### Students' progression in understanding matter

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| **5**       | Systemic particle concept | Students describe matter and their properties through interactions in a system of particles (Crespo & Pozo, 2004; Gómez et al., 2006; Stevens et al., 2010; Talanquer, 2009). Students are able to describe and to explain the structure of simple molecules (Lühahn et al., 2009). They are able to explain why specific interactions in a system of particles occur (Stevens et al., 2010). Examples of typical student statements
  - Carbon atoms may be present in different hybridizations (Taber, 2005).
  - Measurment structures are used to illustrate the molecule. It is stable through covalent bonding (Taber, 2005).
  - By adding heat electrons spin move more spin and more (Adbo & Taber, 2009).
  - Students are able to trace physical properties of matter and conditions for physical changes back to the properties of particle collectives (Johnson, 2005; Johnson & Papageorgiou, 2010; Papageorgiou et al., 2010; Salta & Tsougraki, 2011).
  - The attractive forces between particles are surmounted when water evaporates (García Franco & Taber, 2009; Othman et al., 2008). Lower temperature means stronger forces between particles (Johnson, 2005; Talanquer, 2009). Students are able to use energy and matter concepts to describe conservation for example by including laws of thermodynamics in their explanations (Taber, 2005). Examples of typical student statements
  - The inner energy of a closed system is constant.
  - The mass of the nucleus is smaller than the mass of the atomic nucleus (Stevens et al., 2010). |
| **4**       | Differentiated particle concept | Students describe matter as consisting of particles (e.g. atoms), which also consists of further particles (Gómez et al., 2006; Liu & Lesniak, 2005; Liu & Lesniak, 2006; Lófgren & Hildén, 2009; Smithers & Goldston, 2010; Stevens et al., 2010; Talanquer, 2009). Students are able to describe particles with the use of a differentiated atom model (e.g. nucleus-shell, shell model) (Adbo & Taber, 2009). They differentiate between atoms and molecules and can distinguish between different bond types (Gómez et al., 2006; Lófgren & Hildén, 2009; Othman et al., 2008; Smithers & Goldston, 2010). Students are able to take different interactions into account (Adbo & Taber, 2009; Nahum et al., 2007; Othman et al., 2008; Stevens et al., 2010). Examples of typical student statements
  - Sodium chloride exists as a molecule (Othman et al., 2008). Different carbon isotopes exist, which have a different number of protons in the nucleus (Schmidt et al., 2013).
  - Interactions exist between electrons and nuclei (Adbo & Taber, 2009).
  - Atoms are immobile, but electrons are mobile in their shells (Adbo & Taber, 2009). Students can make statements about the reaction progress only in a small number of chemical reactions (Kern & Mähne, 2011). Examples of typical student statements
  - Chromate and lead(II)-ions react (Rahayu & Kita, 2010). Rust arises through chemical reaction of water with iron and oxygen (Pinto et al., 2012). All of the NH₄⁺-ions and phenol react and are being transposed (Kern & Mähne, 2011). |
| **3**       | Simple particle concept | Students describe matter as consisting of particles, which are regarded as the "last divisible part" (García Franco & Taber, 2009; Liu & Lesniak, 2006; Talanquer, 2009) Students understand particles as a building block of matter (Johnson & Papageorgiou, 2010; Nahkhi et al., 2005). There is nothing between the particles. The particles are often described as the "last divisible unit" that is why they are often described with macroscopic properties (Adadan et al., 2010; Gómez et al., 2006). The particles are constantly in motion, whereby the motion rate depends on the aggregate state (Adadan et al., 2009; Johnson & Papageorgiou, 2010; Talanquer, 2009). Particles in solids are understood as immobile (Talanquer, 2009).
  - A substance is completely made of particles (Löfgren & Hildén, 2009).
  - Gas particles are more mobile than particles of a liquid (Takasawa et al., 2012).
  - Particles in solids are closer together than in fluids or in gases (Eam, 2004).
  - Solids are static and immobile (Adadan et al., 2009; Talanquer, 2009).
  - Air is between particles (Adbo & Taber, 2009).
  - Water is a bunch of little water particles (Nakhkh et al., 2005).
  - Water is made up of H₂O-molecules and you can call water H₂O (Nakhkh et al., 2005). Students are able to describe physical properties and changes with the use of a simple particle model (García Franco & Taber, 2009; Löfgren & Hildén, 2009). They transfer the substantial properties and changes to the particle level (García Franco & Taber, 2009; Löfgren & Hildén, 2009). Examples of typical student statements
  - The wax particles melt when wax is heated (Johnson, 2005; Lófgren & Hildén, 2009; Papageorgiou et al., 2010).
  - Particles have the same properties as the whole substances (Othman et al., 2008; Talanquer, 2009).
  - Water makes baking soda into little baking-soda-particles (Isu & Lesniak, 2006). Students are able to use the principle of conservation of matter as well as the principle of conservation of the amount of particles in a scientifically correct way (García Franco & Taber, 2009; Mohan et al., 2009; Rahayu & Kita, 2010). Examples of typical student statements
  - The product mass arises as a result of the reactant’s mass (Salta & Tsougraki, 2011).
  - By dissolving salt in water you can taste the salt in the water so it does not disappear (García Franco & Taber, 2009). |
Students describe matter as containing particles as entities embedded in a substance (Crespo & Pozo, 2004; García Franco & Taber, 2009; Gómez et al., 2006; Löfgren & Hildén, 2009; Talanquer, 2009).

They consider that between the particles is the actual substance (Gómez et al., 2006; Löfgren & Hildén, 2009; Talanquer, 2009).

But the students are not able to use their perception concerning particles to explain structure and composition of matter (Johnson & Papageorgiou, 2010). Nevertheless, they are able to distinguish substances and their composition. Thus, they can recognize if a substance is pure or a mixture (Calk et al., 2009; Johnson, 2005).

Students understand particles as entities embedded in matter (Johnson, 2005).

Examples of typical student statements

- “Matter is granular” (Talanquer, 2009).
- A sugar cube consists of many little sugar pieces, which are compacted together (Naikieh et al., 2005).
- Particles are embedded in a substance like raisins (Johnson, 2005).

Examples of typical student statements

- When water evaporates water particles remain as a residuum (Crespo & Pozo, 2004).
- Mercury is only a metal in the liquid state (Krmel et al., 2005).
- Phase changes arise through heat and energy (Adbo & Taber, 2009).

Examples of typical student statements

- Rust was already present in the iron and became now visible (Saltha & Tzougriak, 2012).
- The copper particles have changed to black particles (Crespo & Pozo, 2004).
- Mercury arises through a melting metal (Krmel et al., 2005).
- Various substances melt to form mercury (Krmel et al., 2005).
- All of the acid and bases properties are kind of deleted (Liu & Leonak, 2006).

Students describe physical changes as a modification of the original substance without using the particle model for a reasonable explanation (Krmel et al., 2005; Smothers & Goldston, 2010).

Students recognize chemical reactions through the emergence of a new substance with other properties than the reactants (Liu & Leonak, 2006). As they do not have a particle perception in order to explain chemical reactions correctly, the following misconceptions appear frequently:

(a) Students claim that the products of a chemical reaction were already present in the reactants (Krmel et al., 2005; Papageorgiou & Liu, 2010).
(b) Students claim that the reactants are still present but only their properties have changed (Krmel et al., 2005; Smothers & Goldston, 2010).
(c) Students do not recognize the coherence between educts and products. The educts have changed to a new substance or to energy (Kurmen & Mehmet, 2011; Liu & Leonak, 2006; Smothers & Goldston, 2010).

Examples of typical student statements

- Metals are always like iron (Krmel et al., 2005).
- Sugar dissolves in water and causes a chemical reaction (Smoth et al., 2010).
- Water disappears during evaporation (Pimthong et al., 2011).
- Substances can disappear and therefore they become less weight (Adbo & Taber, 2009).

Students do not have any model that allows them to describe physical properties and changes of matter scientifically. They describe only what they have observed (García Franco & Taber, 2009; Liu & Leonak, 2005; Smothers & Goldston, 2010).

They use the behavior of prototypes to describe substance properties, e.g. water is a prototype for liquids (Krmel et al., 2005; Olthman et al., 2008).

Examples of typical student statements

- Liquids are transparent and always contain water (Talanquer, 2009).
- Water disappears during evaporation (Pimthong et al., 2012).
- Metals are always like iron (Krmel et al., 2005).
- Baking soda melts into little bits, which cannot be seen anymore (Liu & Leonak, 2006).

Examples of typical student statements

- Wax disappears when a candle burns (Löfgren & Hildén, 2008).
- Fried eggs disappear when they evaporates (Löfgren & Hildén, 2009).
- Naphthalene reduces by reacting with air (Rahayu & Kita, 2010).
- Substances can disappear and therefore they become less weight (Adbo & Taber, 2009).
References


