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)

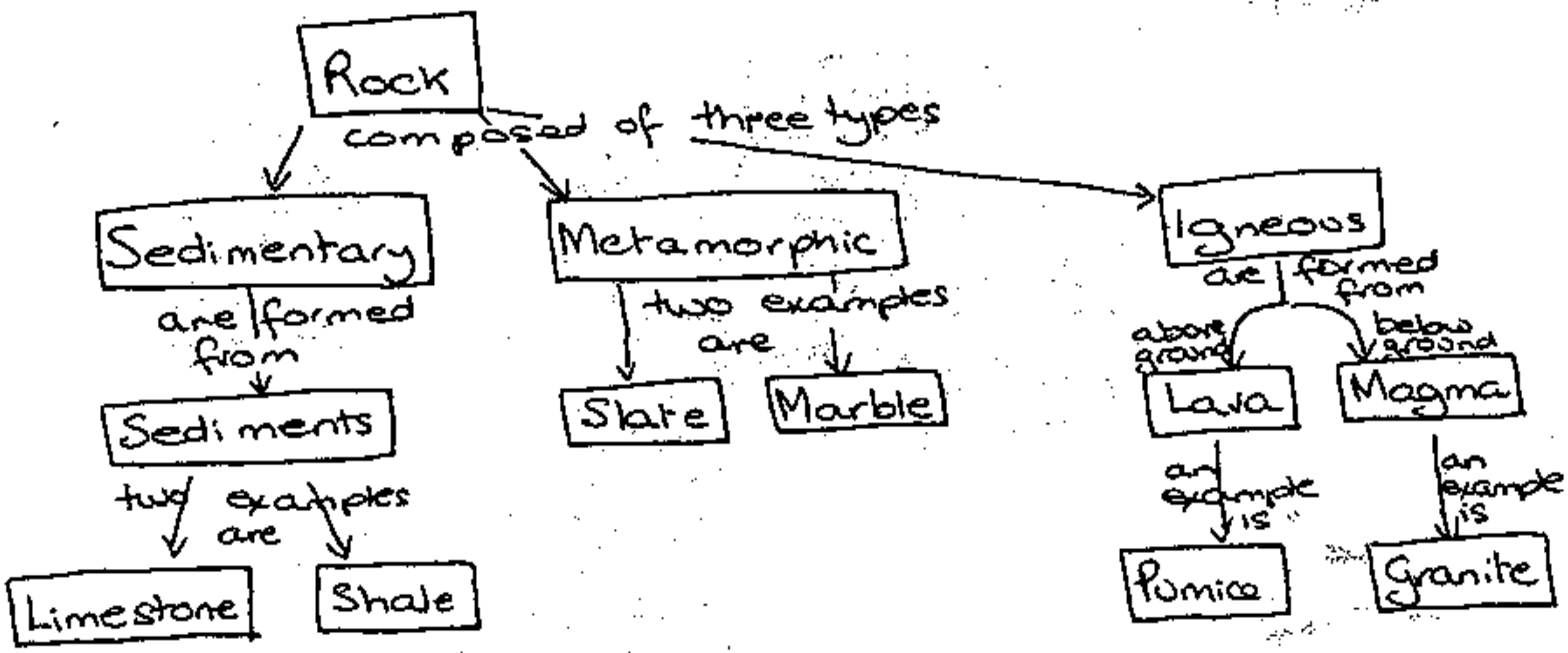
Why concept mapping

- 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

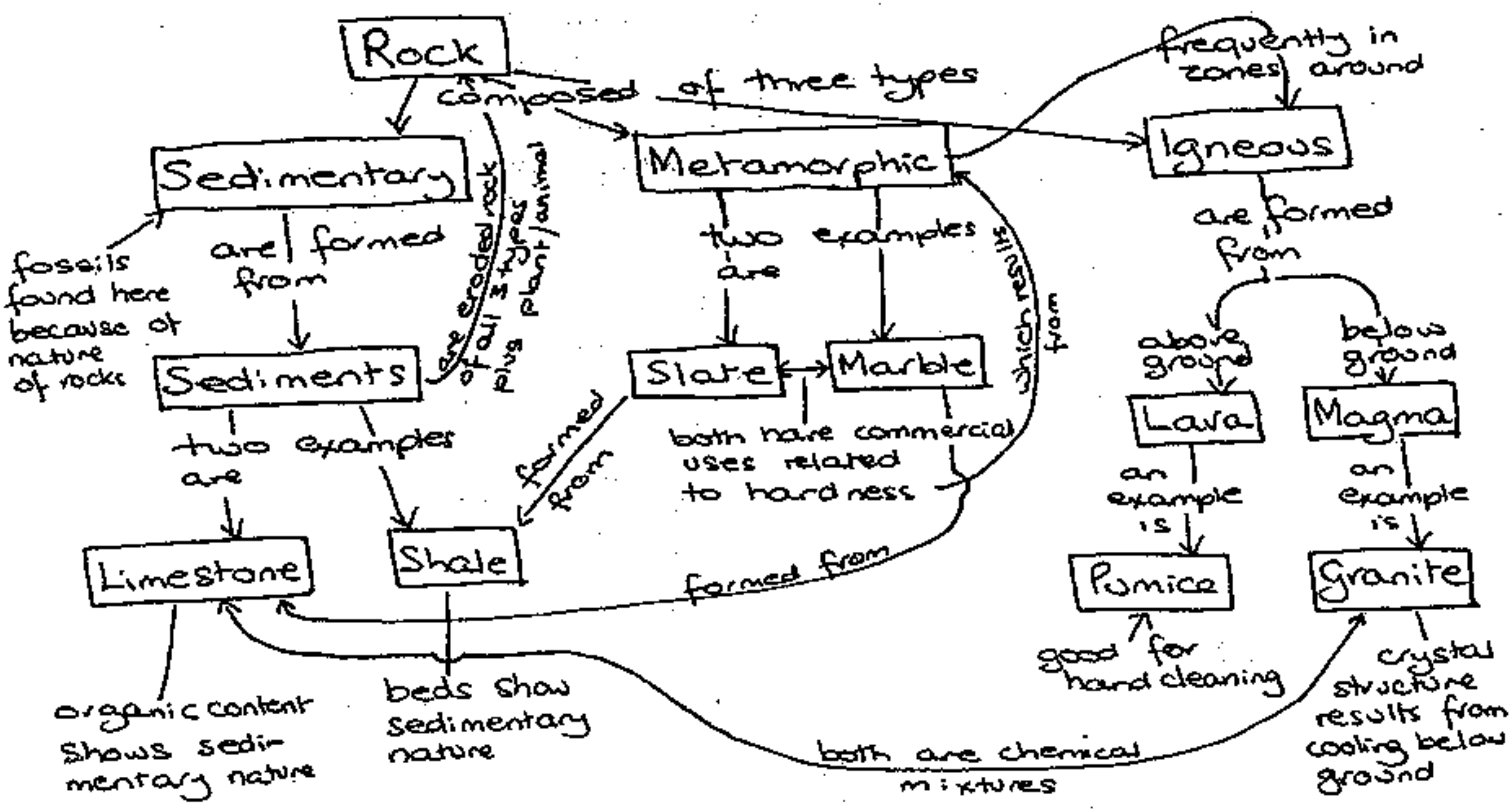
What does concept mapping tell us about A level students' understandings of the particle physics topic?

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 $+1.6 \times 10^{-19}$ C

The neutron is neutral (or has no charge)

The electron is negatively charged

The charge on an electron is -1.6×10^{-19} C

The mass of a proton is 1.67×10^{-27} kg

The mass of a neutron is 1.67×10^{-27} kg

The mass of an electron is 9.11×10^{-31} kg

The mass of a neutron is similar to (or slightly greater than) the mass of a proton

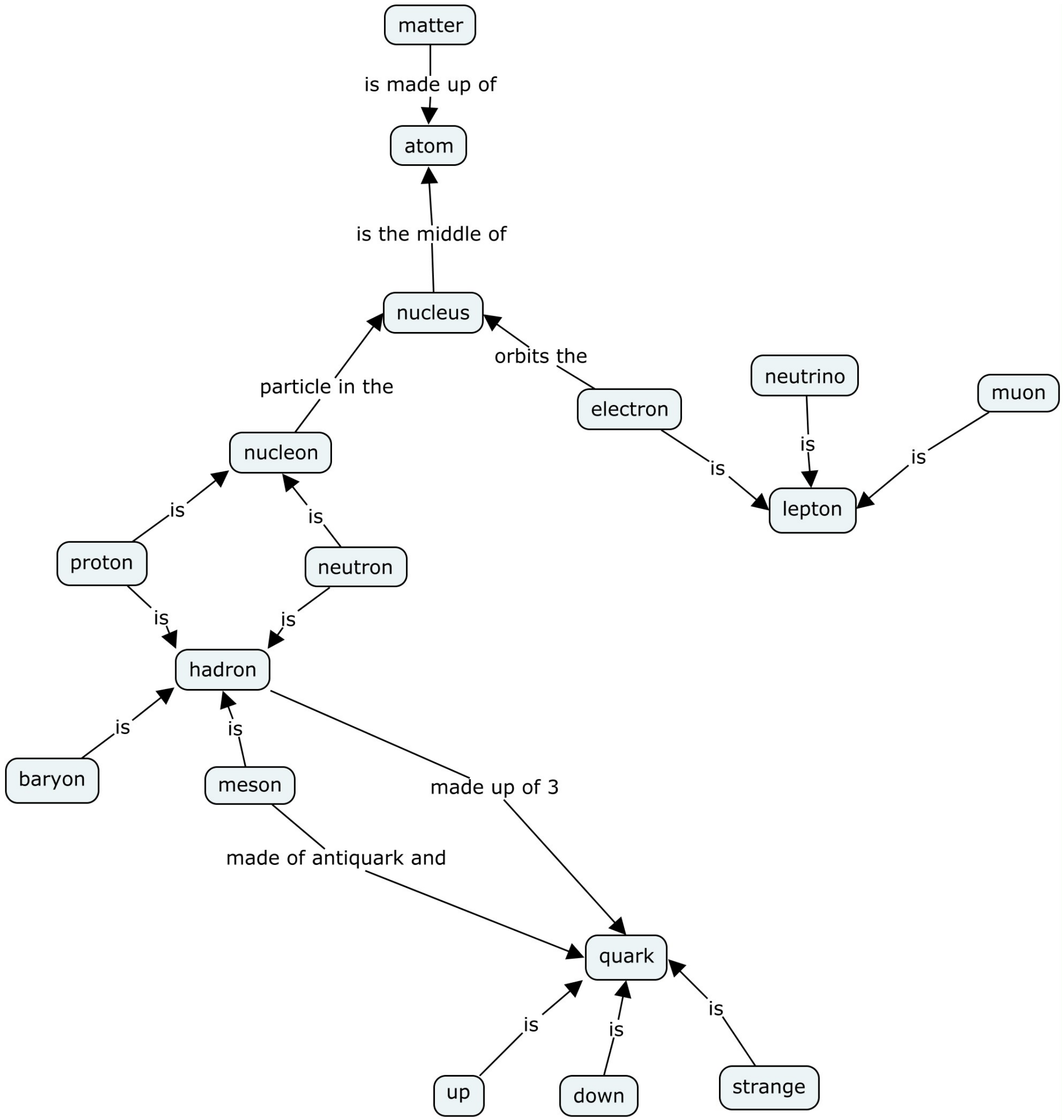
The mass of a proton or neutron is approximately 2000 times greater than the mass of an electron

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

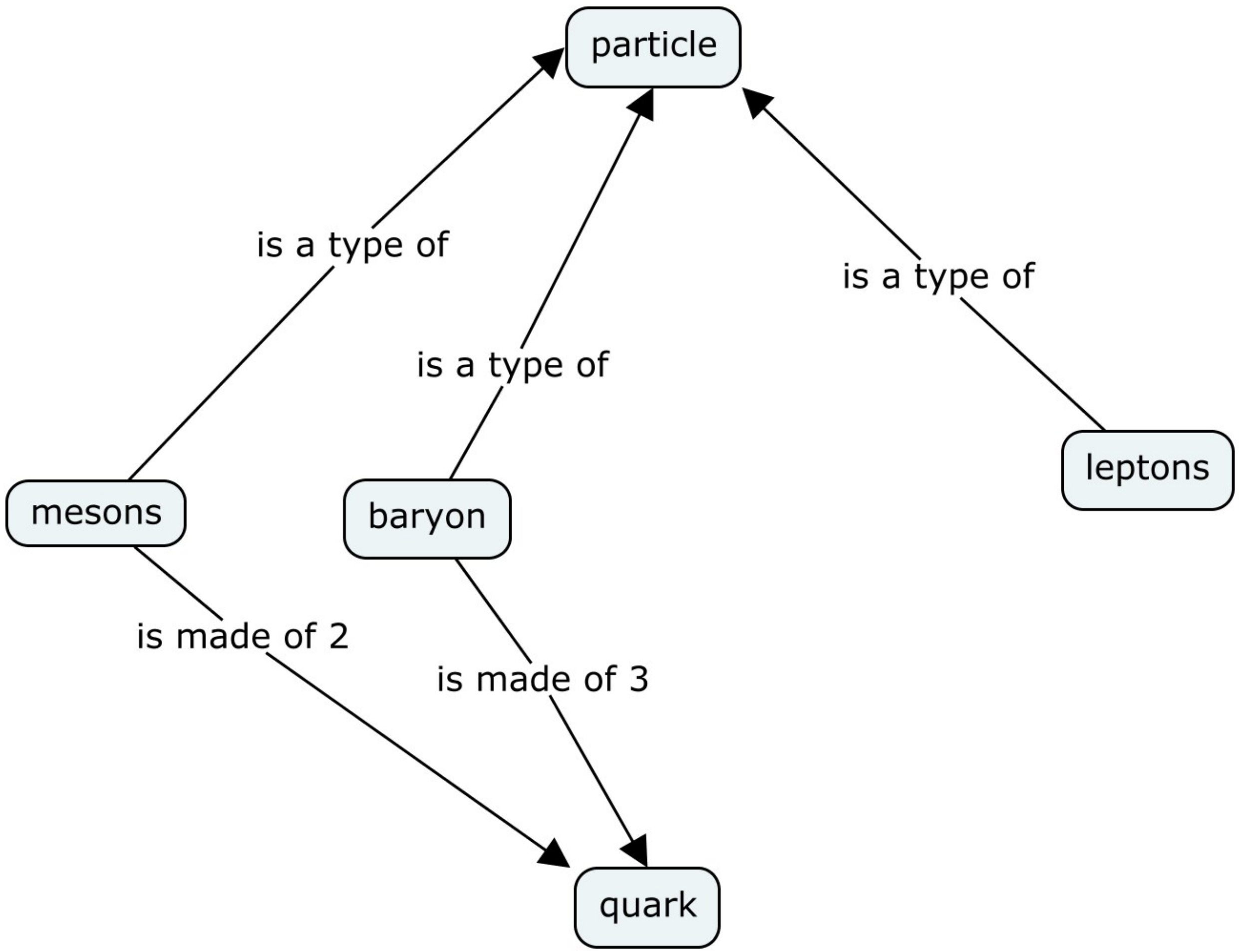
Gourlay (2017)

An example of a student's concept map

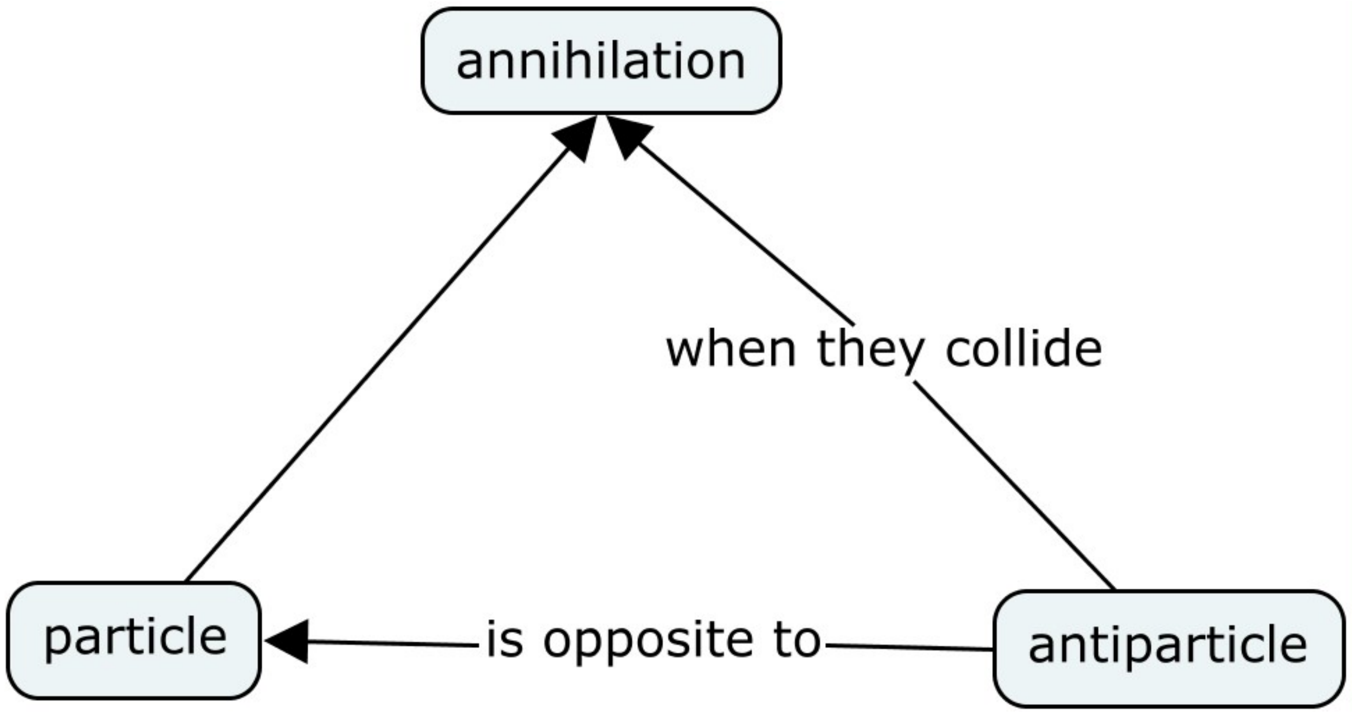


Gourlay, 2017

Quark composition of baryons & mesons



Representation of annihilation



The difficulty with understanding annihilation

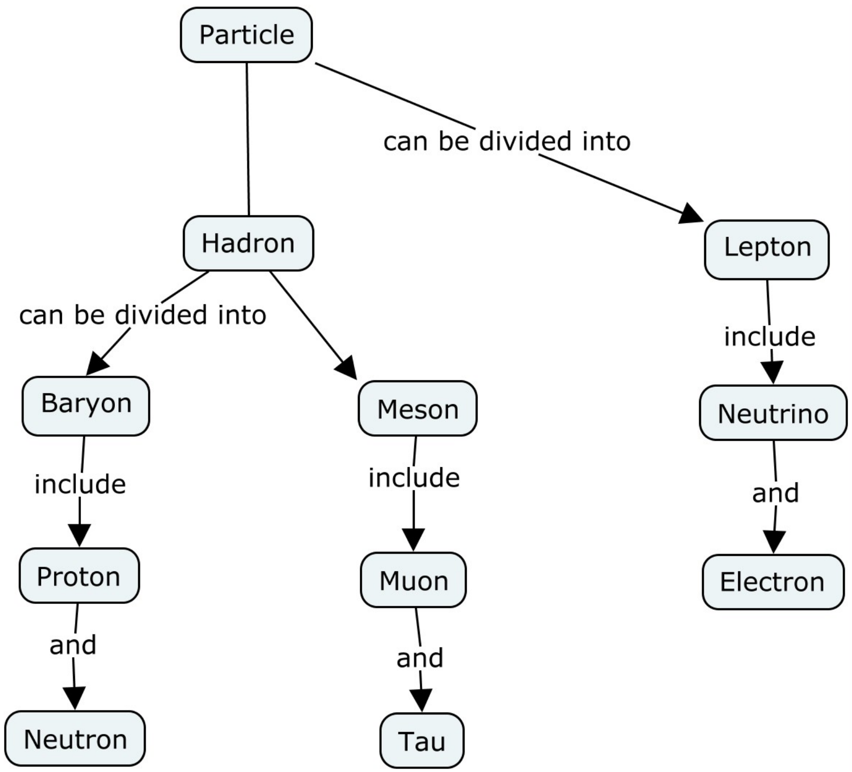
Topic area: Annihilation and pair production
Some leptons are produced by annihilation
Annihilation produces matter and antimatter
Pair production is when an electron with too much energy produces photons
Pair production is when a photon with sufficient energy makes two particles that repel each other
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

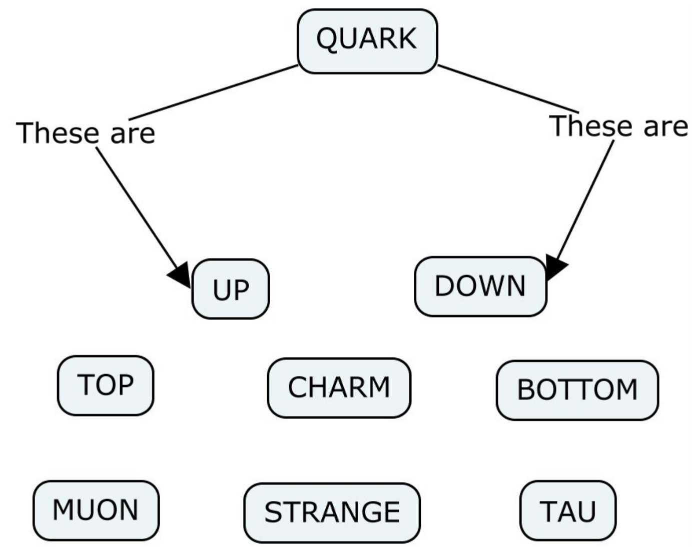
Topic area: Leptons	*Number of instances of incorrect propositions*
Muon is a meson	5
Tau is a meson	5
Tau is a quark	4
Meson is a lepton	1
Hadron is a lepton	1
Pion is a lepton	1
Kaon is a lepton	1
Leptons have an associated neutrino	1
Muon is a quark	1
Total	20

Gourlay, 2017

Misunderstandings about muon and tau particles:



Example 1

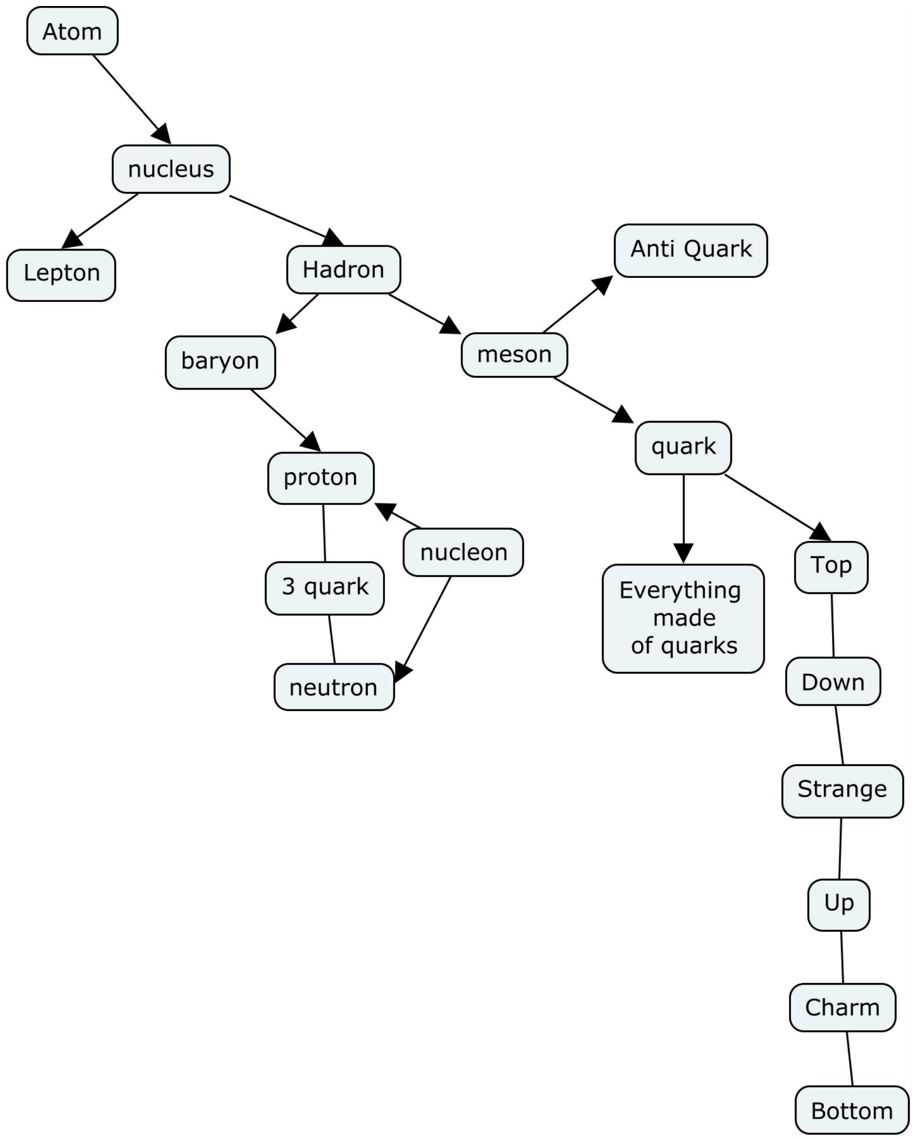


Example 2

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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Software tool

Concept map diagrams have been produced using the Cmap software, available from http://cmap.ihmc.us