Bridging the gap between macro and micro: enhancing students' chemical reasoning: how to use demonstration experiments effectively for the teaching and learning of structure-property reasoning

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Appendices

Appendix 1: The SPR Instrument

Cards for the sorting task

Table A.1: *Ideal sorts for the card-sorting task. The columns are the structure aspects each card contains, the rows represent the property aspects of each card. The numbers in the cells refer to the specific sample problem card. The design is based on the model of Krieter et al. (2016).*

		Structure aspects (deep features)			
		Molecular/atomic Bonding	Molecular/atomic Lattice	Ionic Bonding/Lattice	Metallic Bonding/Lattice
Property aspects (surface features)	Melting point	8	5	14	3
	Conductivity	11	7	2	12
	Toughness	16	13	4	10
	Solubility	1	6	9	15

Figure A.1: *used card set in the unframed and framed sorting task.*

Polyethylene (~C=C-C=C-C~)n is a polymer that can conduct electricity. The applications of such polymers are numerous, for example wafer-thin displays. Explain how it is possible that polyethylene can conduct current. 11	Graphite is composed of carbon atoms and can conduct current. Therefore, it is used in electrodes in batteries. Explain how graphite can conduct current. 7	Table salt (sodium chloride) can conduct electricity in a liquid state only. Solid kitchen salt cannot do this. Explain this conductivity of table salt. 2	In smartphones, gold is used as a material for contact points on the circuit board. Explain why gold is used in these contact points. 12
Water striders are small insects that can walk on water. The water looks like a glass plate to these insects. But if you secretly add some soap to the water they probably drown. Explain. 16	A pencil, like a diamond, consists of carbon. However, you can cut a pencil with a simple iron pencil sharpener and you have to cut a diamond with another diamond. Diamond is the hardest material in the world. Explain this. 13	Concrete is created because cement (Ca_3SiO_5) absorbs crystal water. Concrete is non-combustible, but after a fierce fire, the concrete skeleton must still be broken down, because all its strength has disappeared. Explain. 4	Stainless steel contains iron and carbon. Explain why stainless steel is harder than pure iron. 10
Acrylonitrile (C_2H_3CN) is a liquid and it is used as a raw material to make a polymer for toy bricks. The melting point of acrylonitrile is 191K. Explain why acrylonitrile is a liquid at room temperature. 8	The glass of your smartphone contains crystalline silicon dioxide (SiO_2). Compared to diphosphorus pentaoxide (P_2O_5), SiO_2 has a high melting point, namely 1720°C. Explain the high melting point of SiO_2. 5	Copper (II) sulphate is a white solid. When it has absorbed crystal water, the color has turned blue. Blue copper (II) sulphate has a lower melting point than white copper (II) sulphate. Explain this. 14	Molten metals are easily miscible. An alloy is formed. For example, bronze can be formed by mixing copper and tin. However, bronze has a lower melting point than pure copper. Explain this. 3
A blotch of crude oil at sea is difficult to remove. Oil is not soluble in water. You can burn it or finely disperse it and then hope it breaks down slowly. Explain why petroleum is not soluble in water. 1	Quartz is a form of silicon dioxide (SiO_2) that is commonly found in the earth's crust (12% by volume). You can find quartz in sand, for example. Silicon dioxide is a crystalline powder that is virtually insoluble in water. Explain this. 6	Water can be contaminated with heavy metals. These metals are dissolved in water as charged particles. You can remove them by precipitating them with saline solutions. Explain how this works. 9	Dissolving gold in water is very difficult. You can dissolve gold in royal water (a mixture of hydrochloric acid and nitric acid). In this way George de Hevesy hid two Nobel medals from the Nazis. After the war he had the gold beaten down again and the Nobel Foundation had two new medals beaten from it for the original owners. Explain why gold does not dissolve in ordinary water. 15

Date: ______________________ Code: _______________

Sorting task A

In front of you are 16 problems. Read the problems thoroughly, but do not try to solve them. Arrange (sort) these problems in such a way that the problems - which need a **similar underlying chemical concept** to solve the problem – are grouped together.
An example: you have the following problem - Sugar is made of 12 C atoms, 22 hydrogen atoms and 11 oxygen atoms. What percentage of the mass consists of carbon atoms? You could sort this problem with the chemical concept mole, but also with mass ratios.

Make at least 2 groups and no more than 15 groups. A problem (a card) cannot be part of more than one group at the same time. There are different ways to sort these problems.

When you are finished, **give the groups formed by you a name** that describes the group best for you.

Give each group you have created a name. Number the groups. Write down the numbers of the cards you put in that group after the group name.

Example:
1. Keep in fridge - 3, 5, 7
2. Store in cupboard - 1, 2, 4, 6
3. ….

Attention, have you sorted 16 cards?

Date: ______________________ Code:_______________

Sorting task B

In front of you are the same 16 problems as in the previous task. I would like to ask you again to sort these problems. However, I will now give you the categories in which you can sort these problems:

- Molecular compounds - bonding
- Molecular compounds - lattices
- Salts - ionic bonding / ionic lattice
- Metals - metallic bonding / metallic lattice

A problem (one card) cannot be part of more than one group at the same time. Eventually, each problem must be placed in one of the four categories.

Write down the numbers of the cards in the boxes. **Attention, have you sorted 16 cards?**

Molecular compounds **Bonding**	**Molecular compounds** **Lattices**	**Salts** **ionic bonding / lattice**	**Metals** **metallic bonding / lattice**

Ready? Now collect all 16 cards and slide them back into the paper clip.

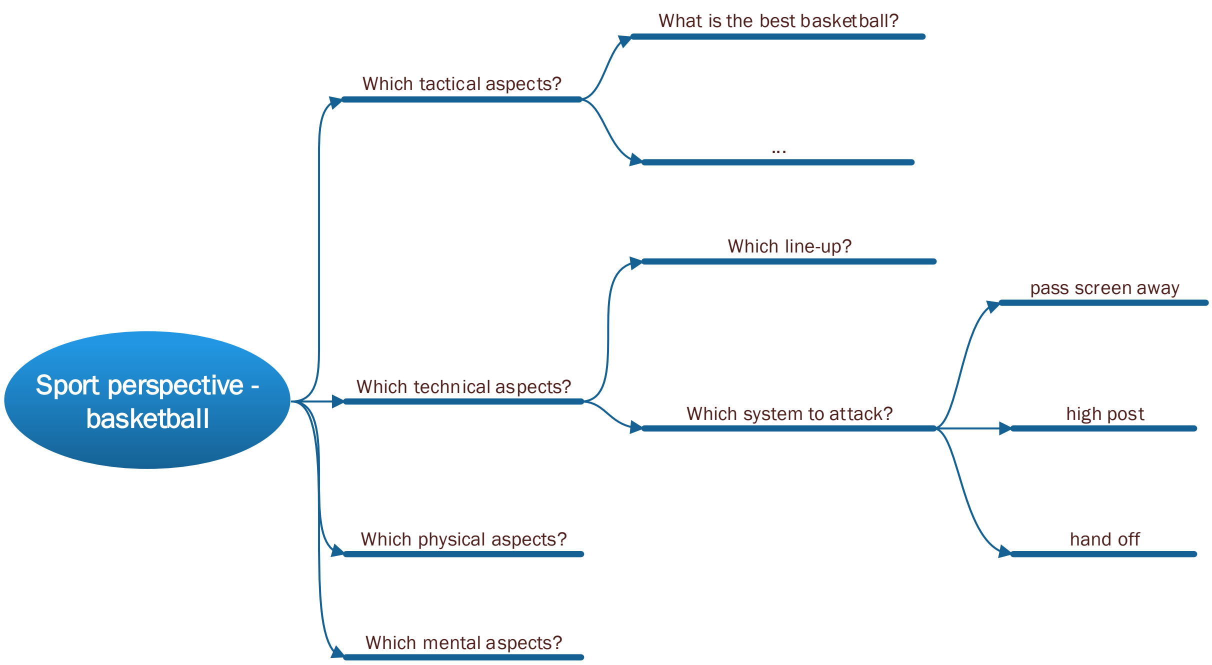
Perspective map – task C

In front of you are the questions of the perspective for structure-property reasoning. A **perspective** is a way of looking at, thinking about, and working with problems. An example is the sports perspective. You can look at your sport, for example basketball, from a technical perspective (what is the best basketball? what are the best shoes?), a tactical perspective (which setup? Which system?) etc. By answering the questions from for example the tactical perspective, you can solve a problem within basketball. The better you get, the more elaborate your perspective is and the better (and faster) you can solve a problem.

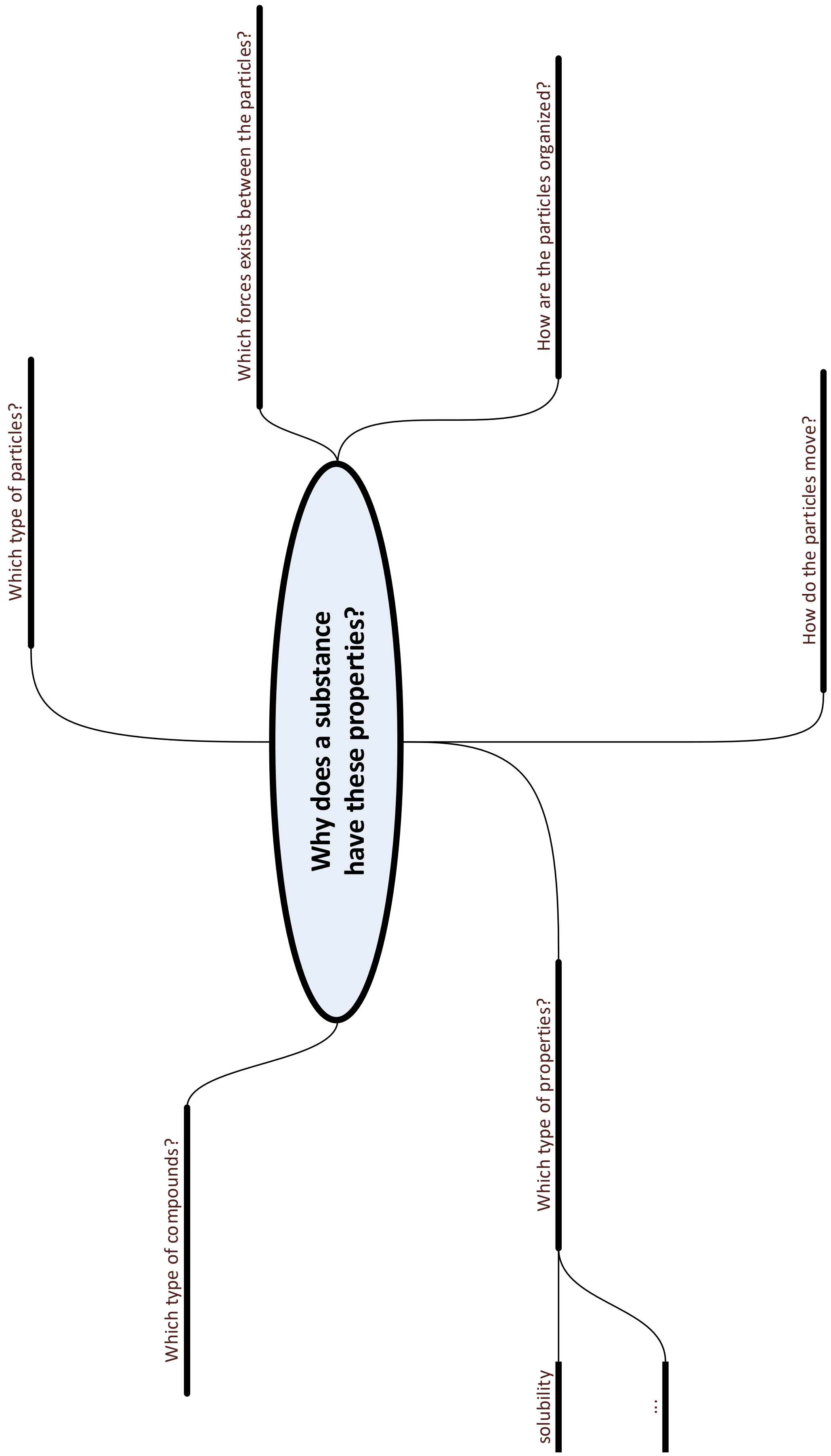
Within chemistry you can also distinguish several perspectives including the perspective for structure-property reasoning and the energy perspective. So, you use such a perspective to question your chemical problem and consequently solve this problem.

Complete this initial perspective for structure-property reasoning by answering the questions with the appropriate chemical concepts. You may give as many answers as necessary. You are also allowed to create a hierarchy if necessary.

An example: A question in the tactical perspective is 'with which attack system can we win the basketball game' – possible answers are: pass-screen-away; high post; hand-over; etc.



Date: _______________ Code:_________ C


Why does a substance have these properties?
Which type of particles?
Which forces exists between the particles?
How are the particles organized?
How do the particles move?
Which type of compounds?
Which type of properties?
solubility
…

Perspective map – task D

In front of you is the beginning of the perspective for structure-property reasoning. Again, I want to ask you to complete this perspective for structure-property reasoning, but this time I want you to use **the concepts below**. You are allowed to create a **hierarchy** if necessary.

amorph	crystal lattice with impurities	solubility
atomic bond	mixture	melting / boiling point
atomic lattice	metal	fast / slow
dipole-dipole interaction	metal atoms	conductivity
hardness	metal bond	Van der Waals force
intermolecular interaction	metal lattice	free / bound
ionic bond	molecular compound	hydrogen bond
ions	molecules	salt
ionic lattice	molecular lattice	pure crystal lattice
crystal lattice	non-metal atoms	pure compound

This was the last task. Thank you for filling it in.

Appendix 2: Demonstration Protocols for Teachers

In Tables A2–A4, the demonstration protocols for the demonstration experiments are provided. In these protocols, for each property, an accompanying demonstration is described. The structure model concept which could be modeled by the students is also indicated. These demonstrations fit in the “observe” phase in the POE task as described in “3.3. Overview of the Lesson Series”.

For each demonstration, the properties of several substances of that group are demonstrated. The choice of substances depends on what is available at school to properly demonstrate the properties. The substances mentioned in the demonstration protocols are therefore only indicative.

Table A2. *Demonstration protocol for metals.*

Property	**Demonstration Instructions**	**Structure Model**
Appearance	The teacher shows different metals (sheets, rods, etc.), such as iron, copper, lead, zinc. The teacher polishes the metal plates and shows the results.	n/a
Phase at room temperature	The teacher shows the metal plates and asks about the phase.	Metallic lattice
Strength	The teacher works the metal plates with a hammer.	Metallic lattice
Malleability	The teacher tries to bend the metal plates.	Metallic lattice
Melting point	The teacher holds the metal lead (mp = 327 K) or zinc (mp = 420 K) in a blue flame. The metal becomes soft. Next, the teacher holds the metals copper (mp = 1083 K) and/or iron (mp = 1535 K) in the flame. These melting points are above the temperature (1273 K) of the blue flame and will not soften.	Metallic bond
Conductivity of electricity	The teacher builds the setup to measure current conductivity: lamp, voltage source, wires and, if necessary, adds a conductivity meter. The teacher measures the current conductivity of various metals.	Metallic lattice, metallic bond
Behavior when heated	The teacher keeps a ribbon of magnesium in the flame. The teacher sprinkles some metal powders (such as iron or magnesium) through the flame.	n/a

Table A3. Demonstration protocol for salts.

Property	**Demonstration**	**Structure Model**
Appearance	The teacher shows different salts, such as sodium chloride, sodium nitrate, iron (III) nitrate, copper sulfate.	n/a
Strength/malleability	The teacher hits lump of salt with a hammer. At the school of the first author, the assistant found an old bottle with big lumps of iron (III) nitrate, which was suitable to hit it with a hammer.	Lattice with uneven particles
Phase at room temperature	The teacher shows different salts with attention to the phase at room temperature.	Lattice with strong bonds
Melting point	The teacher heats a salt such as sodium chloride and iron (III) nitrate.	Lattice with strong bonds
Conductivity of electricity	The teacher tests a solid salt, a liquid salt and a dissolved salt for conductivity.	The particles are charged and stuck in a grid

Table A4. *Demonstration protocol for molecular compounds.*

Property	Demonstration	Structure Model
Appearance	The teacher shows different molecular substances, such as sugar, glucose, ethanol, water, methane (burning), oil.	n/a
Conductivity of electricity	The teacher makes a sugar solution and an ethanol solution and tests the current conduction. The teacher also tests the conductivity of water and oil.	No charged particles: molecules
Behavior when heated (sugar)	The teacher heats sugar until it caramelizes and burns.	The molecules consist of atoms The atomic bond is very strong
Phase at room temperature	The teacher shows liquid and gaseous molecular substances such as water, CO_2 in soft drinks, methane gas, ethanol, acetone.	Weak bond between the molecules
Boiling point	The teacher boils water and ethanol and uses a sensor to measure the temperature. The students search the boiling points of the liquids and search for links.	Van der Waals bond and hydrogen bond
Solubility	The teacher tries to dissolve various substances, such as sugar, oil in water. Two groups emerge.	Van der Waals bond and hydrogen bond
Behavior when heated	The teacher heats up sugar and carbon in a rustling flame.	Molecular lattice/molecular bond vs. atomic lattice/atomic bond