

## **Integrating Crosscutting Concepts into 3-Dimensional Scoring Rubrics**

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## **Integrating Crosscutting Concepts into 3-Dimensional Scoring Rubrics**

### **Rationale**

The *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) respond to concerns that K-12 science instruction lacks coherence across topics and disciplines (e.g. Kali, Linn, & Roseman, 2008). To address this concern, the *Framework* identifies seven “crosscutting concepts” (CCCs) that cross disciplinary boundaries: patterns, cause and effect, scale, systems, energy and matter, structure and function, stability and change. These CCCs help students recognize, for example, how energy transformations occur in both biological and chemical systems or that the same basic definition of a natural system in earth science applies to a constructed system in physics. This shift in emphasis on CCCs aims to make these connections across disciplines explicit for students and teachers and help students “develop a cumulative, coherent, and usable understanding of science and engineering.” (NRC, 2012, p. 83)

Because the NGSS place the CCCs on equal footing with disciplinary core ideas and science practices, assessments are needed that provide insight into student proficiency on CCCs alongside the other two dimensions (NRC, 2014). Assessing students’ understanding of the CCCs has received comparatively little attention relative to the other two NGSS dimensions; little research details the extent to which students are able to integrate science understanding across disciplines. Despite the increased focus on CCCs, new assessments must still reflect the guiding principle of the NGSS that rich science learning requires tight coupling of what students know with what they can do. Research studies that reveal the strong relationships between content knowledge and science practices (e.g. Berland & Reiser, 2009) argue for assessment approaches that unify content and practice.

We describe an approach informed by Evidence-Centered Design (Mislevy & Haertel, 2006) for integrating the CCCs with disciplinary content and science practices into rubrics for scoring three-dimensional assessment tasks. Our approach foregrounds the CCCs relative to the other two dimensions. Foregrounding the CCCs can inform critically important efforts to measure student progress across science topics and disciplines and may be particularly useful for longitudinal studies of students’ science performance.

In this work we use CCC *Patterns* as an exemplar for the rubric development approach. Patterns “guide organization and classification, and they prompt questions about relationships and the factors that influence them.” (NRC, 2012, p. 84) Patterns include repeated occurrences, correlations, similarities, and differences that are evident from phenomena and data. Patterns occur across science disciplines and are identified and described using diverse practices. We describe our approach using rubrics that integrate students’ understanding of patterns inherent in middle school physical and life science topics and involve the practices of data analysis and modeling.

## Approach

Our rubric development approach consists of four steps:

- (1) Unpack the CCC by identifying features and types and describing a high level of student performance
- (2) Develop a construct map describing levels of sophistication in thinking about the CCC
- (3) Identify specific connections among the CCC, disciplinary concepts, and components of scientific practices targeted by the item
- (4) Generate a specific rubric for the item based on steps 1, 2, and 3.

### *Step 1: Unpack the crosscutting concept*

Based on a review of the NRC Framework description of patterns and other frameworks highlighting patterns in science (e.g. AAAS, 1993), we identified three pattern types and three evidence statements describing a high level of student performance for pattern identification, characterization, and classification (Table 1).

Table 1: Unpacking *Patterns*: pattern types and evidence statements

Pattern types
<ul style="list-style-type: none"><li>● Repeating occurrences (e.g. spatial, temporal)</li><li>● Similarities, differences, and classifications based on similarities and differences</li><li>● Correlations and trends</li></ul>
Evidence statements describing a high level of performance
<ul style="list-style-type: none"><li>● Student correctly <b>identifies</b> one or more patterns in phenomena or data</li><li>● Student correctly <b>characterizes</b> the nature (e.g. direction, frequency) of one or more patterns</li><li>● Student correctly <b>classifies</b> objects, events, and/or other patterns into types according to their similarities and/or differences</li></ul>

### *Step 2: Develop a construct map*

Based on the pattern types and evidence statements, we developed a simple construct map on patterns in science (Table 2), inspired partly by Lehrer's (2007) Data Display construct map. Our construct map describes increasing levels of sophistication about patterns by emphasizing the following conceptual distinctions: (1) Patterns are necessarily defined by relationships among two or more cases, instances, or data points. We therefore distinguish between reasoning about individual cases and reasoning about patterns based on two or more cases. (2) A simple pattern captures a basis relationship, such as an observation that two variables correlate positively or that an event repeats. A complex pattern may link multiple simple patterns or represent a more nuanced understanding (based on disciplinary knowledge) of a simple pattern.

Table 2: Patterns construct map

Level	Description
Multiple and complex	Students can validly identify, characterize, and/or classify according to multiple patterns (at least one of which is complex)
Multiple or complex	Students can validly identify, characterize, and/or classify according to either multiple simple patterns OR exactly one complex pattern
Simple Valid	Students can validly identify, characterize, and/or classify according to exactly one simple pattern
Simple Invalid/ Incomplete	Students can identify a pattern but invalidly or incompletely characterize or classify using the identified pattern
Case	Students can discuss a single case, data point, or instance involved in a pattern without discussing the nature of the pattern itself.
None	Students are unable to articulate any relevant pattern-related ideas or individual cases that are part of the target patterns

*Step 3: Identify item-specific connections across patterns, disciplinary concepts, and practices*

Steps 3 and 4 are specific to individual item scenarios. To illustrate the item-specific steps of the rubric development process, we use two contrasting examples from our related research on NGSS-aligned assessment. These items are three-dimensional in that they patterns alongside different disciplinary concepts and scientific practices (Figure 1).

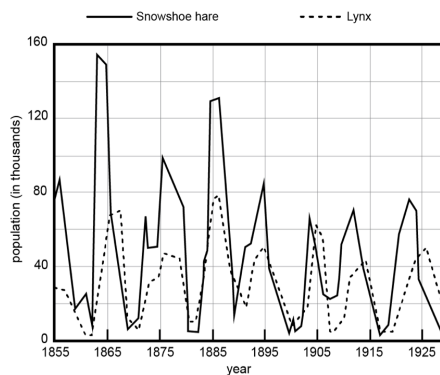
The Hare-Lynx item addresses the life science discipline and science practice of analyzing data. It targets students' ability to analyze data to illustrate the effects of resource availability on populations of organisms in an ecosystem. The availability of food for the hare and lynx and their predator/prey relationship determine the population patterns of the two species. Regarding science practices, identifying patterns constitutes one of several components<sup>1</sup> of the practice of *analyzing and interpreting data*.

The Ice Cube item addresses the physical science discipline and the science practice of developing models. It targets students' ability to develop a model that links states of matter with a particulate view of matter. State changes in matter are characterized by patterns (e.g. correlations, similarities and differences) in the arrangement and motion of particles. Regarding science practices, one purpose of *developing and using models* is to illustrate patterns exhibited by phenomena. In both assessment scenarios, the tight connections across patterns, disciplinary concepts, and practices argue for the development of a single rubric that incorporates all three dimensions while foregrounding students' understanding of the relevant patterns.

<sup>1</sup> Other components may include organizing data or using statistics to summarize data.

### **Hare-Lynx item (patterns, life science, analyzing data)**

The Canadian lynx and the snowshoe hare reside in North America's boreal forests. The graph shows the size of the snowshoe hare and lynx populations over time. Describe the relationships between the snowshoe hare and lynx populations over time. [Refer to the graph on the right]



### **Ice Cube item (patterns, physical science, developing models)**

An ice cube (solid water) in a pot is heated on a stove. In few seconds, the ice cube melts and becomes liquid water. The water then boils and leaves the pot as water vapor (gaseous water). Draw a model to show particles and their movement in an ice cube, water, and water vapor.

Figure 1. Three-dimensional items Hare-Lynx and Ice Cube

*Step 4: Generate a 3-dimensional rubric based on Steps 1 through 3*

We identified simple and complex patterns for each item scenario (Table 3) and generated a specific rubric for each item (Table 4) based on the pattern types. The levels of each rubric correspond to the construct map and emphasize students' thinking about patterns integrated with the target core idea and science practice. In this way, the rubrics still reflect students' ability to incorporate the disciplinary ideas and engage with the practices.

Table 3: Simple and complex patterns for the Hare-Lynx and Ice Cube items

	Hare-Lynx (HL)	Ice Cube (IC)
Simple patterns	<ul style="list-style-type: none"> <li>• The lynx and hare population changes <b>coincide</b> (HL1)</li> <li>• The hare population <b>exceeds</b> the lynx population (HL2)</li> <li>• The lynx population <b>lags</b> the hare population (HL3)</li> </ul>	<ul style="list-style-type: none"> <li>• Temperature <b>correlates positively</b> with particle spacing (IC1)</li> <li>• Temperature <b>correlates positively</b> with particle speed (IC2)</li> </ul>
Complex patterns	<ul style="list-style-type: none"> <li>• The lynx and hare population changes <b>coincide</b> because <b>lynx prey on hare</b> (HL4)</li> <li>• The hare population <b>exceeds</b> the lynx population because <b>lynx prey on hare</b> (HL5)</li> <li>• The lynx population <b>lags</b> the hare population because <b>lynx prey on hare</b> (HL6)</li> </ul>	<ul style="list-style-type: none"> <li>• Solid and liquid particles exhibit <b>close</b> particle spacing, while gas particles exhibit <b>wide</b> particle spacing (IC3)</li> </ul>

Table 4: Rubrics emphasizing patterns in the Hare-Lynx and Ice Cube items

Score/Level	Hare-Lynx	Ice Cube
6: Multiple and complex	Correctly describes at least 2 complex patterns (HL4, HL5, HL6)	Illustrates the simple pattern about speed (IC2) and the complex pattern on spacing (IC3)
5: Multiple or Complex	Correctly describes at least 2 simple patterns (HL1, HL2, H3) or exactly 1 complex pattern (HL4, HL5, HL6)	Illustrates 2 simple patterns on speed and spacing (IC1 and IC2), or 1 complex pattern on spacing (IC3)
4: Simple valid	Correctly describes exactly 1 simple pattern (HL1, HL2, HL3)	Illustrates 1 simple pattern on speed (IC1) or spacing (IC2)
3: Simple invalid/incomplete	Describes lynx or hare population fluctuations without relating them to each other	Illustrates 1 simple pattern on speed (IC1) or spacing (IC2) across 2 states of matter
2: Case	Describes lynx and/or hare populations only at individual time points or intervals	Illustrates particles without distinguishing states
1: None	No valid analysis of patterns or cases	Does not illustrate a particulate view

### Examples of student work

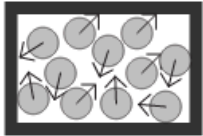

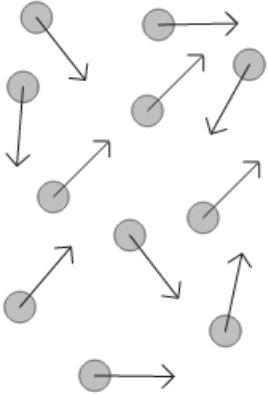
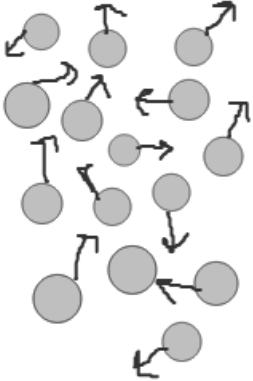
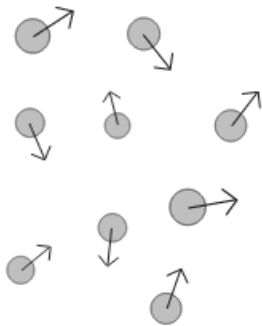
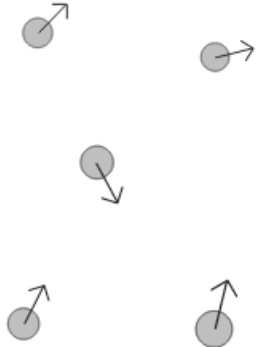


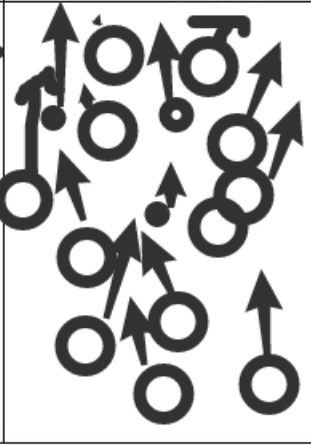
We applied the rubrics to student responses collected during pilot testing of the items. We administered the Hare-Lynx item with high school students and the Ice Cube item with middle school students. Students completed the Ice Cube item on computers using a browser-based assessment delivery system. In order to illustrate how the rubrics distinguish different levels of

sophistication about reasoning with patterns, we show three examples of student responses for each item (Tables 5 & 6). The examples also illustrate how students’ reasoning with patterns is integrated with disciplinary content knowledge in life and physical science and the science practices of analyzing data and developing models.

Table 5: Example high school student responses for the Hare-Lynx item

Level	Response	Patterns (Table 4)
6	<p>“The <b>lynx is likely the snowshoe hare’s predator</b>. As energy pyramids show, there are smaller populations of a predator than their prey, which accounts for why the <b>populations of lynx are smaller</b>. Also, the lynx population is dependant on the hare population since the <b>lynx population increases and decreases shortly after the hare population</b> does so.”</p>	HL5, HL6
4	<p>“Surprisingly, the hare and the lynx’s population have almost the same fluctuation. When the hare’s population was at its all time peak in 1863, the lynx was at its 2<sup>nd</sup> highest peak. When the hare’s population was at its lowest point in 1917, the lynx’s population also plateau’d out at one of its lowest point with the period 1855-1925. <b>As the hare’s population go up or down, the lynx’s population goes up or down, respectively.</b>”</p>	HL1
2	<p>“The snowshoe hare population outnumbered the lynx population back in 1850s to the 1890s. As the lynx population remain generally the same with an average of 40,000-50,000, the snowshoe hare population increased and stays around an average of 70,000-80,000.”</p>	Describes only specific time intervals

Table 6: Example middle school student responses for the Ice Cube item

Level	Response			Patterns (Table 4)
6	<p>Ice cube (solid)</p> 	<p>Water (liquid)</p> 	<p>Water vapor (gas)</p> 	IC2, IC3
4	<p>Ice cube (solid)</p> 	<p>Water (liquid)</p> 	<p>Water vapor (gas)</p> 	IC1
2	<p>Ice cube (solid)</p> 	<p>Water (liquid)</p> 	<p>Water vapor (gas)</p> 	Does not distinguish states based on either particle speed or spacing

## **Implications and contributions**

The *Framework* and NGSS emphasize that CCCs, DCIs, and practices are necessarily and tightly intertwined. In authentic science, these dimensions do not occur in isolation of one another. As such, instruction and assessment need to integrate, rather than isolate, the three performance dimensions. A critically important quality of our rubric approach is that, despite foregrounding the CCCs, it acknowledges and preserves the rich connections that occur across the CCCs, DCIs, and practices. In our examples, a robust understanding of a meaningful pattern in science is linked to disciplinary understanding of phenomena and elicited via the scientific practices of analyzing data and developing models.

This work addresses critical needs of the education community and NARST membership to assess progress on CCCs while maintaining links to disciplinary content and practice. Our approach helps promote more consistent measures of student knowledge across disciplinary boundaries and provides a template for mapping other CCCs onto disciplinary ideas and practices. The approach has particular implications for longitudinal assessment of science learning and for developing curriculum materials that cohere across disciplines.

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