Rubric for the CSI Survey

Purpose: This rubric is intended to be used with all sets (A, B, C, D) of the CSI Survey. The rubric is structured to help teachers identify students' chemical identity thinking in their responses to the CSI Survey. This rubric has been evaluated by practicing chemistry teachers who have used the CSI Survey in their classrooms. While these teachers were not using a Chemical Thinking-based curriculum in their classrooms, they found the CSI Survey to be of value for their teaching. Teachers can use this rubric to help achieve three possible goals: 1) to perform a self-evaluation of their teaching and whether it influences students' chemical identity thinking, 2) to get a "snapshot" picture of individual students or an entire class with regard to chemical identity thinking and reasoning, and/or 3) to track progress in chemical identity thinking and reasoning for individual students or an entire class over time. The CSI Survey and rubric have been designed to provide information on students' current chemical identity thinking; future publications will provide information on pathways students might follow when progressing from novice to advanced chemical identity thinking and suggest methods to develop students' chemical identity thinking.

Step 1: Identify the cues or properties used in the students' responses.
To begin, it is useful to determine the cues or properties students are using when considering the chemical identity of a substance. The cues or properties that students use in these responses tend to be what the students consider to be important when solving questions of chemical identity, and from these cues, instructors can infer what chemistry knowledge the students are applying to the problem. The table below contains some of the more frequently used cues or properties, and can be used to help identify the cues or properties students are using in their responses. The appropriateness of the cue or property that has been used is often dependent on the student's response as a whole. Experts and novices could use the same cue but for very different reasons.

Explicit extensive-intensive properties	**Explicit-implicit intensive properties**	**Composition**	**Structure**
- appearance - hardness - volume - mass - shape	- melting point/boiling point etc. - flammability - viscosity - reactivity - pH	- indication of components, from differentiation of mixture and pure substance to consideration of submicroscopic components (e.g. atoms, molecules)	- indication of arrangement of components, from bond connectivity to overall molecular shape, generally on the submicroscopic level

Step 2: Evaluate the quality of the supporting arguments.
When responding to these questions, students should justify why the cue(s) they chose will help them to determine the chemical identity of the substance in the question. Their justification, or reasoning, can be assessed for its complexity. More complexity is not always

required to provide a sufficient justification and does not always indicate a greater understanding of the chemistry concepts; however, the complexity of students' reasoning can be tracked over time or examined across questions.

Descriptive	**Relational**	**Linear Causal**	**Multicomponent**
Descriptive types of reasoning typically focus on the most salient feature of the system and use it to make a decision or judgment without indicating a cause or reason, and often repeat information from the problem or context.	Relational types of reasoning establish a correlation, or relationship, between the noticed feature and the phenomenon or effect. A phenomenon is often reduced or overgeneralized to a single agent or variable, and no mechanisms are proposed.	Linear causal types of reasoning present a mechanism by which the variable or feature causes the effect or phenomenon. The mechanism is the underlying cause(s) that explains the phenomenon at hand, which is often particulate in the context of chemistry problems. In this type of reasoning, a number of agents or effects may be reduced to a single chain of events.	Multicomponent types of reasoning involve more than one variable or feature. The relationships or interactions between these variables are considered.
Ex. I know that bubbles are filled with air.	Ex. There was water in the pot before, so there must be water in the bubbles.	Ex. The stove provides energy to the water molecules, and some of the water molecules have enough energy to spread out and enter the gas phase.	Ex. When the water molecules reach a certain energy level, they can spread out into the gas phase. The water molecules in the gas phase form a bubble that rises to the top because it is less dense than the liquid water.
Ex. Oxygen is a gas, so the gas in the cylinder is oxygen.	Ex. If the gas is odorless, it is oxygen.	Ex. Since all substances have a specific density, if you can determine the density of the gas in the cylinder and it matches the known density of oxygen gas, you can find out if it's oxygen.	Ex. I know that oxygen is an odorless and colorless gas and that it is flammable. If this gas matches all of those properties, then it is possible that it is oxygen.

Step 3: Look for evidence of assumptions that may be guiding student thinking.
Identification of some of the following assumptions in students' responses may help teachers understand student thinking, although the assumptions might not characterize all of students' chemical identity thinking. Similarly to the cues and the reasoning, there are contexts when specific assumptions are more appropriate to apply than others. Assumptions do not always lead to "correct" or "incorrect" thinking; rather, each assumption may be of value depending on the situation. Students' reliance on assumptions to guide their thinking may be tracked over time or across questions.

Functional usage - Purposes that substances serve in daily life are used to classify them (e.g. chemicals are for cleaning). Additionally, the ability of a substance to perform certain actions may be used to classify or differentiate substances (e.g. liquids can be poured).

- Ex. Oxygen is used for breathing, so if the gas helps me to breathe I know it is oxygen.
- Ex. Chlorophyll is what plants use to produce food from sunlight.

Surface similarity - The tendency to pay attention to perceptual cues or perceivable properties (e.g. shape, color, smell) to classify or differentiate – this can lead to a belief that these observable characteristics stem from an essence or inner structure common to substances with similar characteristics.

- Ex. The object is made of silver because it looks hard, like a metal, and it has a silvery appearance that reminds me of silver jewelry.
- Ex. You would know if the liquid is water if it looks like water and moves like water when you pour it out of the glass.

Historicality - The origin or history of a substance is used to determine a substance's chemical identity or to tell if the identity has been lost as a result of a change (e.g. if a substance is made by two different processes, different chemical identities result).

- Ex. The chlorophyll in the leaf is different than the chlorophyll in the algae because they come from different types of plants.
- Ex. The caffeine in Red Bull is different than the caffeine in the plants because the caffeine in the Red Bull went through a process in the lab that changed it.

Substantialization - Properties are separable from substances, and can be added or removed without a change in chemical identity (e.g. a substance's ability to burn can be "used up," at which point it ceases to burn but retains its original identity).

- Ex. Even though the earring has changed color, it is still silver. It can change color but still be the same metal.
- Ex. The caffeine in Red Bull is synthesized in a lab and its effect as a pesticide is removed before it is put into Red Bull.

Additivity - Properties of a substance result from an additive combination of its components' properties, and thus can be added or removed in conjunction with the components (e.g., CH_4 has one part carbon-like properties and four parts hydrogen-like properties).

- Ex. The bubbles in the water are either hydrogen gas or oxygen gas, in a 2:1 ratio, because that is ratio of hydrogen to oxygen in water molecules.
- Ex. If a substance has the same number of carbon atoms, hydrogen atoms, and oxygen atoms as a molecule of sucrose, then it is the same as sucrose.

Elementalism - A component of a substance (usually an atom, bond or functional group) is the carrier of a specific property (e.g., an aldehyde present in a molecule has the property of an IR absorption peak between 1740 and 1690 cm^{-1}).

- Ex. The oxygen in the carbon dioxide makes carbon dioxide flammable, because oxygen by itself is flammable.
- Ex. The hydrogen atoms in the water molecules make them able to go into the gas phase.

Structuralism - Differentiation using models based on specific composition and molecular structure that can be applied across different classes of substances, and recognition that substances share similarities in structure at the particulate level.

- Ex. The caffeine in the Red Bull might be geometrically arranged in a different way than the caffeine in the coffee. It might have the same components, but these might be put together in a different way, which could explain its different effects.
- Ex. Chemicals are named based on the specific structure they have, so since it has the same name that means the substances have the same structure and are the same.

Emergence - The interactions of components of a substance on a subatomic, atomic, or molecular level emerge as properties of that substance, and can be used to identify or differentiate substances.

- Ex. When the sucrose goes from a solid to a liquid state, the intermolecular forces in between the molecules of sucrose are broken but it doesn’t change the identity of the molecules of sucrose.
- Ex. Chlorophyll appears green because the interaction of light with the molecule of chlorophyll, so if the color is not green this can indicate a difference in the composition or structure of the molecule, making it different from chlorophyll.