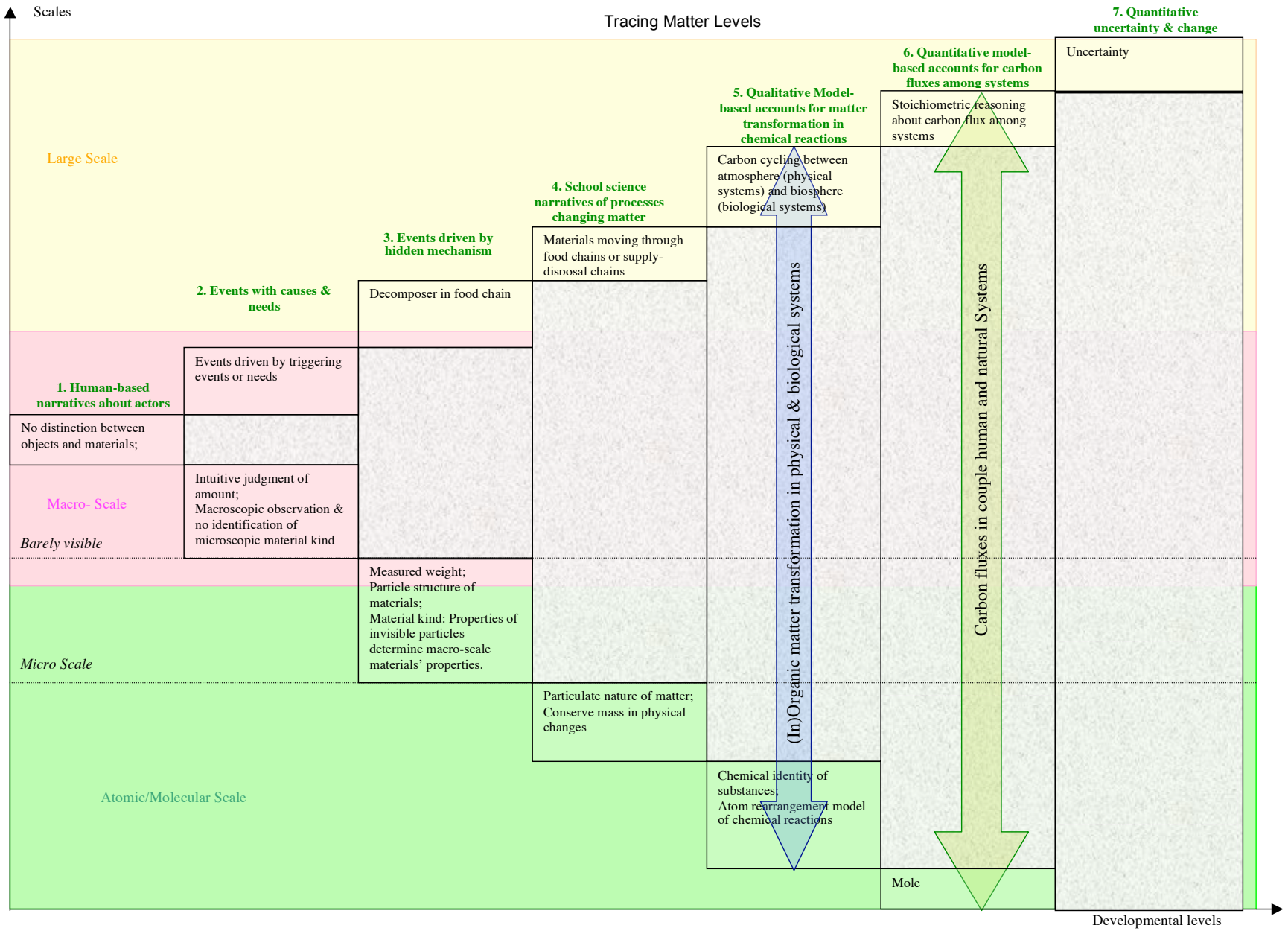
Scales
Tracing Matter Levels
7. Quantitative uncertainty & change
Uncertainty
6. Quantitative model-based accounts for carbon fluxes among systems
Stoichiometric reasoning about carbon flux among systems
5. Qualitative Model-based accounts for matter transformation in chemical reactions
Carbon cycling between atmosphere (physical systems) and biosphere (biological systems)
4. School science narratives of processes changing matter
Materials moving through food chains or supply-disposal chains
3. Events driven by hidden mechanism
Decomposer in food chain
2. Events with causes & needs
Events driven by triggering events or needs
1. Human-based narratives about actors
No distinction between objects and materials;
Intuitive judgment of amount;
Macroscopic observation & no identification of microscopic material kind
Large Scale
Macro- Scale
Barely visible
Micro Scale
Atomic/Molecular Scale
Measured weight;
Particle structure of materials;
Material kind: Properties of invisible particles determine macro-scale materials' properties.
Particulate nature of matter;
Conserve mass in physical changes
Chemical identity of substances;
Atom rearrangement model of chemical reactions
Mole
(In)Organic matter transformation in physical & biological systems
Carbon fluxes in couple human and natural Systems
Developmental levels

	Levels	Measurement	Hierarchy of Systems, Scale	Function/Material Kind/Properties
7	**Quantitative uncertainty & change**	Recognizes the uncertainty of the issue of global warming and takes it into account when analyzing quantitative and qualitative information from multiple media sources. (e.g. quantitative risk assessment, error bars)		
6	**Quantitative model-based accounts for carbon fluxes among systems (physical, biological, & human engineered systems).** Uses stoichiometric calculations of balanced chemical equation to connect multiple scales.	Uses quantitative measurements of carbon fluxes through multiple processes in multiple scales. Uses stoichiometric calculations of balanced chemical equation to connect atomic-molecular quantity with macroscopic measures of mass or volume and measurement at large scale. (e.g. calculate the CO2 emits by a car or CO2 observed by a forest in a year; Tree grow item, a small tree grow into a big tree, where does the gained mass come from) Conserves mass in complex chemical changes (e.g., weight gain and loss in plants and animals) Balances chemical equations, accounting for numbers of individual atoms. Relates measures of energy (megawatt-years) to measures of mass (e.g. gigatons of CO_2).	Relates substances to chemical formula. Correctly identifies reactants and products of life processes: organic matter generation (photosynthesis), organic matter movement (digestion, growth, and refining fuels), organic matter oxidation (combustion and cellular respiration) Identify major carbon-containing organic substances in foods (carbohydrates and lipids) and fuels (hydrocarbons). Recognizes chemical identity of these carbon-containing organic substances and relates it with energy. May need to use tools to find relevant information (e.g. using Google). Identifies chemical relationships among carbon-containing compounds in earth, living systems, atmosphere, and engineered systems.	
5	**Qualitative Model-based accounts for matter transformation in chemical reactions** Mass *Chemical identity* of substances: distinguishes between: Organic substances in all organisms; Chemical identity of gases. Use *atom re-arrangement* model to reason matter transformation in simple chemical reactions. At large-scale, recognizes carbon transforms between organic form and inorganic form in coupled physical and biological systems.	Conserves mass in chemical changes and physical changes involving solids, liquids, gases. Balances equations with qualitative understanding of matter conservation and energy conservation, but cannot use stoichiometric calculations to calculate the amount of certain material involving in chemical/physical changes.	Recognizes that molecule is the basic unit to keep substance's identity and chemical bonds hold the atoms together to form molecules. Describes and distinguishes matter transformation and energy transformation in simple chemical changes. Recognizes carbon cycling between physical systems (atmosphere) and biological systems (biosphere) at large-scale and identifies chemical reactions involved in carbon cycling.	Recognizes that chemical identity of a substance will not change when the substance keep its molecular structure. Consistently identifies reactants and products (including solids, liquids and gases) in chemical changes. Identifies some organic molecules in cells and all organisms including decomposers. Recognizes that both respiration and combustion are processes of organic matter oxidation and release carbon into atmosphere. Recognizes that photosynthesis is a process of organic matter generation and removes carbon from atmosphere. Explains how single event such as running cars are related to global warming. May need to search for information for specific substances that involved in the chemical changes (e.g. using Google).
4	**School science narratives of processes changing matter** Measurement of intensive variables such as density. *Particulate nature* of matter. Uses particulate nature of matter to successfully explain physical changes. Materials moving in food chains and supply-disposal chains.	Conserves mass in physical changes involving gases. Conserves mass in chemical changes involving solids and liquids. (e.g. specific materials moving in food chain) Balances chemical equations without qualitative understanding of relevant chemical reactions. Quantitative measurement of density.	Recognizes particulate nature of matter and explains changes of states by a model of matter composed of atoms/molecules that are in motion. Describes matter movement within and between systems in terms of specific materials moving from one organism/place to another. (e.g. food chains or supply-disposal chains)	Correctly identifies some not all reactants and products of simple chemical changes. Identifies solids and liquids involved in chemical changes, but cannot consistently identify gases as reactants or products. Recognizes that matter/energy is being passed through food chain, supply-disposal chain, but cannot consistently identify relevant both matter transformation and energy transformation. Distinguishes between substances and forms of energy or conditions (e.g., heat, light, temperature) in physical and chemical changes.

3	**Events driven by hidden mechanism** Distinction between extensive & intensive variables; Identifies *material kind at micro-scale* and constructs a relevant explanatory framework: Macroscopic materials are composed of invisible particles, so macroscopic properties of materials are determined by the properties of individual particles. Food chain as sequences of events	Identifies weight and mass as the most fundamental measure of amount of material. Relies on measured weight over felt weight. Begins to Distinguishes between extensive variables measuring amount (e.g., weight, volume) and intensive variables measuring concentration (e.g., density) Macroscopic materials are composed of invisible particles. Recognizes the mass of a matter is equal to the mass of all the small particles it has.	Recognizes that matter are made of invisible particles, which have weight and take up space, but does not recognizes the molecular structure of materials. Attention to hidden mechanism. Describe events (e.g., burning, growth) as changes in materials. Conserve substances in physical changes involving solids, liquids, and gases.	Hold the notion of "material kind" – different materials are composed of different invisible particles and material will not change if the particles do not change; material "particles" have mass and take up spaces, so matter (solids, liquids, and gases) have weight and take up spaces. Identifies specific materials that are changing during events (e.g., burning, growth), but does not hold the idea of "reaction". (e.g. one substance can change into other substance without reacting with any other substances.) Recognizes that physical changes (dividing, melting, freezing) do not change material, because the material "particles" do not change. Recognizes food chain as sequences of events. (e.g., rabbit eat grass and coyote eat rabbit but does not pay attention to the underlying matter movements of those events.)
2	**Events with causes and needs** Intuitive judgment of amount; Reasonable separation between possible and impossible events and processes. Views events as being driven by causes and needs	Intuitive judgment of amount. Hold the idea of felt weight such as: a lot or a little, more or less, heavier or lighter. No clear distinction among size, mass/weight, and volume.	Describes changes as events caused by triggering events and/or needs and does not identify changes in materials. Holds images and tells intuitive stories about the microscopic world. Notice objects has properties that are not determined by people. Organizes thinking around events or objects, rather than changes or material properties. Uses **Romantic narratives (nature videos)** to talk about connections among events and relationships among organisms.	
1	**Human-based narratives about actors** Events described in terms of personal causation and effects – how to make things happen Uses mythic narratives to describe relationships and connections among organisms.	Does not recognize that the amount of material will not change when the material changes its shape.	Uses human analogy to explain why changes happen. Describes changes in terms of personal intentions or actions – how to make them happen as opposed to how or why they happen. Uses mythic narratives to describe relationships and connections among organisms. (e.g. lion king, deer bambi)	

Level		Microscopic/Atomic-Molecular	Macroscopic	Large Scale
7	**Quantified uncertainty & change**	Recognizes the uncertainty of the issue of global warming and takes it into account when analyzing quantitative and qualitative information from multiple media sources. (e.g. quantitative risk assessment, error bars)		
6	**Qualified model-based accounts across scales**	**Quantitative:** Uses stoichiometric calculations of balanced chemical equation to connect atomic-molecular quantity with macroscopic measures of mass or volume and measurement at large scale. (e.g. calculate the CO2 emits by a car or CO2 observed by a forest in a year; Tree grow item, a small tree grow into a big tree, where does the gained mass come from) **Material Kind:** Identify major carbon-containing organic substances in foods (carbohydrates and lipids) and fuels (hydrocarbons). Recognizes chemical identity of these carbon-containing organic substances and relates it with energy. May need to use tools to find relevant information (e.g. using Google).	**Quantitative:** Conserves mass in complex chemical changes (e.g., weight gain and loss in plants and animals) Balances chemical equations, accounting for numbers of individual atoms. **Material Kind:** Relates substances to chemical formula. Correctly identifies reactants and products of life processes: organic matter generation (photosynthesis), organic matter movement (digestion, growth, and refining fuels), organic matter oxidation (combustion and cellular respiration)	**Quantitative:** Uses stoichiometric calculations of balanced chemical equation to connect atomic-molecular quantity with large scale measures of mass or volume. (e.g. calculate the CO2 emits by a car or CO2 observed by a forest in a year) Uses quantitative measurements of carbon fluxes through multiple processes in multiple scales to make scientific reasoning. Relates measures of energy (megawatt-years) to measures of mass (e.g. gigatons of CO_2). **Material Kind:** Identifies chemical relationships among carbon-containing compounds in earth, living systems, atmosphere, and engineered systems. Relates substances to chemical formula. Correctly identifies reactants and products of life processes: organic matter generation (photosynthesis), organic matter movement (digestion, growth, and refining fuels), organic matter oxidation (combustion and cellular respiration)
5	**Model-based accounts across scales**	**Quantitative:** Conserves mass in chemical changes and physical changes involving solids, liquids, gases Balances equations with qualitative understanding of matter conservation and energy conservation, but cannot use stoichiometric calculations to calculate the amount of certain material involving in chemical/physical changes. **Material Kind:** Recognizes that molecule is the basic unit to keep substance's identity and chemical bonds hold the atoms together to form molecules. Identifies some organic molecules in cells and all organisms including decomposers.	**Quantitative:** Conserves mass in chemical changes or physical changes involving solids, liquids, gases. **Material Kind:** Consistently identifies reactants and products (including solids, liquids and gases) in chemical changes. Describes and distinguishes matter transformation and energy transformation in simple chemical changes. Recognizes that chemical identity of a substance will not change when the substance keep its molecular structure.	**Quantitative:** N/A **Material Kind:** Recognizes that both respiration and combustion are processes of organic matter oxidation and release carbon into atmosphere. Recognizes that photosynthesis is a process of organic matter generation and removes carbon from atmosphere. Explains how single event such as running cars are related to global warming. May need to search for information for specific substances that involved in the chemical changes (e.g. using Google). Recognizes carbon cycling between physical systems (atmosphere) and biological systems (biosphere) at large-scale and identifies chemical reactions involved in carbon cycling.
4	**School science narratives of processes**	**Quantitative:** Conserve mass in physical changes involving gases. Conserve mass in chemical changes involving solids and liquids. (e.g. specific materials moving in food chain) Balances chemical equations without qualitative understanding of relevant chemical reactions. **Material Kind:** Recognizes particulate nature of matter and explains changes of states by a model of matter composed of atoms/molecules that are in motion.	**Quantitative:** Conserves mass in chemical changes or physical changes of solids and liquids, but not gases. (e. g. matter movement through food chain) Understands and formularizes mass, volume, density relationship. **Material Kind:** Correctly identifies some not all reactants and products of simple chemical changes. Identifies solids and liquids involved in chemical changes, but cannot consistently identify gases as reactants or products. Distinguishes between substances and forms of energy or conditions (e.g., heat, light, temperature) in physical and chemical changes.	**Quantitative:** Conserves mass in food chain, supply-disposal chain **Material Kind:** Identify the materials that move through food chains, supply chains and etc. Describes matter movement within and between systems in terms of specific materials moving from one organism/place to another. (e.g. food chains or supply-disposal chains); Recognizes that matter/energy is being passed through food chain, supply-disposal chain, but cannot consistently identify relevant both matter transformation and energy transformation.
3	**Causal sequences of events with hidden mechanisms**	**Quantitative:** Macroscopic materials are composed of invisible particles. Recognizes the mass & volume of a matter is equal to the mass & volume of all the small particles it has. **Material Kind:** Hold the notion of "material kind" – different	**Quantitative:** Distinguish changes in mass, volume. Identifies weight/mass as the most fundamental measure of amount of material. Relies on measured weight over felt weight. **Material Kind:** Identify properties of substances in	**Quantitative:** Distinguish changes in mass, volume. Identifies weight/mass as the most fundamental measure of amount of material. Relies on measured weight over felt weight. **Material Kind:** recognizes food chain as sequences of events. (e.

		materials are composed of different invisible 3particles and material will not change if the particles do not change; material “particles” have mass and take up spaces, so matter (solids, liquids, and gases) have weight and take up spaces.	physical change and recognizes that physical changes (dividing, melting, freezing) do not change materials. Identifies specific materials that are changing during events (e.g., burning, growth), but does not hold the idea of “reaction”. (e.g. one substance can change into other substance without reacting with any other substances.)	g. rabbit eat grass and coyote eat rabbit but did not pay attention to the underlying matter movements of those events.)
2	**Events based narratives about materials**	**Quantitative:** N/A **Material Kind:** Describes changes as events caused by triggering events and/or needs and does not identify changes in materials. Holds images and tells intuitive stories about the microscopic world.	**Quantitative:** Intuitive judgments of amount. (Felt weight such as: A lot or a little, more or less, heavier or lighter, and etc.) No clear distinction among size, mass(weight), volume. **Material Kind:** Notice objects has properties that are not determined by people. Organizes thinking around events or objects, rather than changes or material properties.	**Quantitative:** N/A **Material Kind:** Uses **Romantic narratives (nature videos)** to talk about connections among events and relationships among organisms.
1	**Human-based narratives about actors**	**Quantitative:** N/A **Material Kind:** N/A	**Quantitative:** Does not recognize that the amount of material will not change when the material changes its shape. **Material Kind:** Uses human analogy to explain why changes happen. Describes changes in terms of personal intentions or actions – how to make them happen as opposed to how or why they happen.	**Quantitative:** N/A **Material Kind:** Uses **mythic narratives** to describe relationships and connections among organisms. (e.g. lion king, deer bambi)