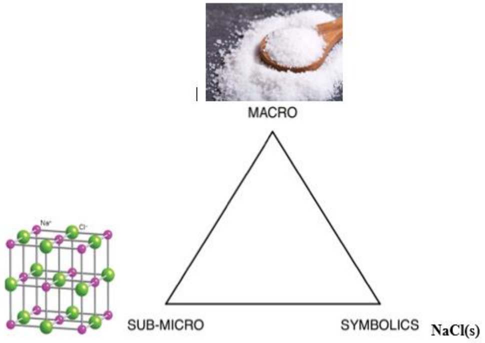

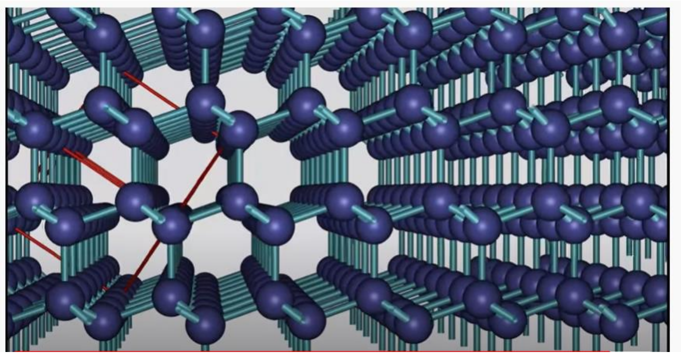

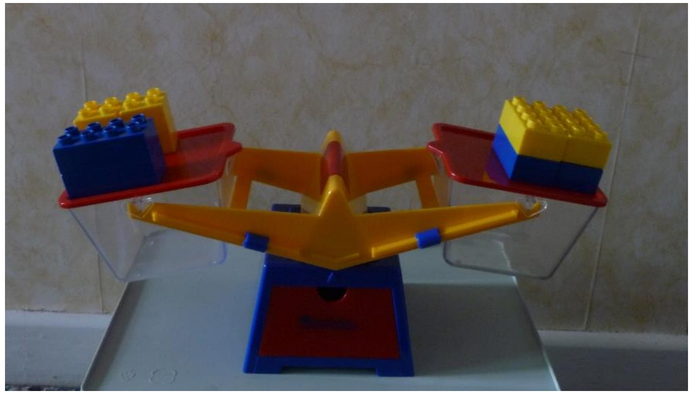

Building a good foundation: teaching the basics of Chemistry

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Outline

1. Getting the basics right – the key/core/big ideas of chemistry: the particulate theory of matter

2. Johnstone's triangle: teaching the three levels of chemistry, using models to introduce abstract ideas

3. Using real objects and samples of elements and compounds

4. Connecting the submicroscopic and macroscopic worlds

5. Taking account of chemistry misconceptions

6. Conclusions and recommendations

1. Getting the basics right – the key/core/big ideas of chemistry: the particulate theory of matter

Majoring on the basics

Our aim as chemistry teachers, especially in junior science, is to help our students understand (as well as learn) the basics of Chemistry.

We also want to make Chemistry interesting and relevant to the real world.

We need to take account of what our students bring into science lessons from primary science and everyday experience.

We want our students to carry their understanding and interest into LC Chemistry and into third level.

The big/core/key ideas in chemistry

Peter Atkins' 9 big ideas

Matter is made of atoms

Elements display periodicity

Chemical bonds form when electrons pair

Molecular shape is a crucial feature in chemistry

There are residual forces between molecules

Energy is conserved

Entropy tends to increase

There are barriers to reaction

There are only four types of reaction

Big ideas of AP Chemistry (USA)

Big Idea 1: Structure of matter

Big Idea 2: Properties of matter-characteristics, states, and forces of attraction

Big Idea 3: Chemical reactions

Big Idea 4: Rates of chemical reactions

Big Idea 5: Thermodynamics

Big Idea 6: Equilibrium

The big/core/key ideas in Chemistry

1. The particulate nature of matter
2. Structure and bonding
3. Periodicity

These are found in most initial chemistry courses at second level (except bonding in JCSA).

They are also the topics students find most difficult and do not understand.

We must get the basics right at the start!

Chemistry topics that students find difficult (Maria Sheehan, PhD, 2010)

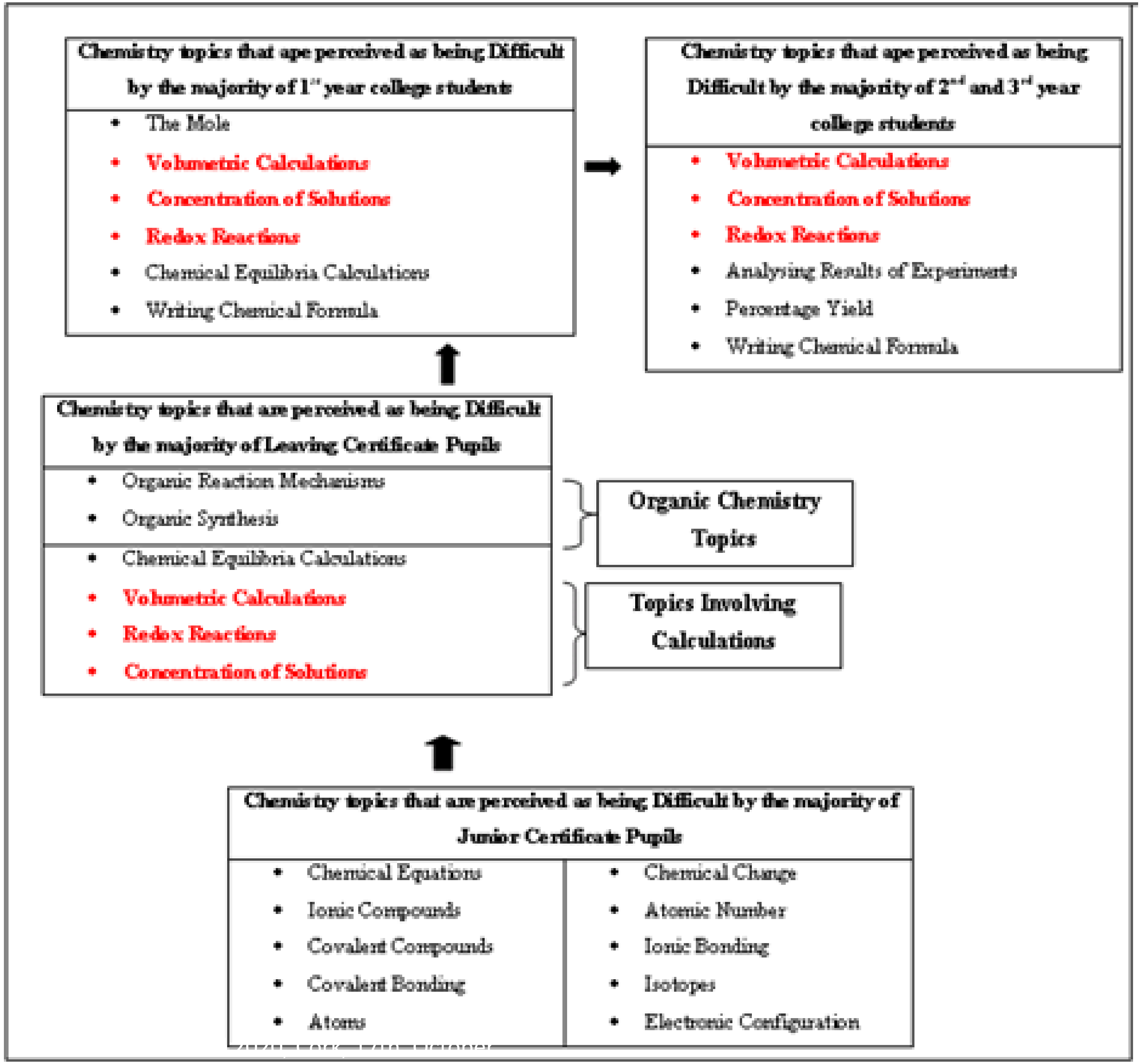


Figure 9: Flow Chart of Topics that are found difficult by pupils/students throughout their

Why kids hate school – subject by subject

Roger C. Schank

Washington Post, September 7, 2012

Chemistry: A complete waste of time. Why? Do you really need to know the elements of the periodic table? The formula for salt? How to balance a chemical equation? Ridiculous. Most of the people who take chemistry in college, by the way, intend to be doctors and while there is chemistry a doctor should know, they don't typically teach it in college. Why should you take chemistry? Because someone is making you. Otherwise don't bother. You won't remember a thing (except NaCl.)

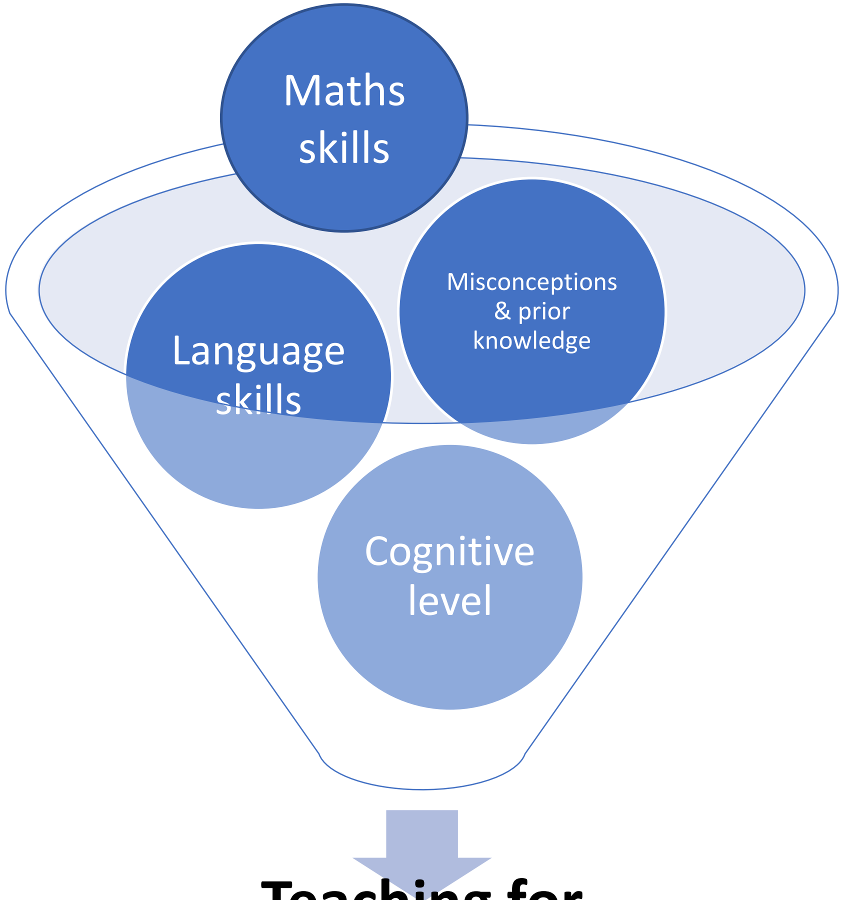
https://www.washingtonpost.com/blogs/answer-sheet/post/why-kids-hate-school--subject-by-subject/2012/09/06/0bf1acc4-f5d6-11e1-8398-0327ab83ab91_blog.html

Key idea:

Understanding the particulate nature of matter - atoms, elements, compounds, molecules, and periodicity and bonding are the core ideas in chemistry, which underpin everything else.

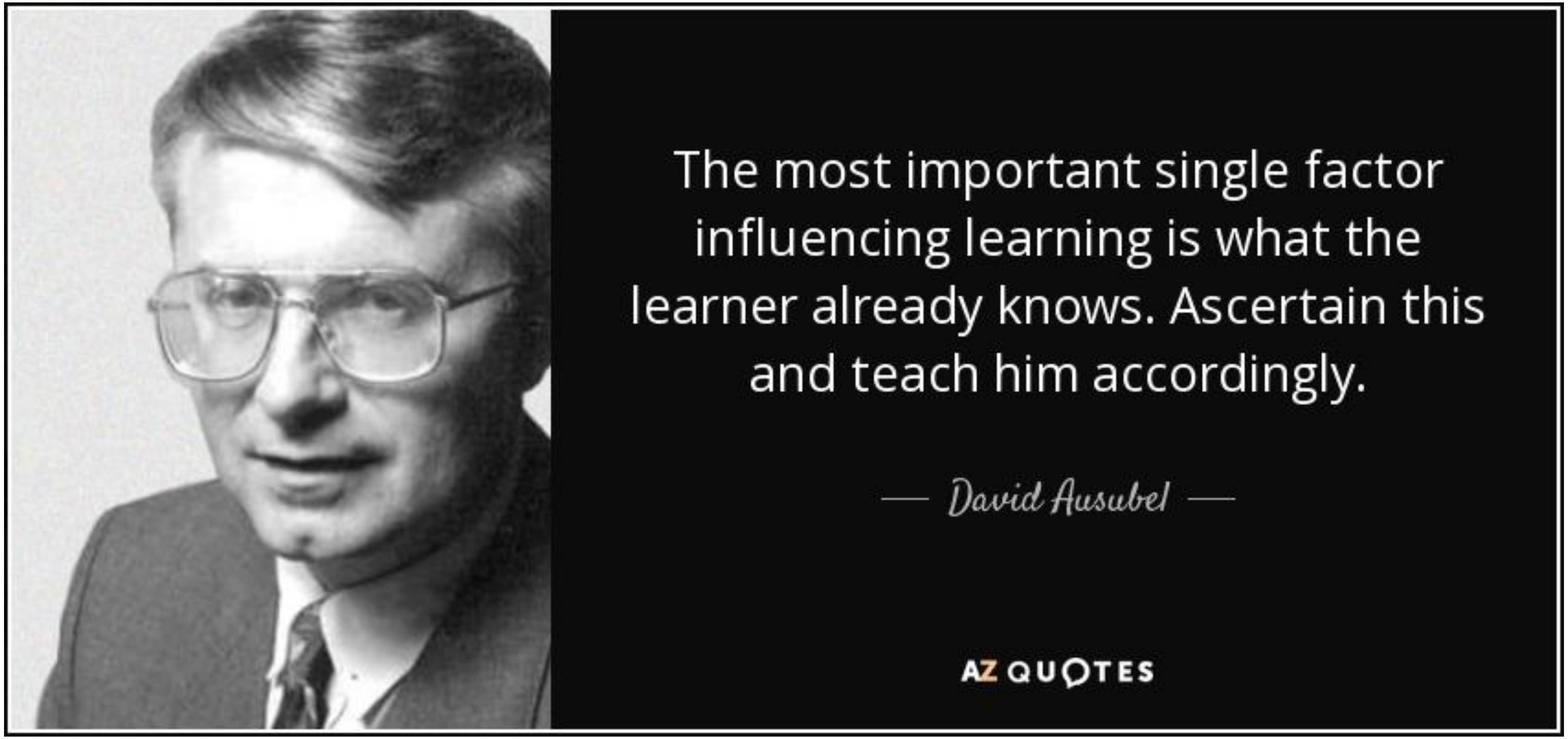
We also need to make Chemistry relevant to everyday life and interesting to students, so that they will want to continue into LC Chemistry and on to third level.

Chemistry basics: teaching for understanding



Teaching for understanding in junior science

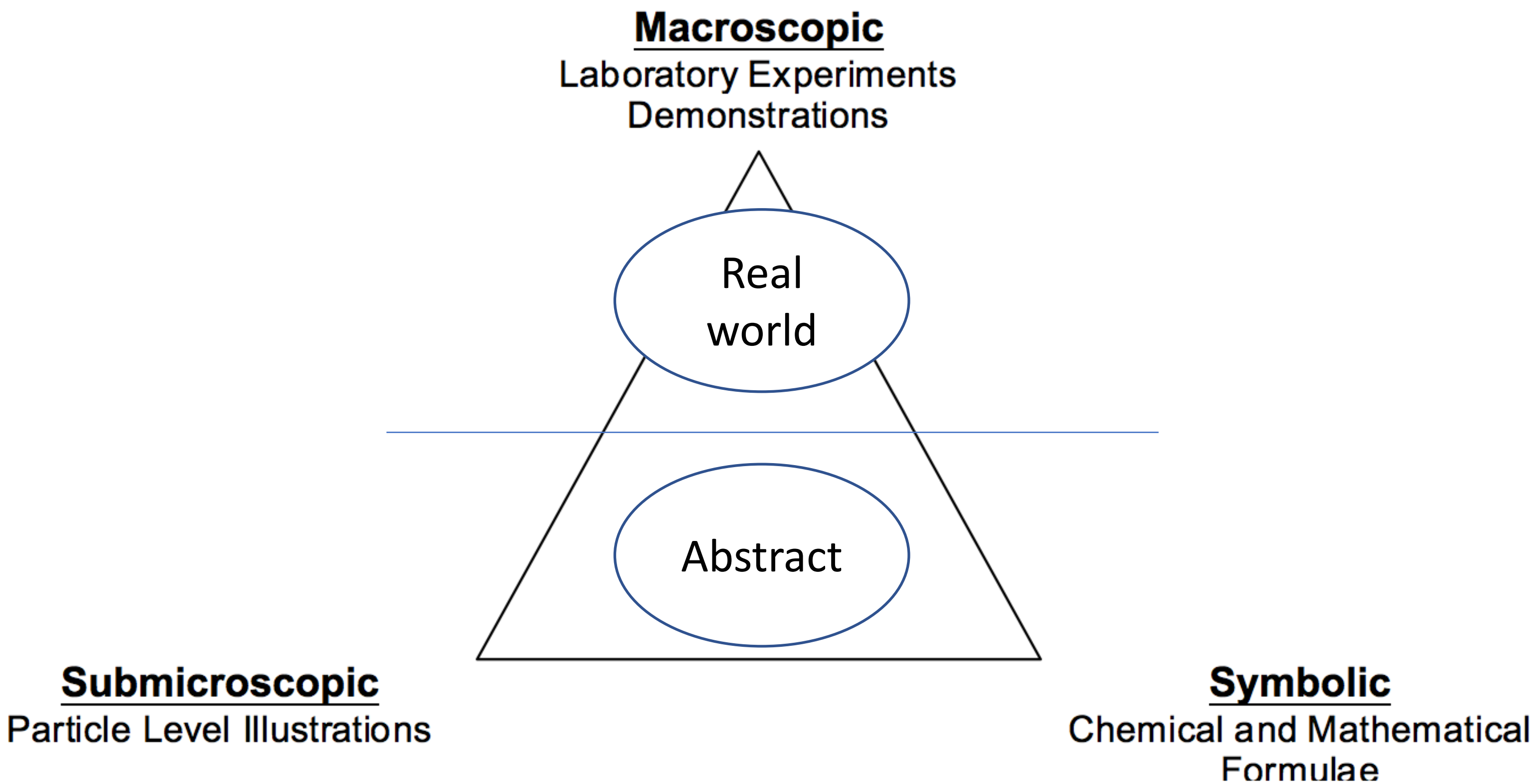
David Ausubel's prescription (1968)



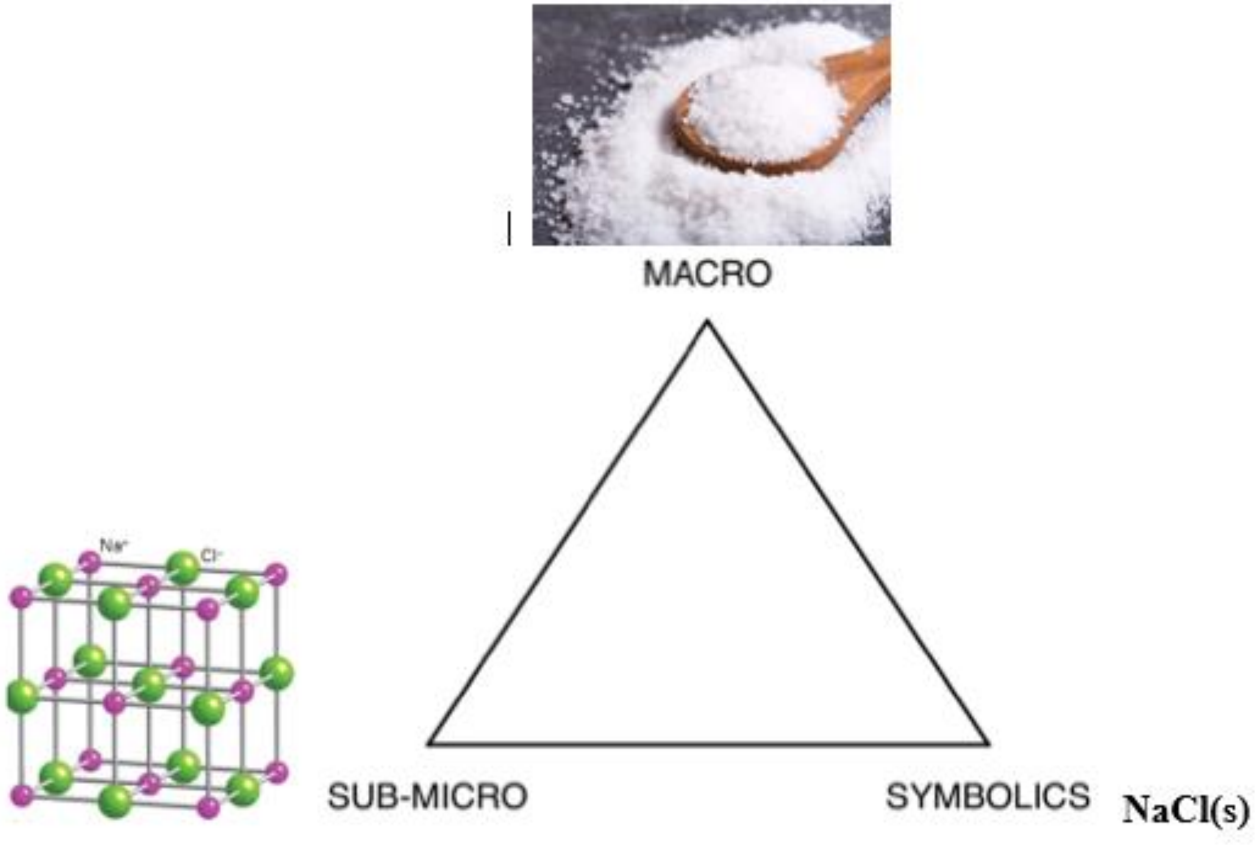
2. Alex Johnstone’s triangle: teaching the three levels of chemistry, using models to introduce abstract ideas

Alex Johnstone's triangle: 3 levels of chemistry

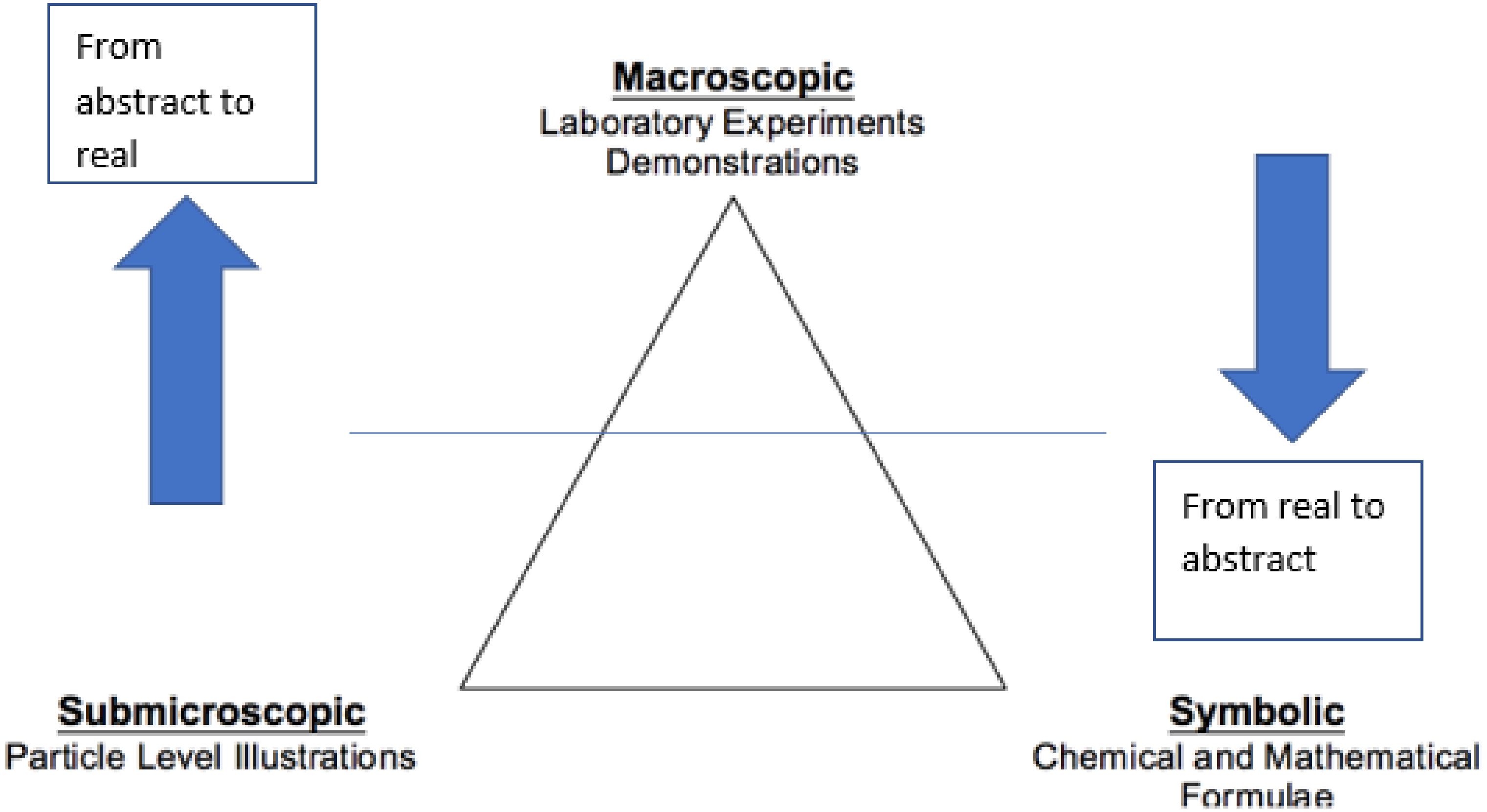
(Johnstone, A.H. (1982) 'Macro and microchemistry', *S.S.R.*, 64, 377-379
Childs, P.E. (2020), 'Alex Johnstone (1930-2017): working memory man and Johnstone's triangle', PoSE #10, *SCIENCE*, Nov.)



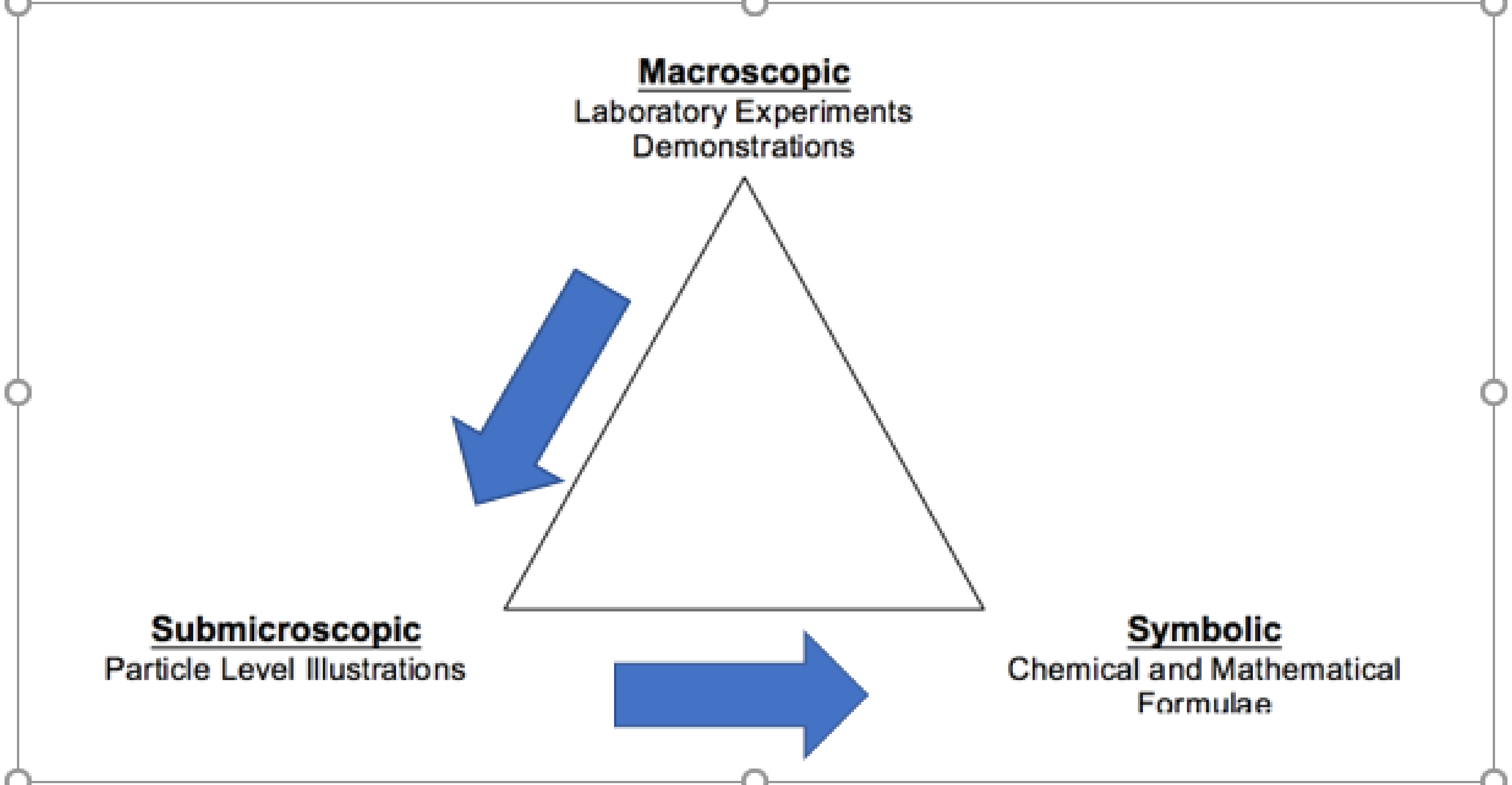
The three levels of chemistry – sodium chloride



Teaching the three levels for beginners: which way to teach?



Teaching the three levels for beginners: macroscopic → submicroscopic → symbolic



Important ide ng the basics

- Know where students
- Understand the topic
- Be aware of misconce
- Always aim for under nformation, facts, definitions etc.
- **Start with the macro h models, illustrations, animati ons.**
- **Move to visualising t models,diagrams, animations.**
- **Introduce the symbo**
- Don't overload stude - use a spiral approach

"Mr. Osborne, may I be excused? My brain is full."

3. Use real objects and samples of elements and compounds

Henry Armstrong – pioneer of IBSE

(See Childs, P.E. () ‘Henry Armstrong: champion of heuristic science teaching (1848-1937), PoSE #7, *Science*,

“Armstrong led a crusade against the dry, verbal, didactic pedagogy that prevailed in the science classroom [at the end of the 19th century].” (p.20)

“Armstrong believed that experience should precede theory, that percept should precede concept. This was one way of saying that science learning should be practical; students should be familiar with the phenomena to which scientific theory is applied.” (p. 21)

M.R Matthews, (1994), *Science Teaching: the role of history and philosophy*, London and New York: Routledge

Experiments and demonstrations matter as well as mo

The use o ations etc to make students with the hould be built on a foundat experien d simple experiments and demonst

The teac gap by simple experiments students visualising the particulate na matter. Ask students what is happening, and why and how.

e.g. opening a bottle of ammonia or perfume at the front of NO_2 in a measuring cylinder; potassium permanganate cryst water; Brownian motion; hot and cold water mixing; iodine bag. **What simple idea can explain all these phenomena?**

Choosing experiments to make a clear point!

A. Elements, atoms, molecules and compounds – making the abstract visible and tangible to students

Childs, P.E., (2009), *Chemistry in Action!*, #89, 19-24 (available at www.cheminaction.com)

Start with Lego bricks – familiar to your students!

A limited number of building blocks (size, shape and colour)

An infinite number of models from a finite number of bricks

Analogy: the world of matter is made from a finite number (~90) of small particles called ATOMS

Atoms are the building blocks or everything.

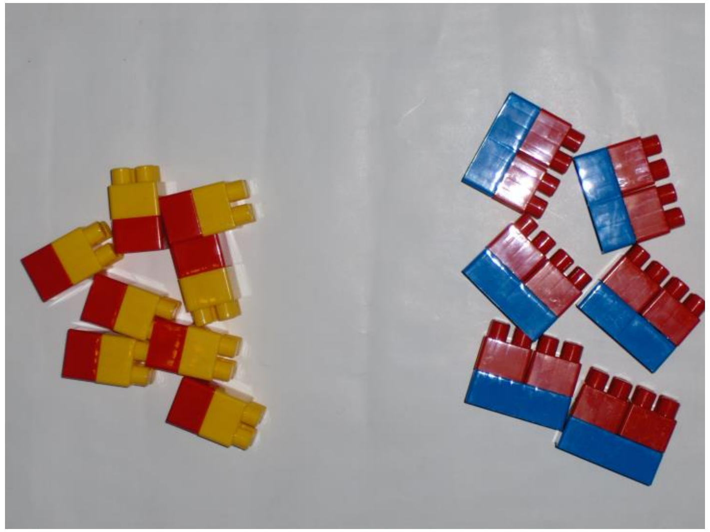
Teaching about elements, compounds and mixtures

From Lego bricks to atoms and compounds – elements contain one sort of atom (brick); a mixture contains two or more different particles.

Teaching about elements, compounds and mixtures

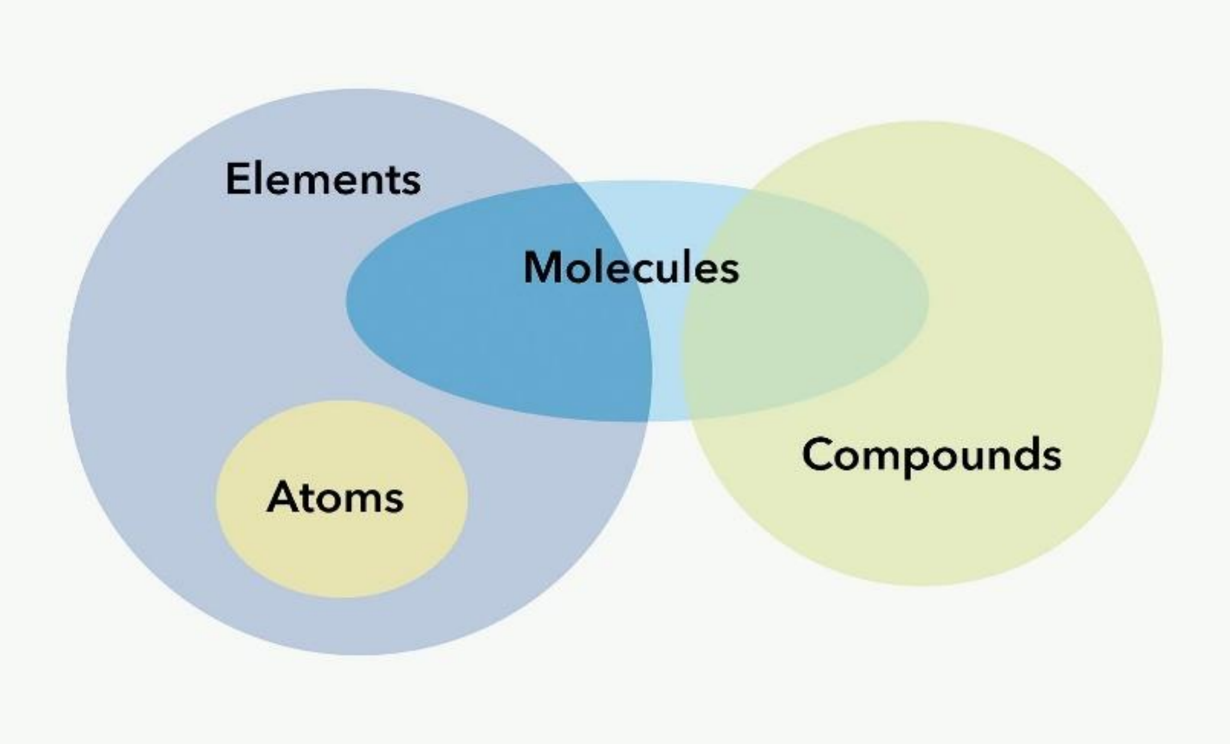
Compounds are made from two or more different blocks (atoms) – size of the block determines how many others it can join with (valency)

A molecule contains two or more similar or different blocks (atoms)



Elements, atoms, molecules and compounds

A molecule is not always a compound. An element can exist as molecules, e.g. Cl_2, O_3, P_4.



Key ideas:

Matter is made of a limited number of types of atoms (elements), which can be combined in many ways to form compounds.

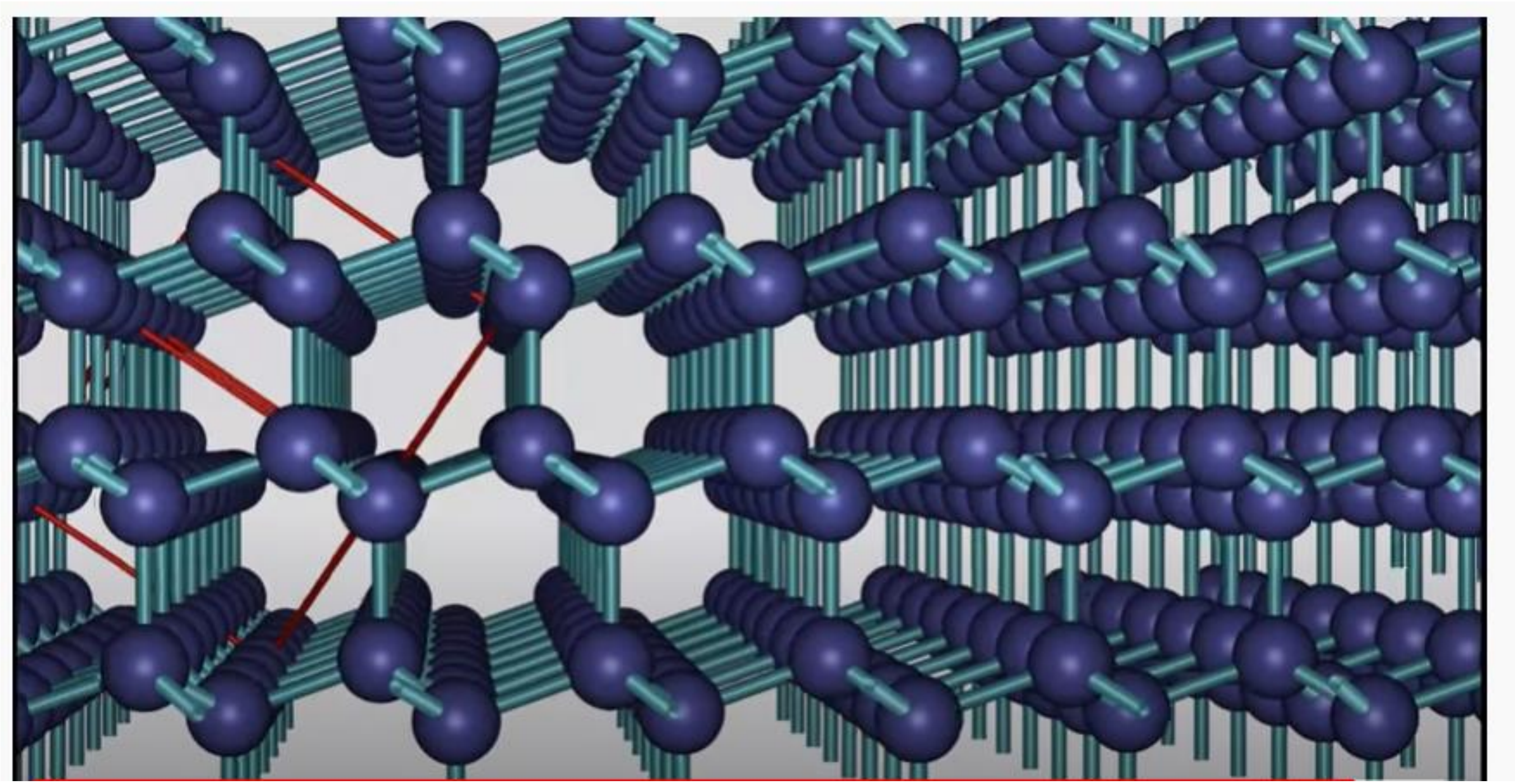
The nature of the atom determines how many other atoms it can combine (bond) with.

Atoms which have similar properties form families (groups) of elements.

Substances may be pure (one sort of particle) or a mixture (2 or more sorts of particle).

3. Using real objects and samples of elements and compounds – connecting to the real world

Moving from models and visualisations to real substances e.g. silicon https://youtu.be/ApqFLVd0XaI



A. Use samples of elements and compounds to bridge from real substances to models and diagrams

Use same-size glass bottles (~200 mL) and weigh out **1 mole** of various elements and compounds – label with name, formula and mass.

Using real samples to make chemistry visible

- Introduce the idea of elements, metals and non-metals
- The difference between elements and compounds e.g. iron, sulfur, iron sulphide
- Include different classes of solid to relate to bonding e.g. zinc (metallic), silicon dioxide (covalent network), sugar (molecular), sodium chloride (ionic)
- Link to simple experiments comparing metals and non-metals, ionic and molecular compounds (5 white solids)
- Return later to discuss **the mole concept** – they all contain 1 molar mass, same number of particles

B. Linking the macroscopic to the submicroscopic level

We now want to make the link stronger between what we can ‘see’, the visible macroscopic world, with what we cannot see, the invisible submicroscopic world.

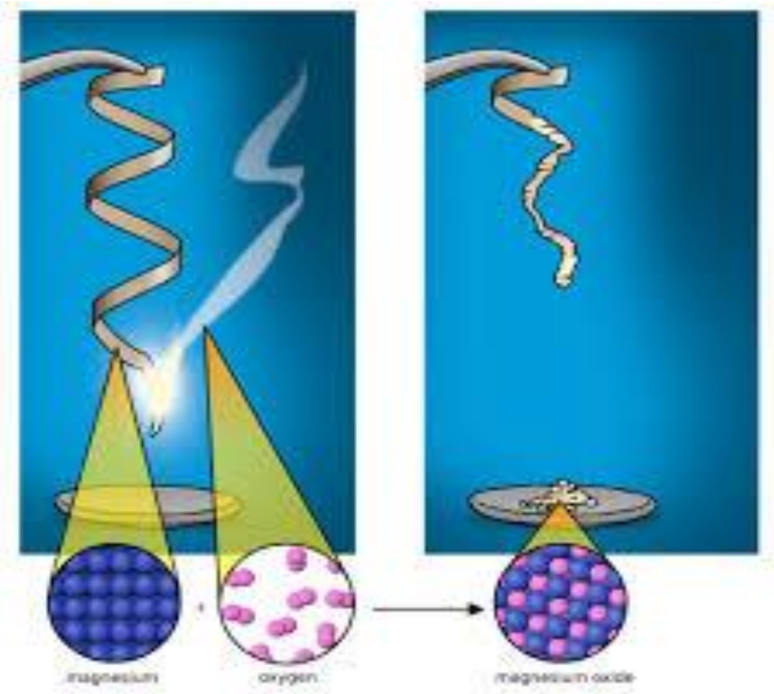
Use visuals and/or models to show what real substances look like at the submicroscopic level.

We also now bring in more chemical reactions – illustrating what happens in a chemical reaction where substances change due to a rearrangement of atoms into new substances.

Chemical reactions with visualisation: 1

1. Burning magnesium in air (oxygen)

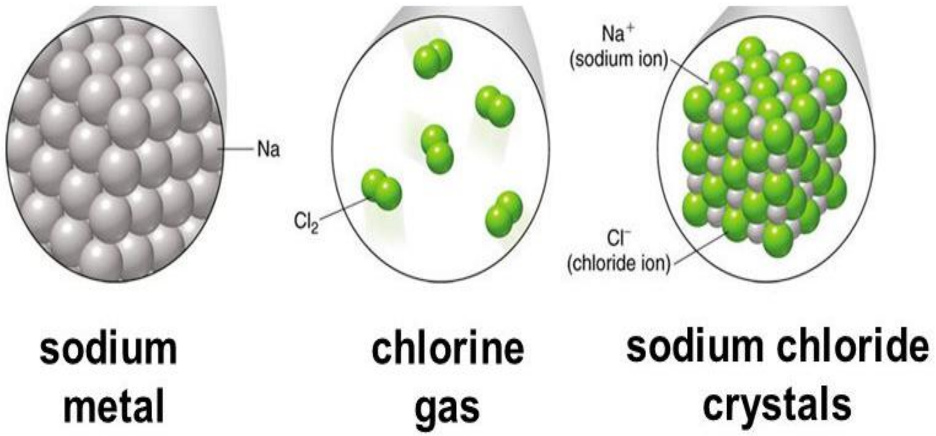
- Magnesium + Oxygen → Magnesium Oxide



Chemical reactions with visualisation: 2

2. Sodium burning in chlorine gas
https://www.youtube.com/watch?v=lhC42qxk5kQ

Sodium + Chlorine → Sodium Chloride



Key ideas

- **Elements can be grouped into two broad categories – metals and non-metals – with different physical and chemical properties. (This will link to the Periodic Table and to groups of similar elements.)**
- **Compounds have different properties (physical and chemical) to their constituent elements, and may be solid or liquid or gaseous depending on the component elements, and may be white, colourless or coloured. (This will link to the type of bonding holding particles together and how these particles are arranged.)**

C. Can we see atoms and molecules?

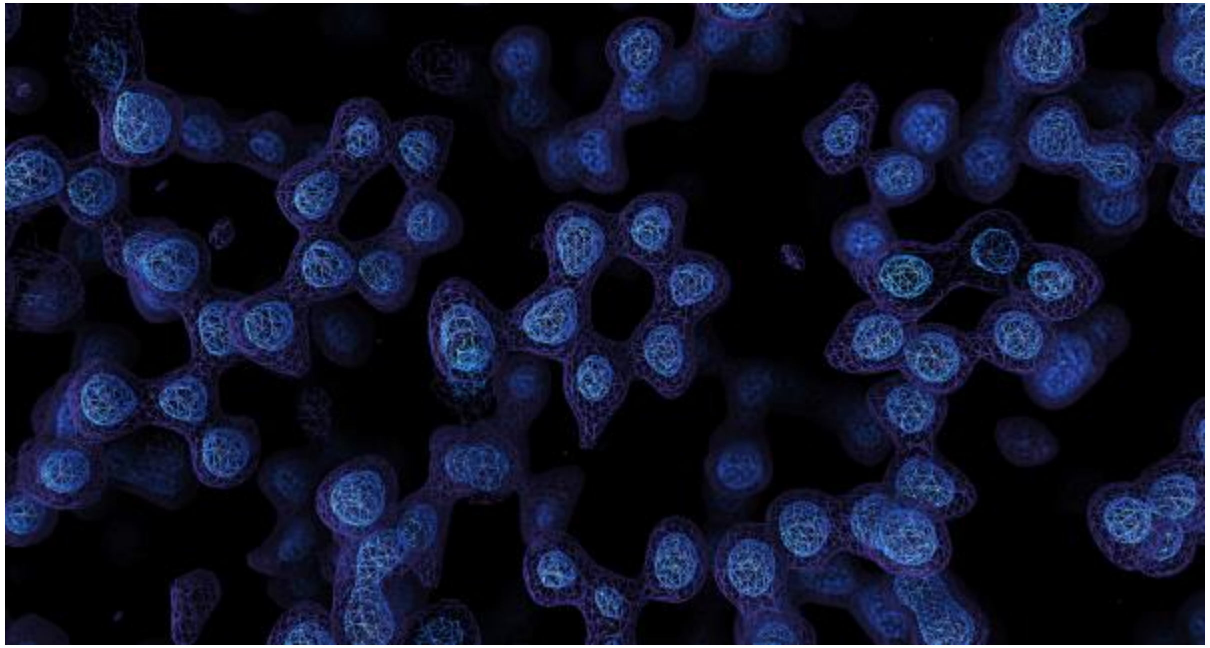
A common occurrence in science classrooms is a child asking: If no one has seen atoms, how come we are drawing pictures of them? Such a child is raising one of the most interesting questions in philosophy of science: the relationship of evidence to models, and of models to reality. Good science teachers should encourage such questions and be able to provide satisfactory answers, or suggestions for further questions. To reply "I do not know," or "because it is in the book" is to forego the opportunity of introducing students to the rich methodological dimensions of science.

Matthews, 1994, p.4

Matthews, M.R, (1994), *Science teaching: the role of history and philosophy of science*, London & New York Routledge

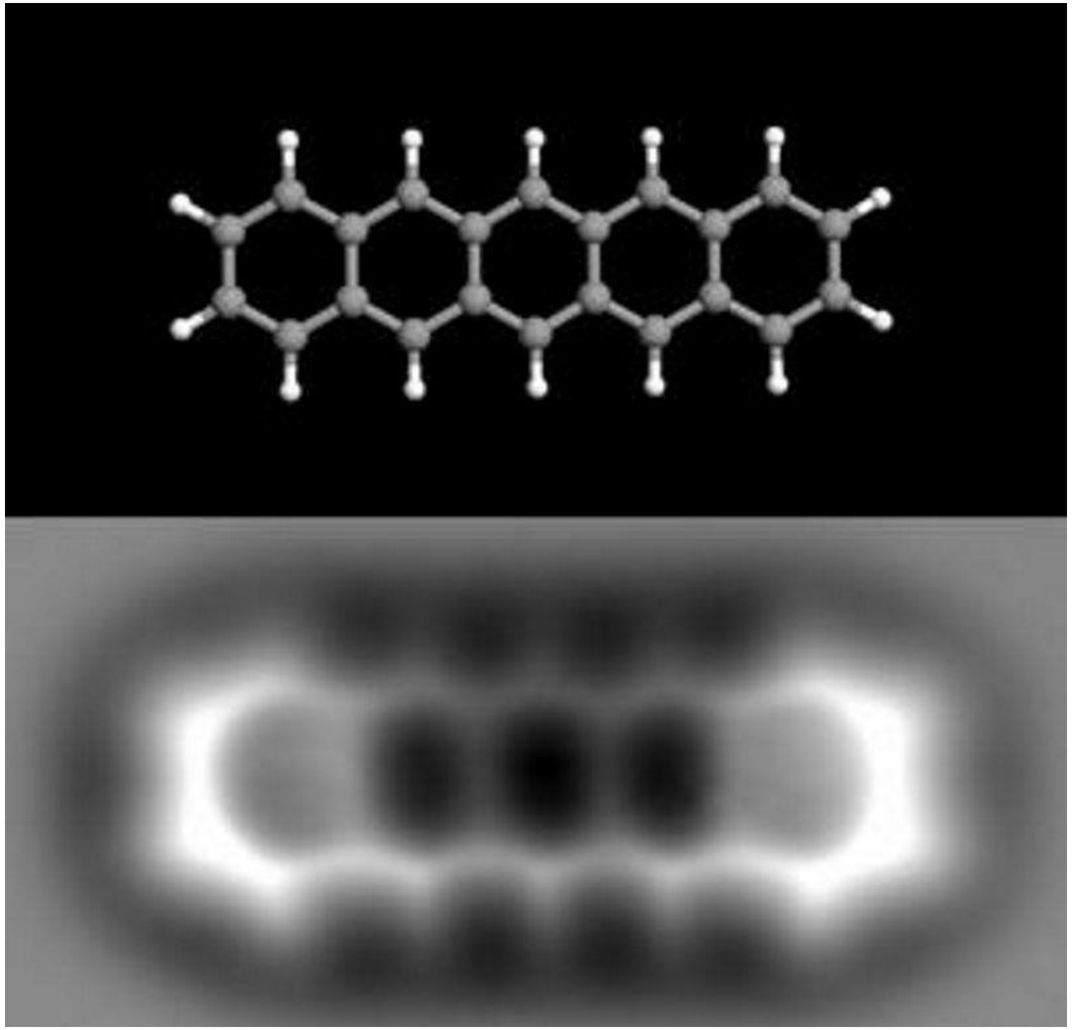
Can we see atoms and molecules – yes we can!

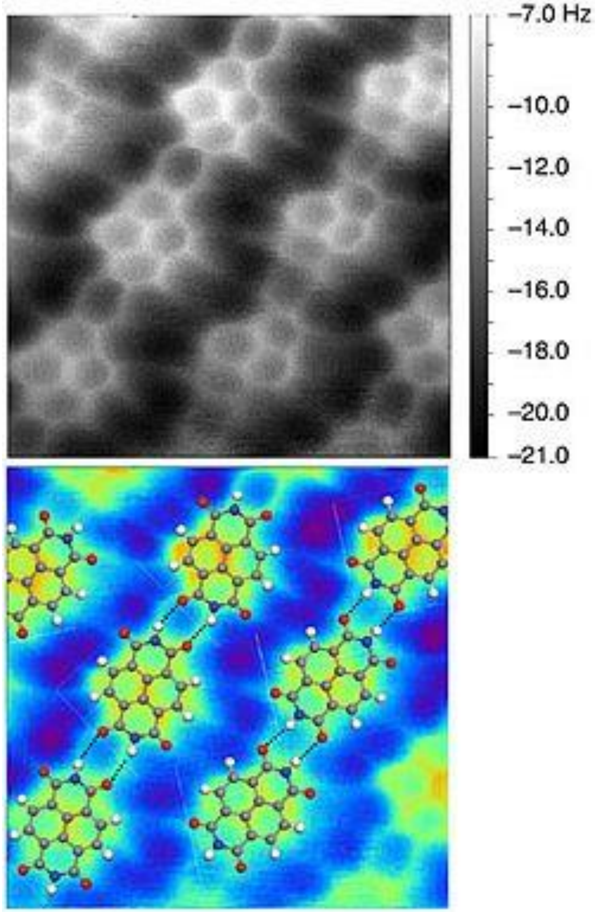
https://www.freethink.com/articles/cryo-electron-microscopy

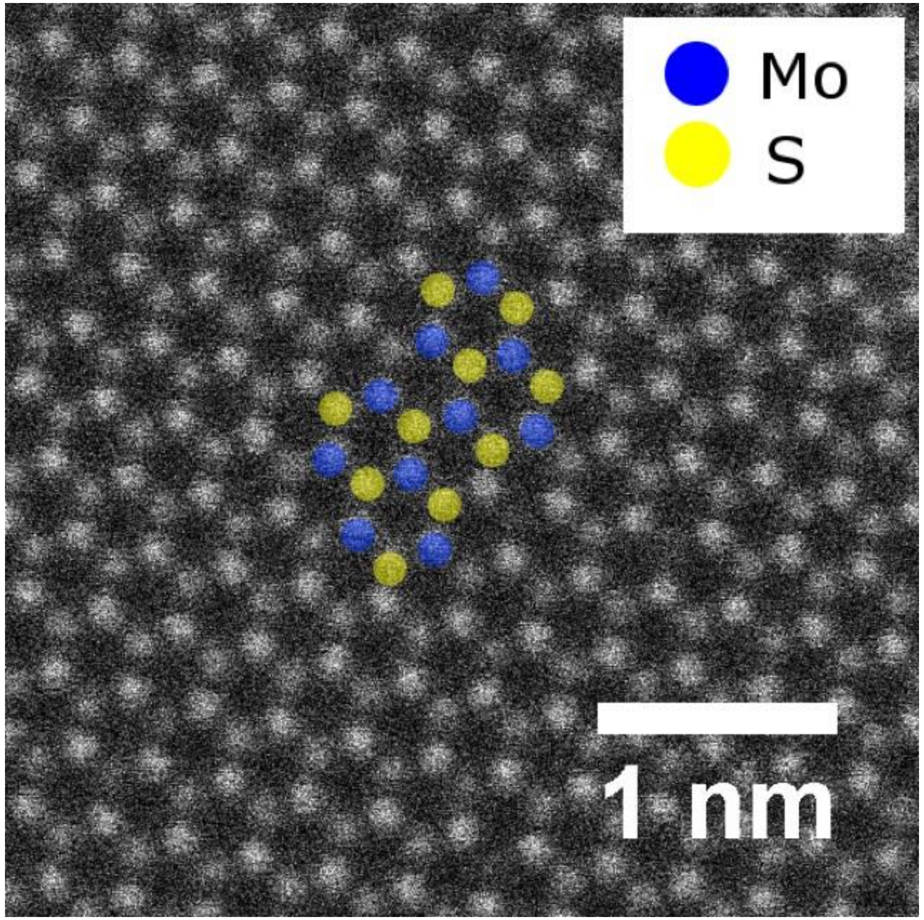


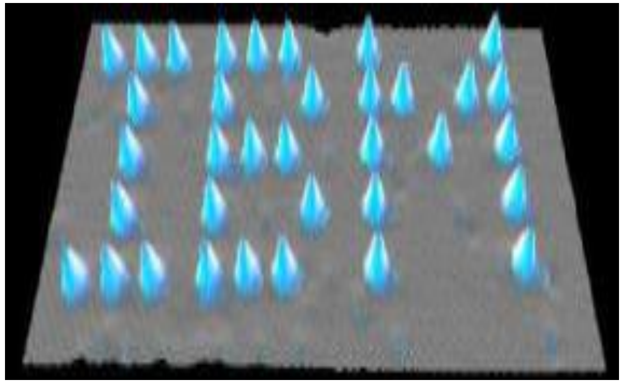
An image of the protein apoferritin created with cryo-electron microscopy. Credit: MRC Laboratory of Molecular Biology

Making the real atomic world visible

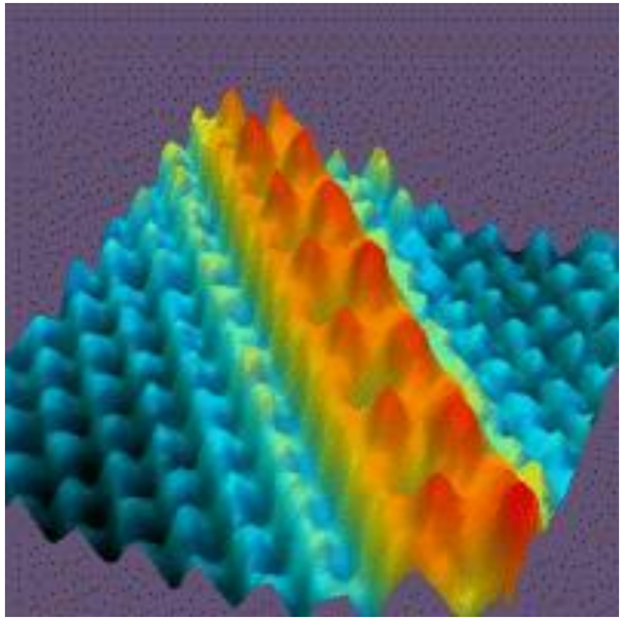








Atoms can be positioned on a surface using the STM tip, creating a custom pattern on the surface.
PHOTO COURTESY NIST PHOTO SOURCE: IBM'S ALMADEN RESEARCH LABS



STM image (7 nm x 7 nm) of a single zigzag chain of cesium atoms (red) on a gallium-arsenside surface (blue)
PHOTO COURTESY NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST)

4. Connecting the submicroscopic and macroscopic worlds

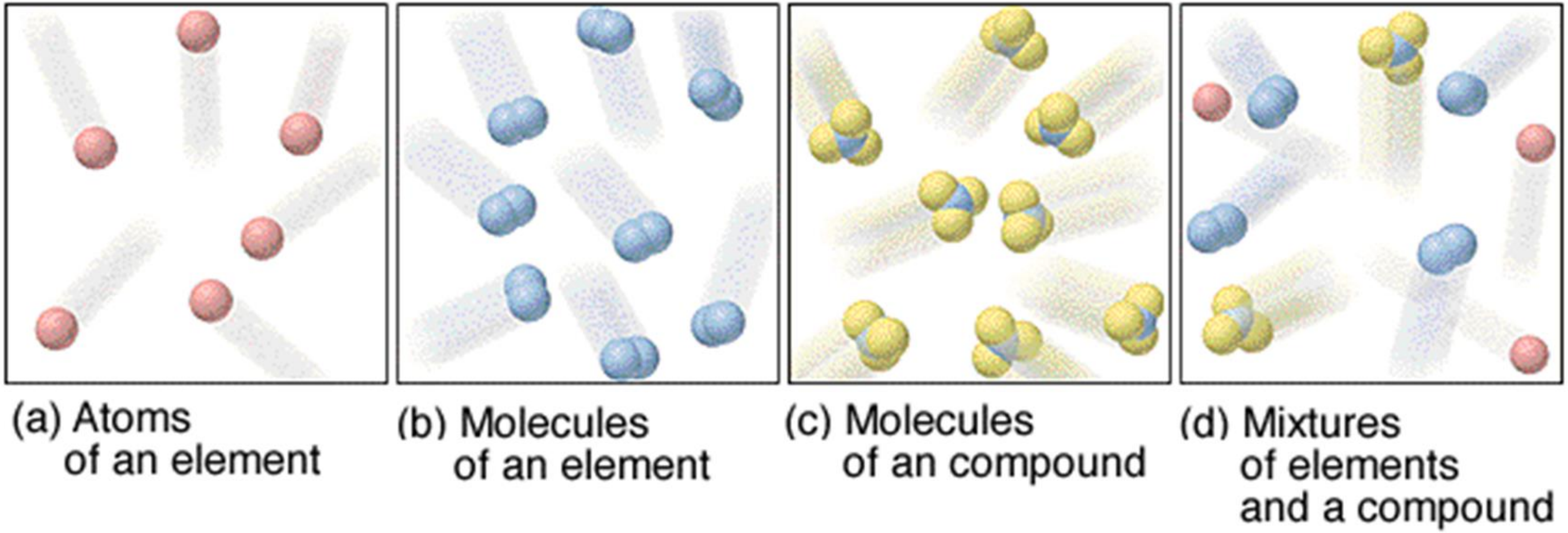
A. Visualising atoms, molecules , compounds – the submicroscopic world

Move from using physical models (Lego bricks) to using diagrams to represent the same things.

This is a way of picturing, imagining, what we can’t see.

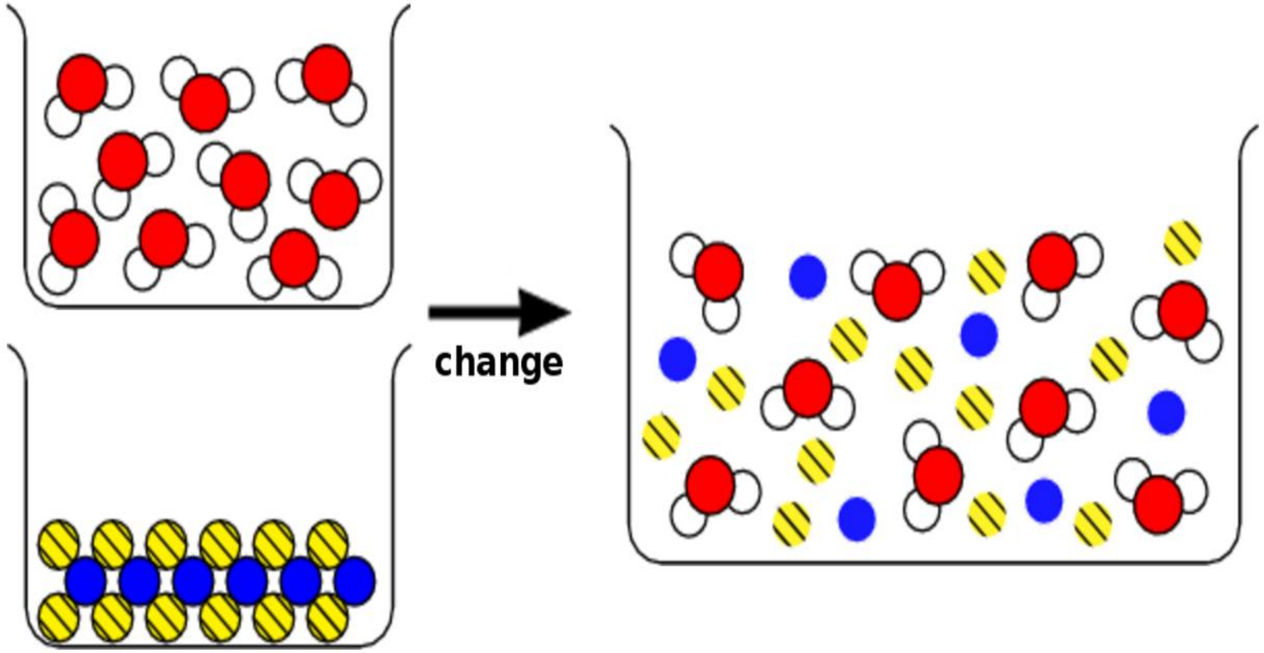
Using diagrams reinforces the basic ideas and uncovers student misconceptions.

Illustrating the invisible submicroscopic world

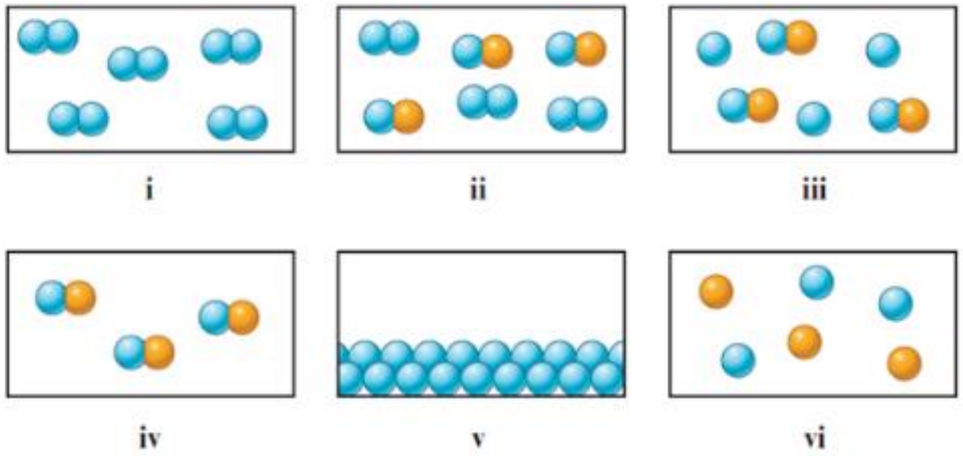


Visualising the invisible submicroscopic world

A diagrammatic representation of solubility of an ionic compound in water at a submicroscopic level.



Visualising the invisible submicroscopic world



An example of a diagnostic test – which diagram(s) represents a solid element, a gaseous compound, a gaseous element, a mixture of gaseous element and compound, a mixture of two gaseous elements.

Taking account of students' cognitive level

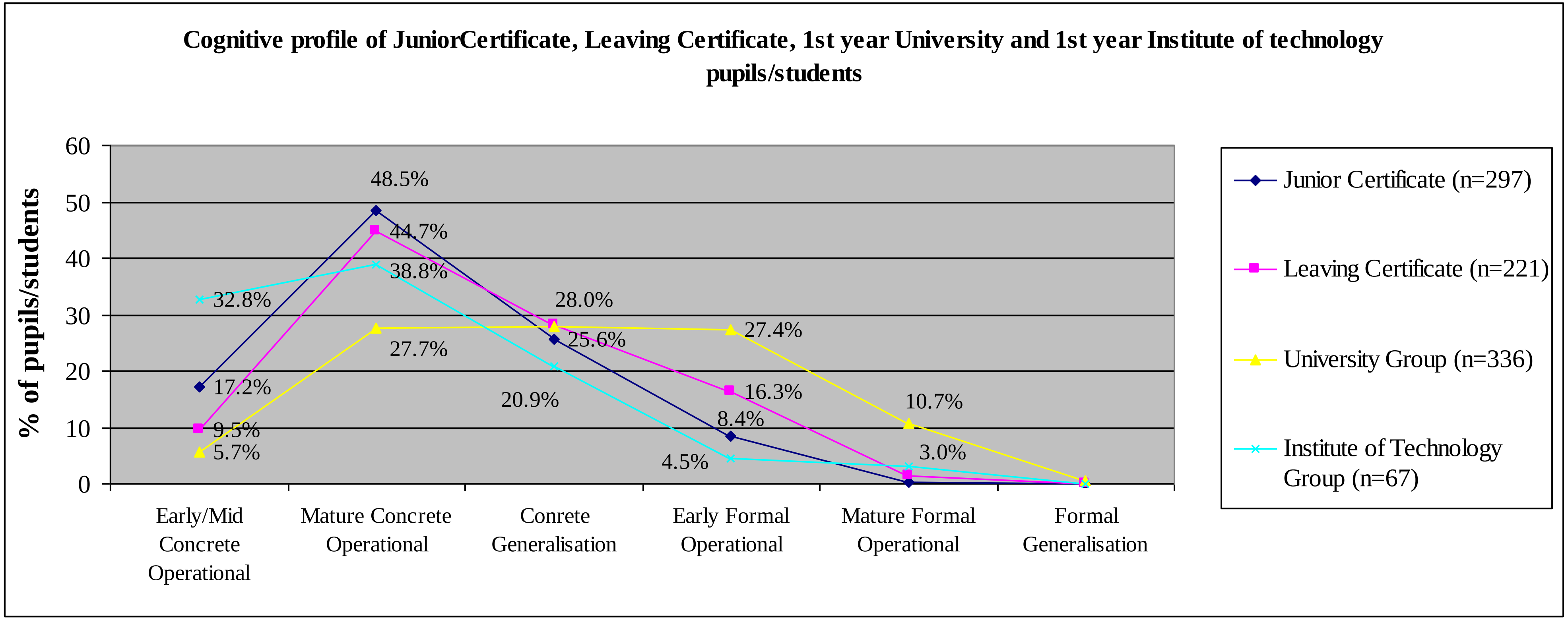
Research tells us that students develop mentally with age, and at different rates. All your classes are mixed ability!

Most students at junior cycle, and many at senior cycle and even at third level, are still in the concrete operational stage of thinking – they need to see things!

By introducing the abstract and conceptually demanding parts of Chemistry too early, we put students off and they default to memorisation.

We need to move gradually (e.g. using a spiral approach) from concrete to abstract, using models, visuals, analogies to bridge the gap between real and abstract. We need to encourage conceptual change.

Cognitive profile of Irish students (Sheehan, 2010)



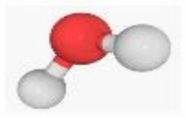
B. Symbols and formulae

This would be a good place to introduce the symbols and names of the elements (first 20) and how to write a shorthand formula for simple molecules and compounds.

Symbols and formulae are needed for balancing equations but not all at once – use word equations first.

But remember, the symbols of Chemistry and chemical names and terminology are new languages for students.

Models → **Formulae**

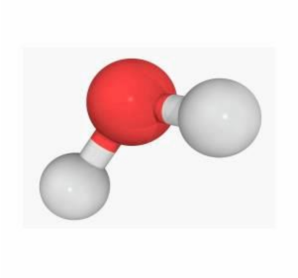


H_2O

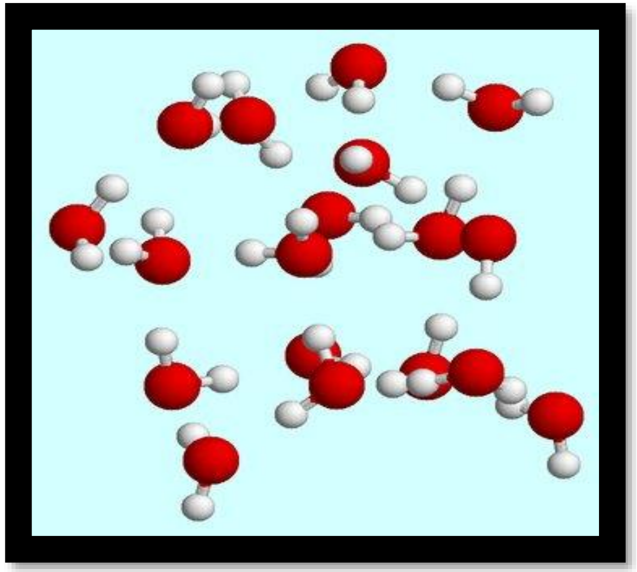
C. The scale of chemistry

Chemistry includes the very small (atoms and molecules), with sizes in the range 0.1 nm (10^{-9} m) upwards.

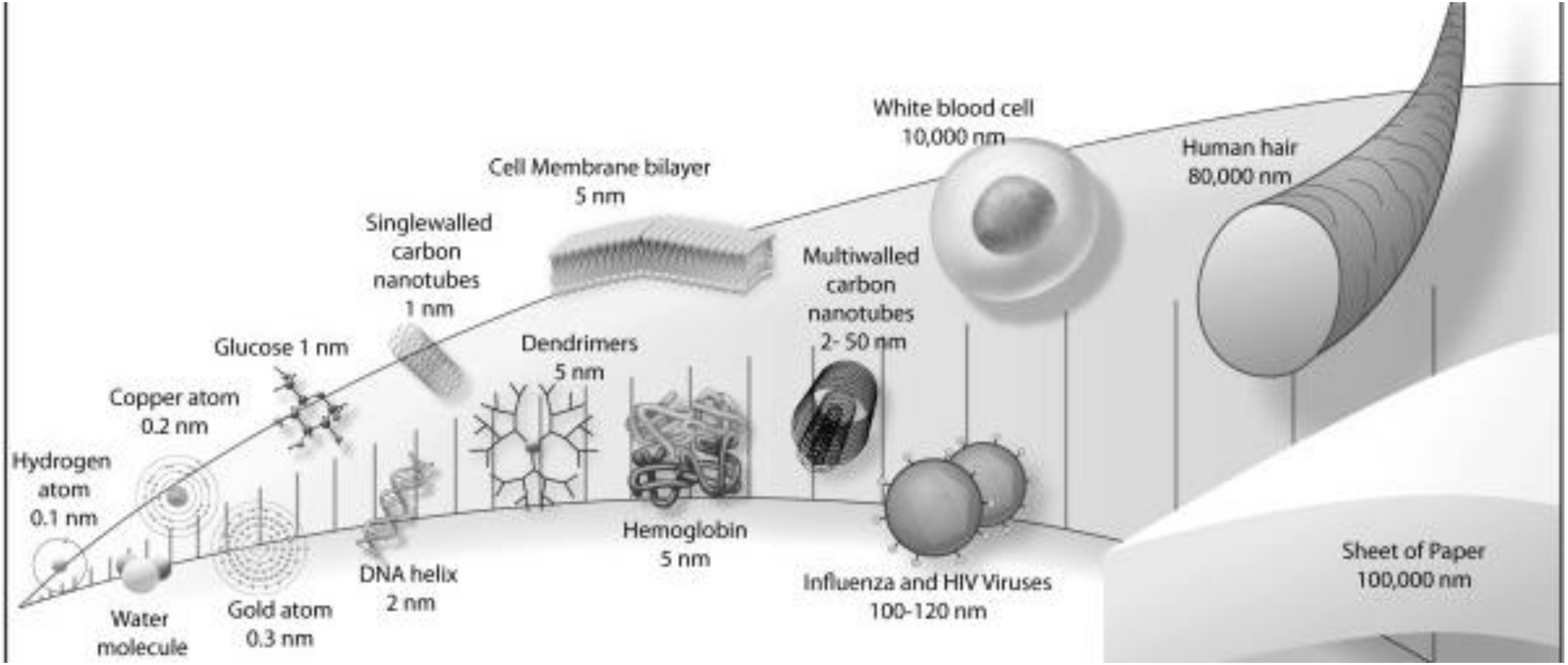
It also involves very large numbers – the number of water molecules (~0.3 nm) in 18 mL of water is 6.023×10^{23}.



x 6.023×10^{23} →

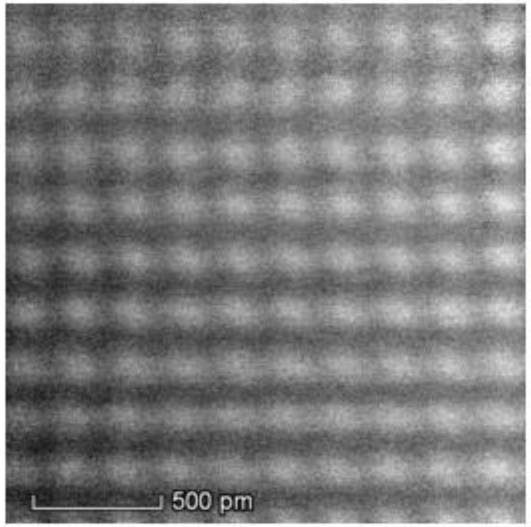


The scale of chemistry



How many atoms thick is Al foil?

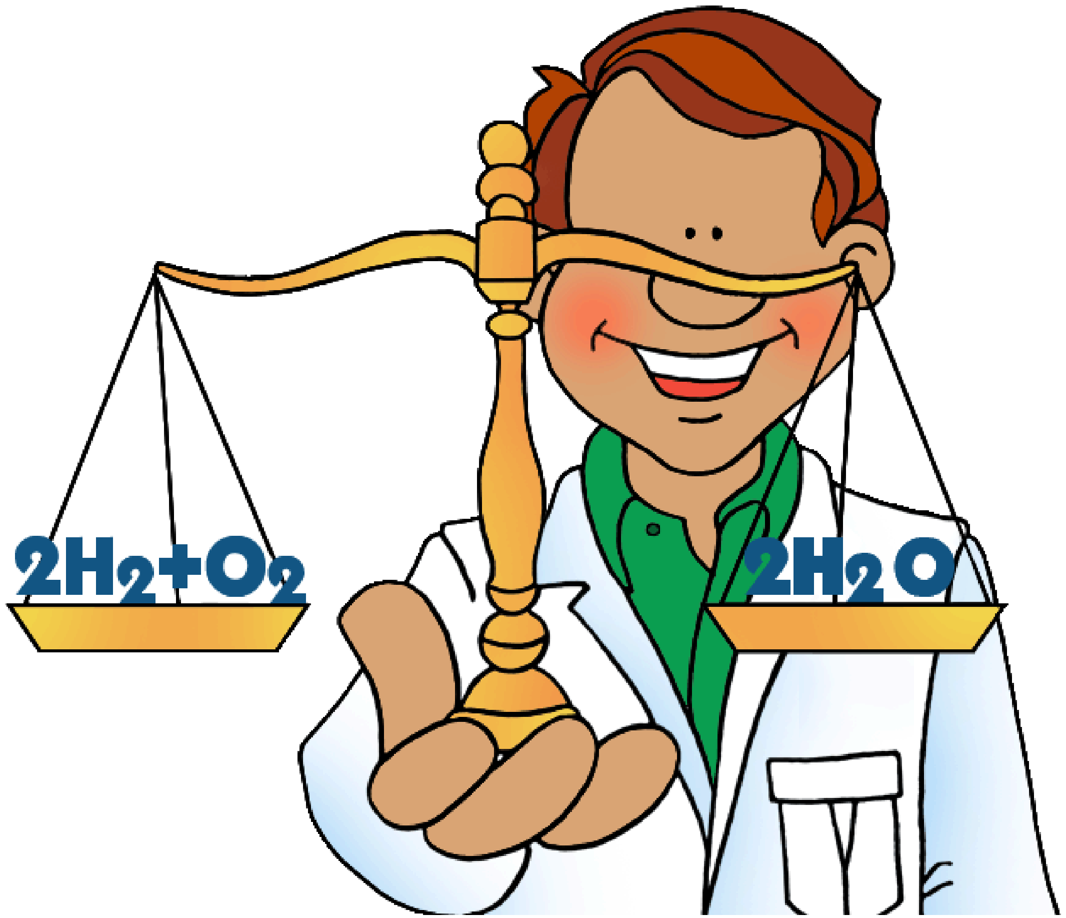
- Weigh the roll (minus the core!) and measure its dimensions (length and width).
- Use the density of Al to calculate its thickness.
- Use the diameter of an Al atom to work out the number of atoms.



High resolution image of Al foil **Roll of Al foil**

https://upload.wikimedia.org/wikipedia/commons/d/d9/Aluminium_Atomic_lattice.png

D. Balancing equations: conservation of matter (mass) – atoms are not lost in a chemical reaction

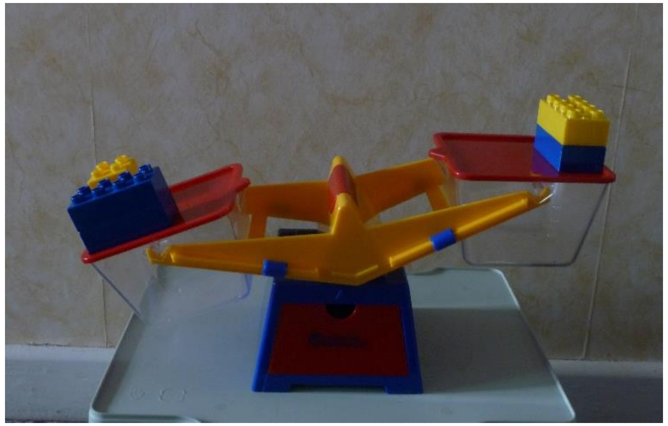


A model approach to balancing equations (1)

This uses the Lego blocks to help students understand what balancing chemical equations means.

The hydrogen-oxygen reaction:

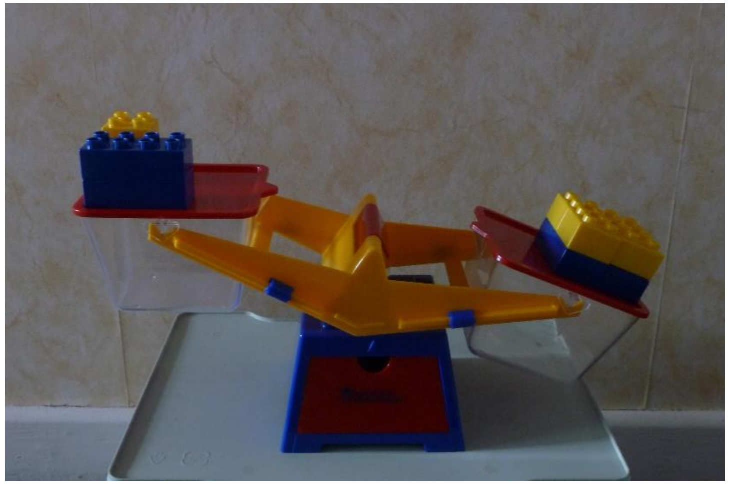
1) $H_2(g) + O_2(g) \rightarrow H_2O(l)$ unbalanced



A model approach to balancing equations (2)

Add 1 $H_2O(l)$ molecule to RHS to get right number of oxygen atoms on RHS

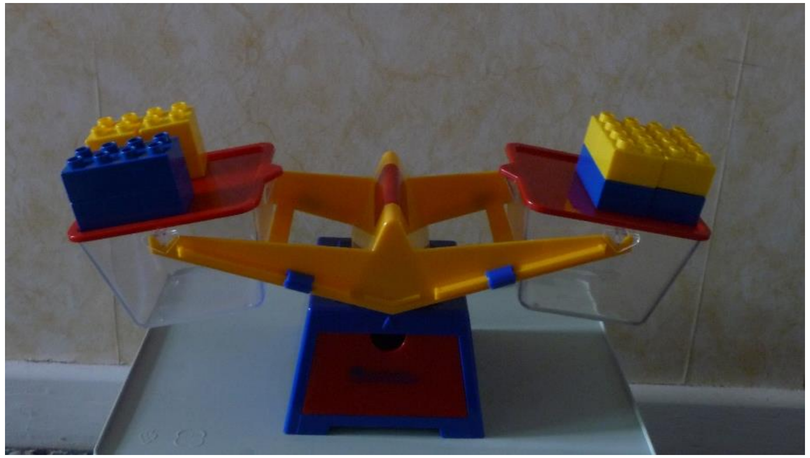
2) $H_2(g) + O_2(g) \rightarrow 2H_2O(l)$



A model approach to balancing equations (3)

Add H_2(g) to LHS as it is 2 hydrogens short.

3) $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$



A spiral approach to balancing equations

Little by little … but lots of practice

1. Start with reactions and visualising what's happening.
2. Identify starting material (reactants) and products: Mg, O_2, MgO
3. Write word equations:

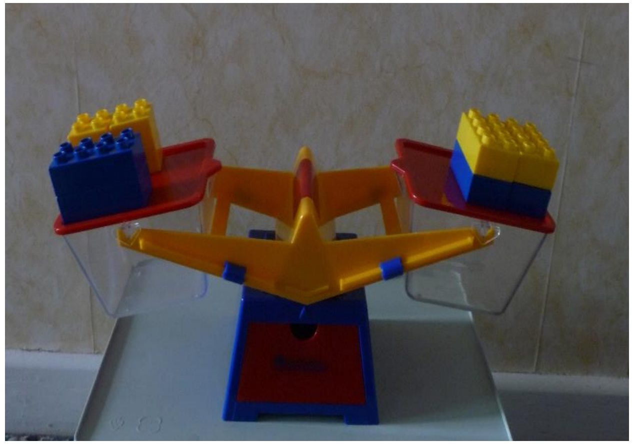
Magnesium + Oxygen → Magnesium oxide

4. Write the formulae under the words (done previously).

Magnesium + Oxygen → Magnesium oxide

$Mg + O_2 \rightarrow MgO$

5. Remind them of the conservation of matter (mass).
6. Use the simple balance to introduce balancing equations.
7. Practice with simple, familiar examples.
7. Introduce states of matter (when needed)
8. Balancing redox equations – LC Chemistry

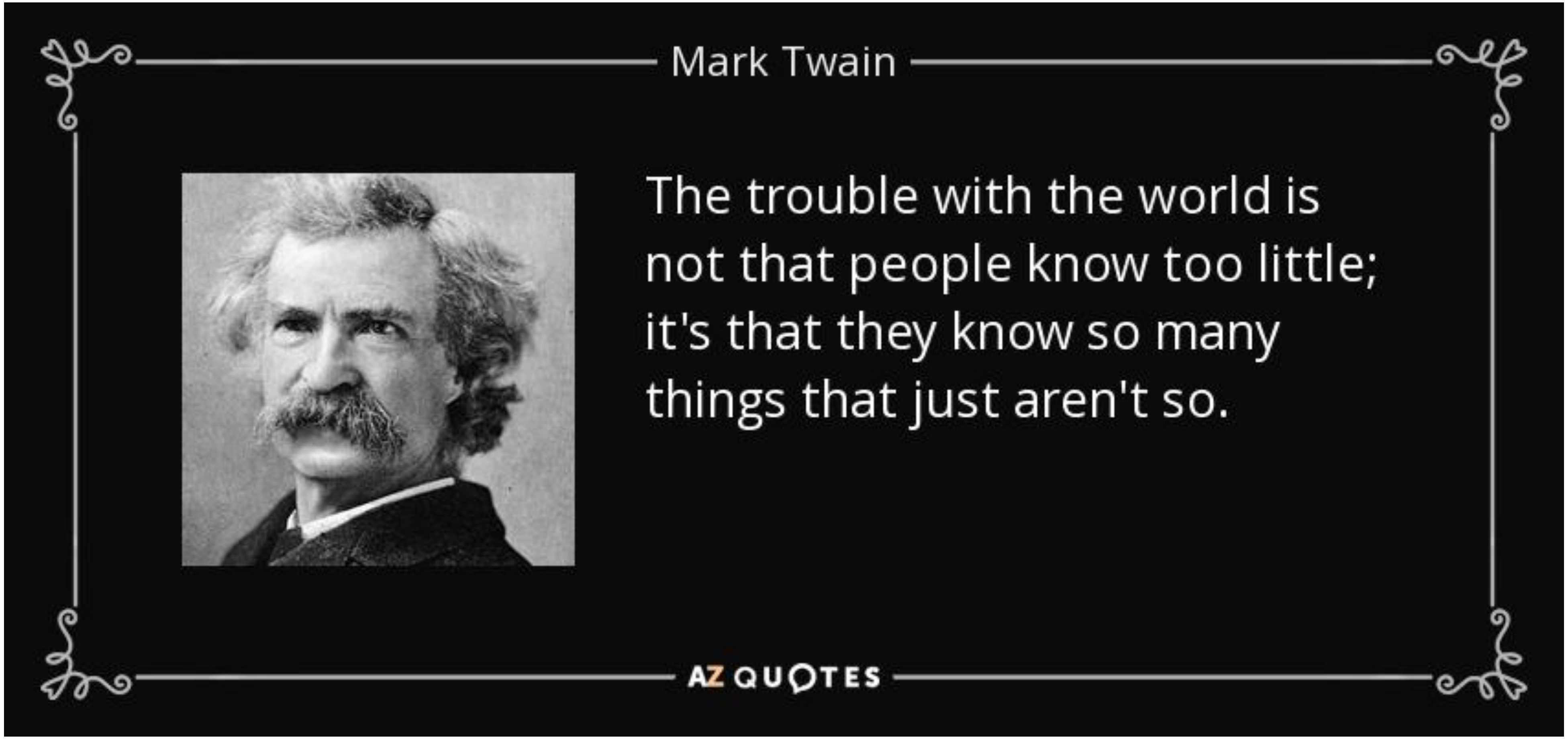


Key ideas:

- **We need to move from the macroscopic world of real things to the submicroscopic world using models, visualisations and animations, experiments and demonstrations, to help students understand the submicroscopic nature of matter and its scale (small particles in massive numbers).**
- **We need to take account of students' cognitive level in introducing abstract ideas, bridging the concrete and the formal operational levels, the visible and the invisible.**
- **We need to help them understand the limitations of all models – physical, visual, mathematical and mental.**

5. Taking account of chemistry misconceptions

Dealing with misconceptions



Taking account of misconceptions

- The topics of particulate nature of matter and chemical bonding are rife with student (and teacher?) misconceptions
- Much research over 40+ years on misconceptions in chemistry.
- Very little evidence of change in the classroom!

Misconceptions are:

Prevalent – they are widespread at all levels and in teachers and textbooks

Persistent – they are hard to change and replace by correct views

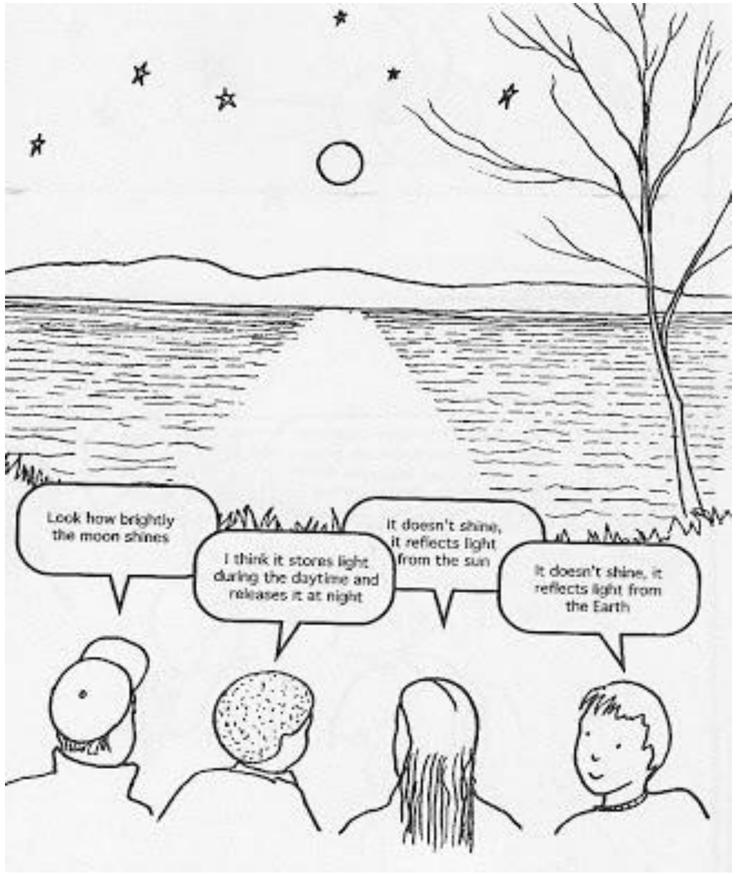
Pervasive – they undermine present and future learning of chemistry

Pernicious – they prevent students from proper understanding

Misconceptions in chemistry

They come from various sources:

- prior experience and teaching,
- teachers,
- textbooks,
- media,
- models,
- language …..



Teachers and textbooks!

- Didaktikogenic: Teacher induced, or induced by instruction. From Greek: didaktikos meaning "skillful in teaching", and -genic, meaning "induced by".
- Didaktikogenic misconception: a misconception induced by the educational process.
- That's the way all the books were: *“They said things that were useless, mixed-up, ambiguous, confusing, and partially incorrect. How anybody can learn science from these books, I don't know, because it's not science.”*

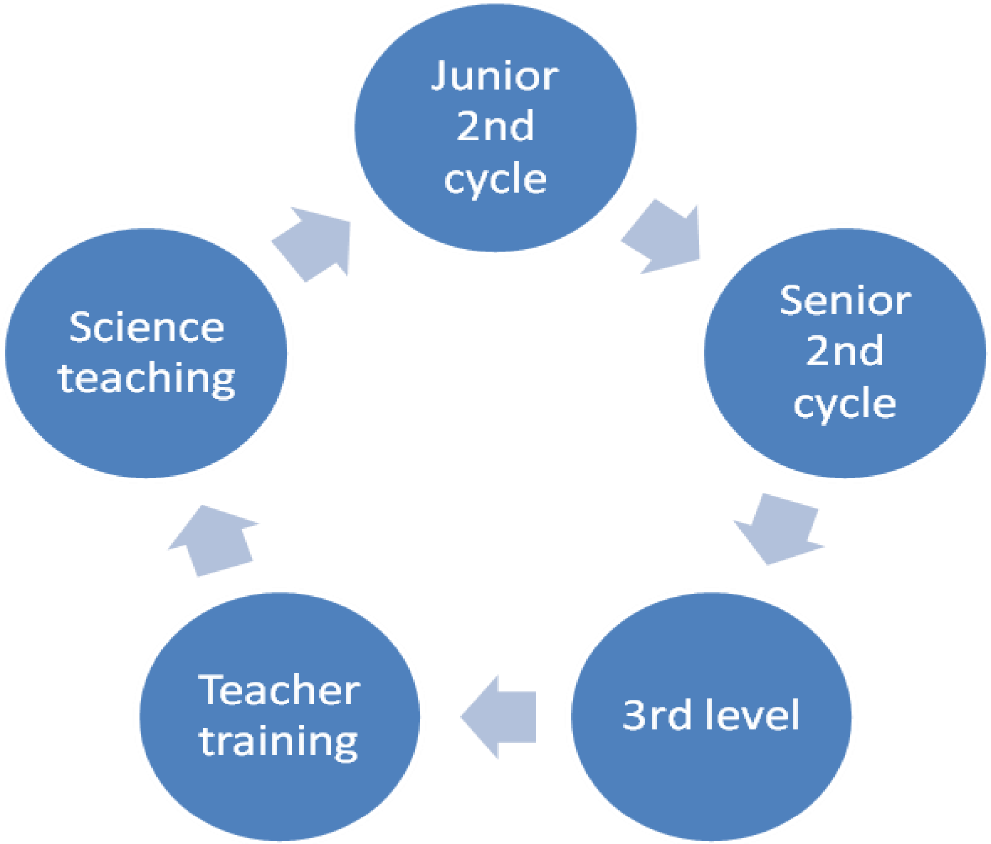
Richard Feynman, in "Surely you're Joking, Mr. Feynman".

Layers of information in our chemical education

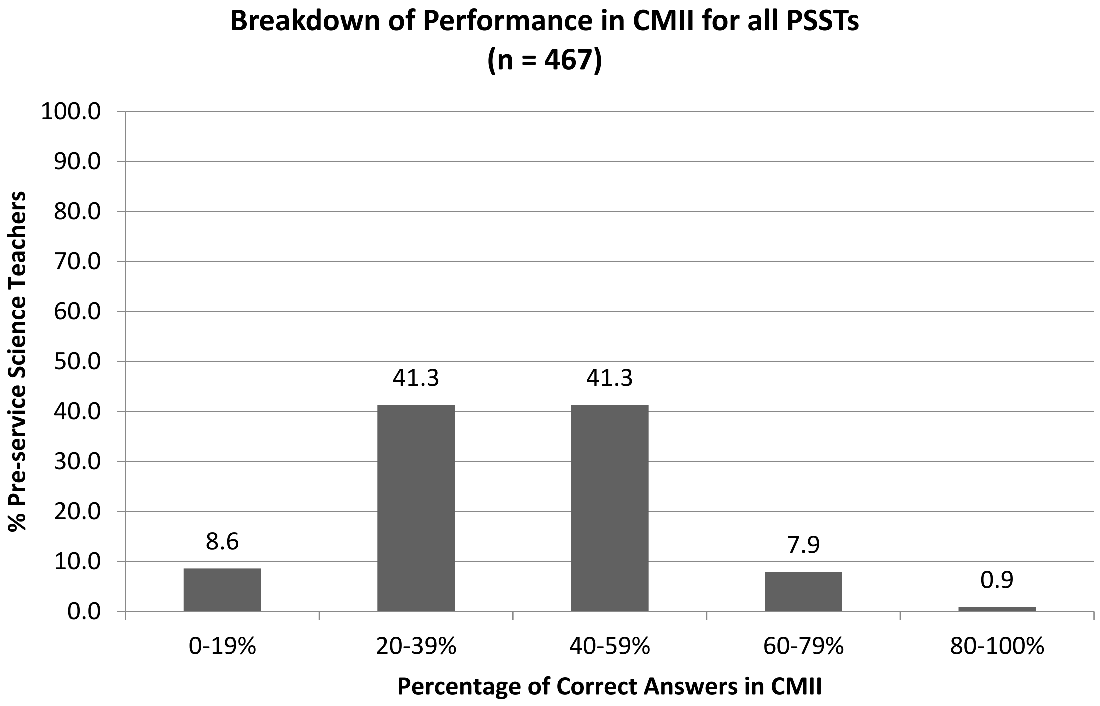
Teach

Educati
Even more advanc
Advanced ch
Basic cher

The vicious cycle in education – perpetuating miconceptions



Performance of the 467 Irish Pre-service Science Teachers in the diagnostic instrument



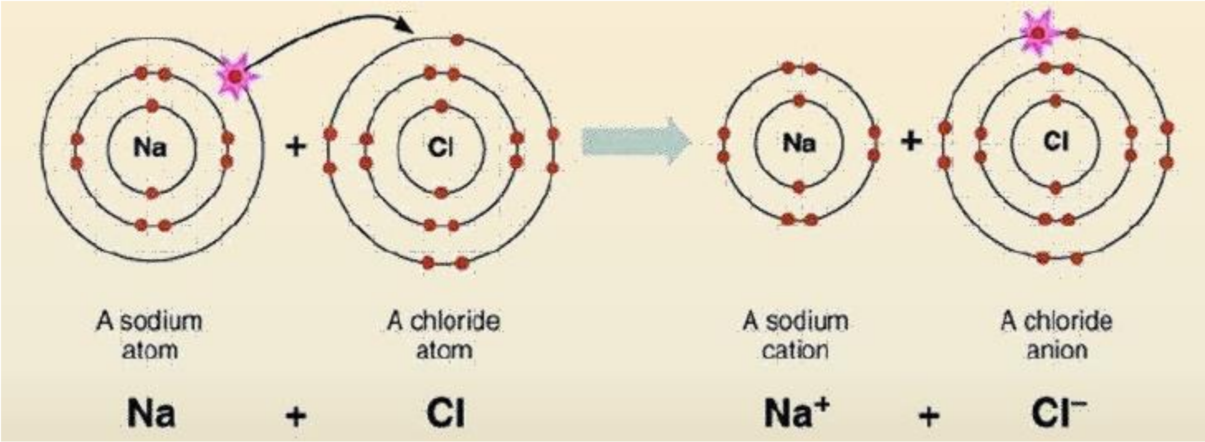
Sheehan, M. and Childs, P.E., (2013), ESERA Conference Proceedings, ESERA 2013, Cyprus"There is no failure except in no longer trying" Addressing the chemical misconceptions of pre-service science teachers; Sheehan, M., PhD thesis, 2016

Example: ionic bonding – formation of sodium chloride

Presented as an electron transfer between a metal and a non-metral atoms:

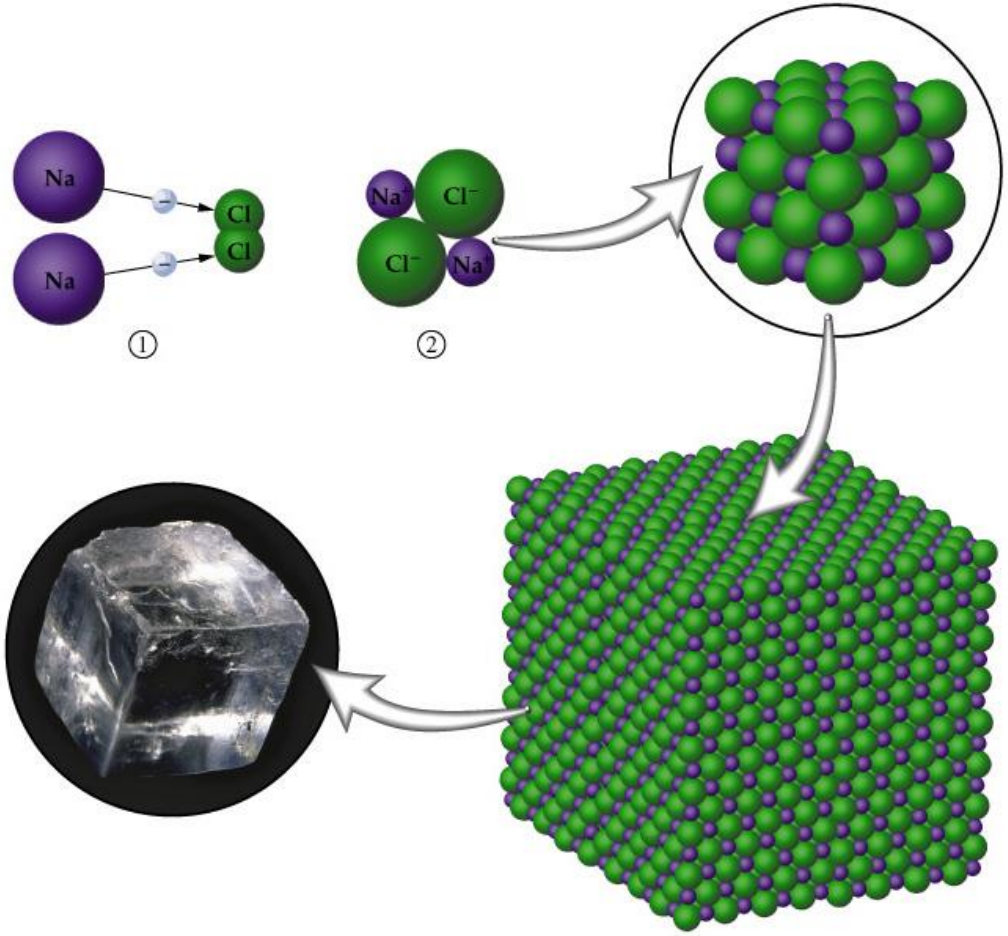
e.g. Na(s) + ½ Cl(g) → NaCl(s)

Na + Cl → $Na^{+}Cl^{-}$



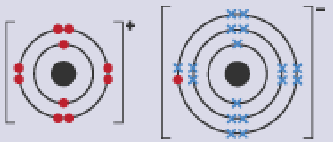
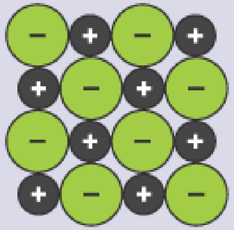
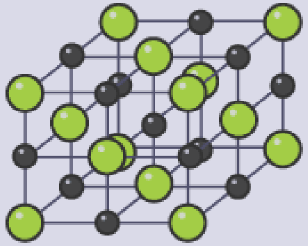
Misconceptions of ionic bonding

1. Elements react
2. Electron transfe an ionic molecule.
3. Unit cells exist a



Be aware that models have limitations and can create misconceptions

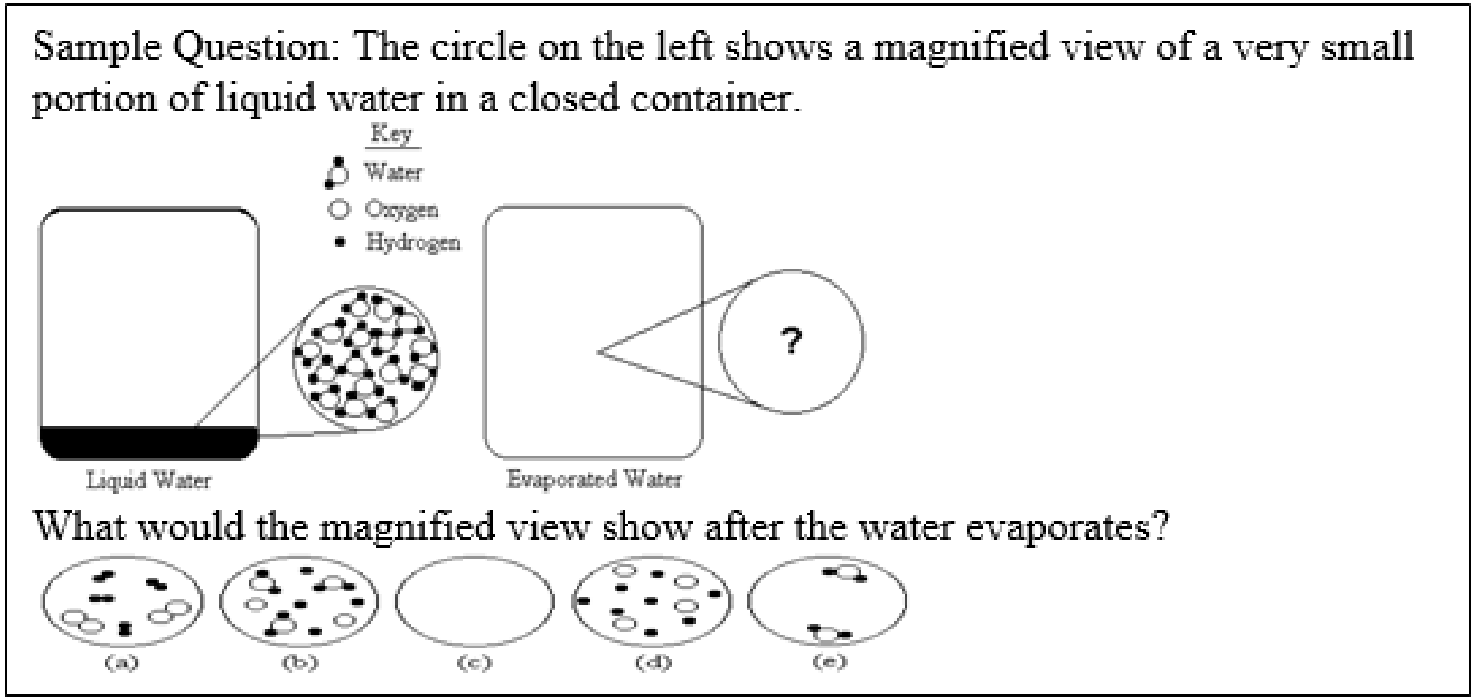
https://www.bbc.co.uk/bitesize/guides/zwxp8mn/revision/7

Model	Example	Does not show
Chemical formula	NaCl	• Charges • Lattice structure
Dot and cross diagram		• Lattice structure • Ionic bonds
2D diagram		• How ions were formed • More than one layer
3D diagram		• Charges • That there are no spaces between ions

Addressing chemical misconceptions in your students

1. Be aware/beware of common misconceptions
2. For example, look at the resources from the RSC.
3. Correct your own misconceptions! (We all have them!)
4. **Teach in a way that uncovers, addresses and corrects your students' misconceptions early on!**
5. Use diagnostic texts and formative assessment to reveal misconceptions.
6. Use concept cartoons to uncover and address misconceptions.
7. Don't assume that recall and repetition mean understanding.

Assessing understanding of the submicroscopic world



Sample question testing understanding of the particulate nature of matter

…ept Cartoons in Science Education

…ted by Brenda Keogh and Stuart Naylor, Concept Cartoons have been thoroughly …arched in classrooms around the world. Simple cartoon-style drawings present …arners with their own misconceptions and generate discussion and argument. They are …emarkably easy to use in the classroom as a part of normal teaching."

From the Millgate House website

The idea for using *Concept Cartoons* comes from this great resource:

http://www.millgatehouse.co.uk/science/ccs…

Conceptual change texts

Texts and teaching materials that build in conceptual change.

e.g. 'Using Conceptual Change Texts to Address Misconceptions in the Middle School Science Classroom' Daniel M. McKenna (2014)

https://digitalcommons.brockport.edu/cgi/viewcontent.cgi?article=1534&context=ehd_theses

Beerenwinkel, A., Parchmann, I. & Gräsel, C. (2011), 'Conceptual change texts in chemistry teaching: a study on the particle model of matter', *International Journal of Science and Mathematics Education,* 9, 1235-1259

https://link.springer.com/article/10.1007/s10763-010-9257-9

6. Conclusions & recommendations

My main message: teach for understanding of the basics

The main message of this talk is that we need to focus on getting our students to **understand** the basics of chemistry, rather than just learning off the material.

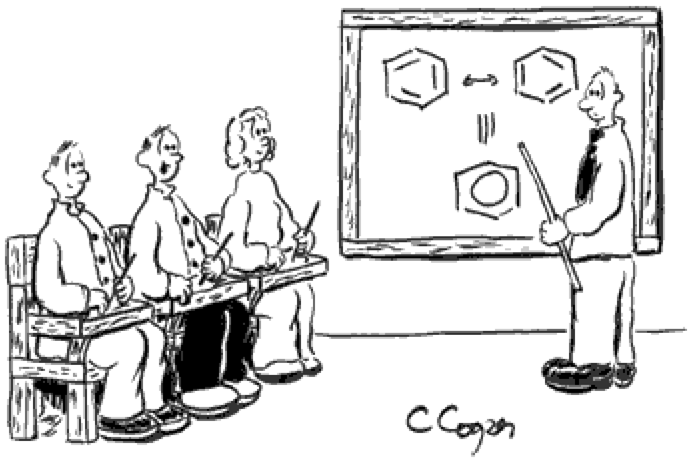
A focus on understanding means that learning is more meaningful and the facts become part of students' framework of knowledge.

"Science is built of facts the way a house is built of bricks, but an accumulation of facts is no more science than a pile of bricks is a house." Henri Poincaré

- Bricks + Plan → Building
- Facts + Structure → Understanding

Recommendations (1)

- Start with real obje … tudents see and smell and experien …
- Use a mix of mode … lustrations to make the abstract tangib … e, and link the macroscopic to the …
- Take account of stu … sconceptions, and address them in yo …
- Watch your language – especially new words, terminology and symbols.



"Define 'resonance'? Sure, that's where you live."

Recommendations (2)

- Make chemistry relevant to the real world and to the students' lives.
- Watch out for overloading students' short-term memory – adopt a spiral curriculum to develop difficult topics slowly, step by step.
- Take account of the cognitive demand of what we teach and simplify by using language, analogies and mental and physical models, **without** establishing wrong ideas.
- Aim towards understanding rather than the acquisition and repetition of facts.
- Try to develop higher order thinking skills (HOTS) rather than lower order thinking skills (LOTS) by the way we teach and assess students.

A final word

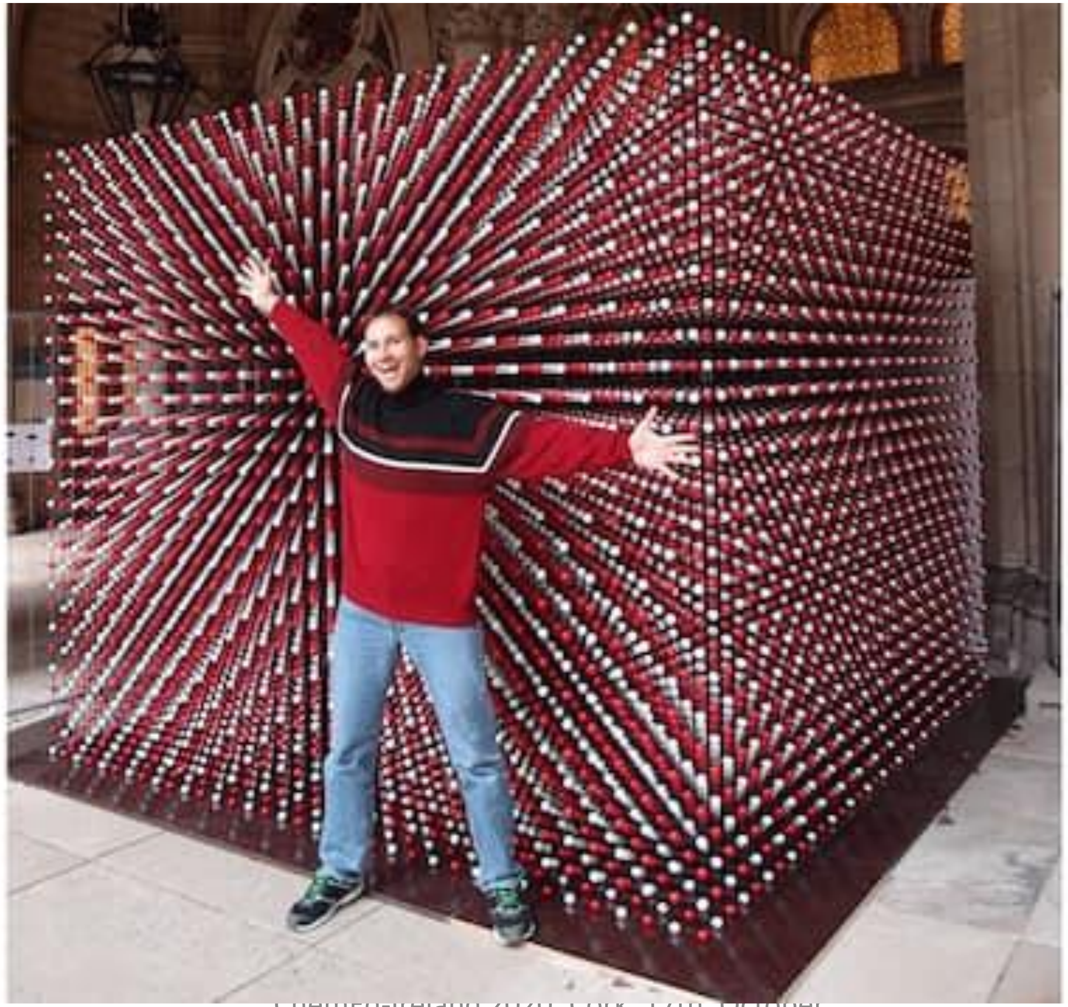
"With Aristotle we declare that the ultimate test of understanding rests with the ability to transform one's knowledge into teaching.

Those who can, do. Those who understand, teach."

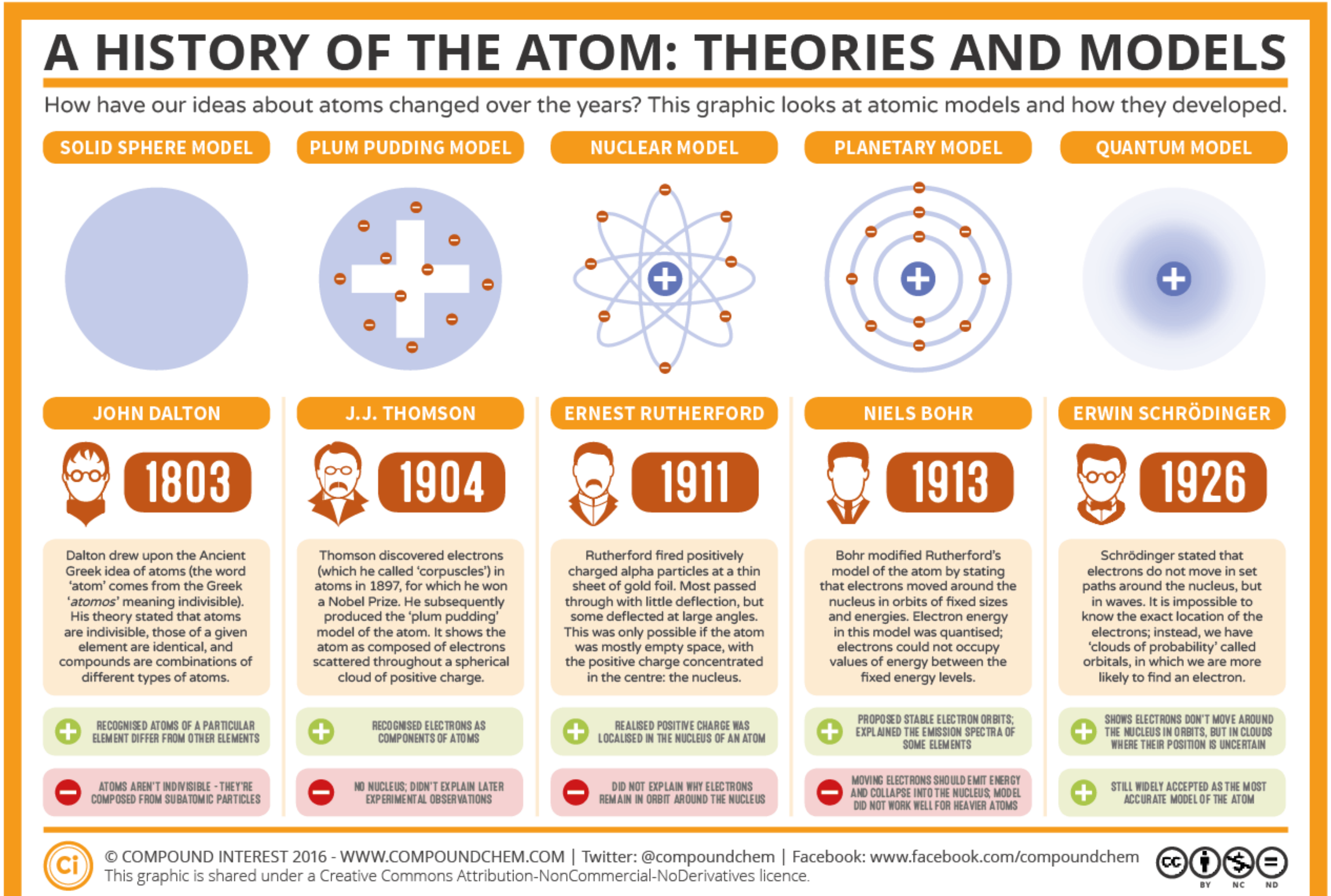
Lee S. Shulman (1986)

'Those who understand: Knowledge growth in teaching', *Educational Researcher*, 15(2), 4-14

Thanks for listening!
The world's largest model of NaCl



https://www.compoundchem.com/2016/10/13/atomicmodels/



Chemistry/science is more than a heap of facts