spatial relationship matters for behavior and function.
- For the model, describe the behaviors by which the structures accomplish their functions.

After presenting students with a novel system students have not explored before to investigate:

- What function do you think [structure] serves in this system? How could we find out?
- This system performs [describe functions]. How do you think the structures support or enable those functions?
- When observing living organisms in an unfamiliar system: This organism engages in [behavior] to [describe function.] How might [structure] help explain how they are able to perform [behavior]?

After presenting students with a description of a microscopic system:

- Together, what the parts of the ________ (system) do? What do you think the structures look like?
- Based on the overall function of the system, how do each of the individual structures behave? What properties do they have?

After asking students to design a solution (e.g., a mechanical system):

- Describe the structures in your solution. Describe the function in your solution. What is important about the relationship between structure and function in your solution that make it a successful design?
- Describe the sub-structures in your solution. Describe the function in your solution. What is important about the relationship between sub-structures and function in your solution that make it a successful design?

*When asking students about **structure and function** in ecosystems:*

- Identify the properties of the environment that constrain behavior of organisms. What about the structures of an organism allow them to survive within the environment? What is the behavior of the organism and the function of the structures it has?
- You find a new animal in an environment it has [structure] it uses to [perform function]. Given whatyou know about the ecosystem, explain the how [structure] supports its survival in this ecosystem.

Crosscutting Concept: Stability and Change

A Framework for K-12 Science Education description of **stability and change:** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

When the scenario presents a system that periodically experiences equilibrium:

- Is the system described in the scenario stable or unstable? Present evidence to support your claim.
- How was this system affected by [sudden event described in the scenario]?
- How might this system be affected by [sudden event not described in the scenario]?
- What are the factors causing this system to be stable at [time point identified in scenario where the system is at equilibrium]?
- What are the factors causing this system to be unstable at [time point named in scenario where the system is changing or not at equilibrium] ?
- What is happening at the [specify scale, such as atomic] scale to make this system stable at [time point identified in scenario where the system is at equilibrium]?
- What is happening at the [specify scale, such as atomic] scale to make this system unstable [time point named in scenario where the system is changing or not at equilibrium]?

When the scenario presents a system or phenomenon where there are repeating patterns of change:

- What things change in [the system presented in the scenario]?
- What is the rate of change in [the system presented in the scenario]?
- What patterns do you observe in the way that [the system presented in the scenario] changes over time?
- What explains why [repeating pattern] is happening in this system over time?

When the scenario presents a designed system:

- In what ways is [the system presented in the scenario] stable?
- What might cause [the system presented in the scenario] to become unstable or imbalanced?
- How can you design [the system presented in the scenario] to be more stable?

When the scenario presents a system or phenomenon with feedback loops:

- How does [process or mechanism A] affect [process or mechanism B]?
- What explains why when [process or mechanism] happens, ________ changes and then affects [process or mechanism]?

When the scenario presents a system that looks stable at one scale and unstable at a different scale:

- How was this system affected in the long term by [gradual changes described in the scenario]?
- When the scenario presents a system or phenomenon where competing effects are balanced?
- How might this system be affected in the long term by [gradual changes not described in the scenario]?
- How does is the effect of [process or mechanism A] offset by the effect of [process or mechanism B] in this system?