Using concept mapping to learn about A level physics students’ understandings of particle physics

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What do we know about children’s ideas about particles?

1. Atoms have the same properties as bulk material
2. Idea of empty space between the atoms not well understood
3. Children think atoms can be seen
4. Motion of particles in gases not well understood
5. Spacing of particles in solids, liquids and gases not well understood
6. Conservation of matter in phase change not appreciated
7. Thermal expansion explained by particles expanding

Harrison and Treagust (2002)
“The key to understanding the matter concept is the appreciation that all things in the universe consist of matter and, although they can change in form and composition, the total mass remains the same. Further, all the changes and properties can be explained by the molecular and atomic structure theories of matter”

Liu & Lesniak (2005:444)
At the subatomic level

• About 60% of students aged 14-16 knew protons were in the nucleus and electrons orbit it

• Confusion about charges on protons, neutrons and electrons (Lynch & Paterson, 1980)

• For 15-18 year-olds, electrical forces of attraction between nucleus and electrons not well understood (Taber, 2012)
Why concept mapping

- Potential to reveal learner’s cognitive structure (Novak & Canas, 2008)
- Potential to help teachers see what has been learned or not learned (Novak & Gowin, 1984)
- Method feasible for teachers to use themselves
Research question

What does concept mapping tell us about A level students’ understandings of the particle physics topic?
A students’ concept map about ‘Rock’

White & Gunstone, 1992:21
A second example

White & Gunstone, 1992:21
| annihilation | bottom | baryon | antiparticle |
|--------------|--------|--------|-------------|
| atom         | electron | down | neutrino |
| charm        | hadron | meson | nucleon |
| lepton       | matter | muon | proton |
| neutron      | top   | nucleus | quark |
| up           | particle | tau | strange |
How to construct a concept map

1. Look at the key words and write ones you know on the Post-It notes. Leave out any terms you don’t know or which you think are not related to any other term.

2. Put the remaining terms in rank order (or diamond) with the key concept(s) (most general) at the top and the most specific at the bottom.

3. Arrange the Post-It notes on the sheet of paper in a way that makes sense to you. As far as possible arrange them in a hierarchy with the most general at the top.

4. When you are happy with the arrangement, leave them stuck down, or write them on the paper.
5. Draw lines between the terms you see to be related.

6. Write on the line the nature of the relation between the terms. It can help to put an arrowhead on the line to show the direction of the relation. Examples of linking words: is, is made of, can be, contains, have, are.

7. If you left out any words in step 1, go back and see if you want to add any of them to the map. Remember to include links and to write on the nature of the relation.

8. You may add your own examples.
Example of coding categories

Exam specification (AQA, 2007, p 6):

“Constituents of the atom:
Proton, neutron, electron
Their charge and mass in SI units and relative units. Specific charge of nuclei and of ions. Atomic mass unit is not required.
Proton number Z, atomic number A, nuclide notation, isotopes.”

Categories for coding:
The proton is a constituent of the atom
The neutron is a constituent of the atom
The electron is a constituent of the atom
The proton is positively charged
The charge on a proton is +1.6 x 10^-19 C
The neutron is neutral (or has no charge)
The electron is negatively charged
The charge on an electron is -1.6 x 10^-19 C
The mass of a proton is 1.67 x 10^-27 kg
The mass of a neutron is 1.67 x 10^-27 kg
The mass of an electron is 9.11 x 10^-31 kg
The mass of a neutron is similar to (or slightly greater than) the mass of a proton
The mass of a proton or neutron is approximately 2000 times greater than the mass of an electron
Proton number Z is the number of protons in the nucleus
Atomic number A is the total number of protons and neutrons in the nucleus

Gourlay (2017)
An example of a student’s concept map

Gourlay, 2017
Quark composition of baryons & mesons

- particle
  - is a type of
    - mesons
      - is made of 2
        - quark
    - baryon
      - is made of 3
        - quark
  - is a type of
    - leptons
Representation of annihilation

annihilation

when they collide

particle

is opposite to

antiparticle
The difficulty with understanding annihilation

**Topic area: Annihilation and pair production**

- Some leptons are produced by annihilation
- Annihilation produces matter and antimatter
- Pair production is when an electron with too much energy produces photons
- Pair production is when a photon with sufficient energy makes two particles that repel each other
- Pair production is what happens when a particle splits in two
- Annihilation produces hadrons and leptons
- Quarks can annihilate to produce bigger, heavier more exotic particles as well as photons
Misunderstandings about leptons

| Topic area: Leptons | Number of instances of incorrect propositions |
|---------------------|-----------------------------------------------|
| Muon is a meson     | 5                                             |
| Tau is a meson      | 5                                             |
| Tau is a quark      | 4                                             |
| Meson is a lepton   | 1                                             |
| Hadron is a lepton  | 1                                             |
| Pion is a lepton    | 1                                             |
| Kaon is a lepton    | 1                                             |
| Leptons have an associated neutrino | 1 |
| Muon is a quark     | 1                                             |
| Total               | 20                                            |

Gourlay, 2017
Misunderstandings about muon and tau particles:

Example 1

Example 2

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**Misunderstandings about fundamental particles**

**Topic area: Fundamental particles**

- Antiparticles are made of antiquarks
- Quarks and baryons are elementary particles
- Leptons are made of quarks
- Matter and particles are made from atoms which are made up of quarks
- Particles are made of quarks
- Atom is the fundamental particle of all matter
- Electrons are made of quarks
- Everything is made of quarks
- Particles and antiparticles are made of quarks
Is everything made of quarks?

Excerpt from a student’s concept map
Recommendations for A level teachers

- Introduce the standard model at the beginning
- Explicitly address difference between muons, pions and kaons
- Teach annihilation separately from pair production
- Consider using concept mapping to promote discussion
Recommendations for university lecturers

- Students may have prior knowledge
- Consider asking students to use concept mapping
Recommendations for further research

- Carry out follow-up interviews:
- To what extent are students aware that the atom consists of protons, neutrons and electrons?
- To what extent are they aware of the charges of protons, neutrons and electrons?
- Does improved teaching sequence improve learning?
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Concept map diagrams have been produced using the Cmap software, available from http://cmap.ihmc.us