Conceptual integration and science learners - do we expect too much? [1]

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One of the characteristics of science is that it produces a highly interlinked, and largely coherent body of knowledge. This reflects the epistemological commitments of scientists who tend to seek and highly value such consistency, and assign particular significance to those principles and models of widespread application that are considered to be unifying and 'fundamental' in nature - ideas such as the conservation of energy; the molecular model of matter; and natural selection. Clearly, we would expect and hope that science learners would come to appreciate such scientific values, and that their own scientific knowledge would develop towards greater coherence and integration. The national KS3 strategy recognises this in the presentation of a framework built around a number of 'key ideas'. Some commentators on the research into school level students' ideas and thinking in science have characterised student knowledge as generally weakly structured, and often piecemeal and atheoretical. Yet, there has been little research to specifically investigate the level of integration, and the development of integration, in students' scientific knowledge. This is a core focus of the ECLIPSE project, which sets out to explore concept learning, integration and progression in Science Education.

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I would like to thank *Prof. Phil Scott*, and the ***Centre for Studies in Science and Mathematics Education***, for inviting me here to give this seminar paper this afternoon.

Introduction:

This presentation is based on the following assumptions:

1) that what I'm calling conceptual integration is generally 'a good thing': that, generally speaking, being able to see how aspects of our knowledge of the world can be related in meaningful ways is both intellectually satisfying, and useful in making sense of our lives;
2) that, therefore, education - in general - should seek to help learners develop integrated conceptual structures;
3) that conceptual integration is a feature of scientific knowledge, and the quest for conceptual integration is a feature of scientific research,
4) and that an authentic science education would also reflect the way that science as an activity seeks to build coherent knowledge;
5) that at secondary/sixth form level, learners' scientific ideas probably do not commonly reflect the high level of integration that we might hope for, but
6) research explicitly exploring this feature of conceptual learning is limited;
7) and that therefore more research into aspects of conceptual integration is indicated.

I'm assuming some of these points may be taken as non-contentious - although you may tell me otherwise! – so I do not intend to dwell on all the items on this list in great depth. I will, however, attempt to establish a basic argument for this position.

Conceptual integration is a good thing.

By conceptual integration I mean that the knowledge structures of an individual are organised in such a way that there is strong linking between different 'areas', and that, generally speaking, there is consistency between different parts of the person's personal knowledge.

I am aware, of course, that one could write a book just exploring and justifying that statement.

- What do I mean by knowledge - or do I mean belief?
- Is it valid to talk about knowledge structures, and their organisation, as we know so little of the detail about how knowledge is 'stored' in brains.
- Does my language imply something that is static and rigid, when what we observe is an output that results from processing of unobservable underlying elements that may themselves be dynamic.
- To what extent is it appropriate to see knowledge as being personal, when it can only ever be explored or revealed in an interaction with others – even if that interaction is the reading (interpretation) of something written in another place and at another time.

These are all substantial and interesting questions, and I am aware that I am neglecting them, but I hope you will grant me that:

- people's behaviour strongly suggests that they do represent aspects of their experiences through changes in brain structure that can reasonably be considered as 'the storage of knowledge';
- our [sic] introspection convinces us that we have knowledge that is stored, and can be accessed and applied, and that out conceptions can be linked to a varying extent, and have varying levels of coherence;
- our [sic] 'theories of mind' suggest that we can infer that the situation is similar in others who seem to have minds like us.

I think that in what follows the neglect of these important issues does not undermine my case, as I believe that what I say does not depend on detailed consideration of these issues.

So, I'm talking about two aspects of our 'conceptual structures': the degree of linking and the level of coherence.

I think it is reasonable to suggest that

a) in general, a high level of linking is to be welcomed.

b) usually, coherence, is to be welcomed.

Now in terms of linking, I am not suggesting that any *random* linking is a good thing. I am assuming that to be effective our knowledge structures have to correspond to our experience of the external world, and that therefore linking is useful where it reflects the patterns we perceive in the external world in a non-arbitrary way. Of course, this immediately invites questions as to the nature of reality, and the possibility of there being any meaningful correspondence between knowledge as represented in brains and a possible external reality. Again I duck a substantial issue, on the grounds that unless one assumes some kind of stable external reality as experienced, and believe it is possible to represent this in some meaningful way in brains, then it is difficult to see how we can possibly proceed. In practice, we all behave as if the world is real and out there, and has some stability. I'm sure this even applies to those philosophers who propose alternative notions, but none-the-less seem to write 'books' on the matter for what seem to be 'other people' who seem to sometimes buy them; and who hope that there really are 'publishing houses', who really will send them 'royalties' in what they hope will be 'the future'

'It's worked so far' is not a logically sound justification, but it is what humans pragmatically do (cf. Toulmin, 2003), so I'm going to move on.

If one models knowledge structures as some kind of semantic network, like some kind of giant concept map (and I'm aware this may not be everyone's preferred image) then it is clear that links are important as the concepts (the nodes) take their meanings from their position in the net – from the way they are linked to other concepts.

To a significant extent, the links may actually be seen as representing the way we *make sense* of our worlds. Links may be more of less appropriate (i.e. alternative conceptions could be considered as inappropriate links), and will ideally vary in 'strength': some are more central and significant than others. This notwithstanding, an effective knowledge structure will generally be highly structured.

A simple constructivist model of learning might see appropriate learning as the learner adding to existing knowledge structures by linking new 'input' into the existing system in appropriate ways (i.e. assimilation, and sometimes accommodating new 'input' by modifying existing structure to give a better fit for new information). 'Appropriate' could be

(i) so that the knowledge structure better reflects external reality;

(ii) so that the knowledge structure better reflects a given target knowledge (e.g. curriculum science);

(iii) so that the knowledge structure better enables the knower to act in the world in way to achieve goals;

(or (iv) so the knowledge structure better reflects epistemological assumptions of what our knowledge should 'look like')

As my concern here is science education, I will be using the second of these criteria as the background to this seminar, i.e. appropriate linkage allows the learner to demonstrate what is judged (by teachers, examiners etc.) to be a satisfactory understanding of the target knowledge expressed in the school curriculum. If this sounds a little mechanistic, then I hope this is because of our current experience of the National Curriculum, QCA, GCSE coursework etc., and not because there is anything wrong with *the principle* of wanting students to demonstrate specified learning.

Work on human memory also suggests that recall is more readily attained when the target memory has a number of 'access routes', i.e. when there is more linkage with other potentially related material.

It seems that greater linking of conceptual learning is something to be desired, and something to be worked towards in education. Better-integrated knowledge systems are surely more desirable than just learning 'lots of stuff' (cf. meaningful vs. rote learning, Ausubel, 2000).

Before moving on, I should also refer to the other aspect of integration, that is, the level of coherence. Again, there are substantial discussions to be had about the extent to which we should seek or want highly coherent knowledge. And, again, I'm going to avoid exploring this matter too deeply. There are many areas where our information is partial and perhaps contradictory, or where the phenomena are multifarious, and where a simple, entirely consistent, representation would not be of optimum utility. Indeed, this may be a sure way to produce ‘closed minds’. It is unrealistic to expect total coherence in our thinking, whether for ontological or epistemological reasons.

That said, a generally inconsistent and incoherent knowledge of the world does not provide a helpful guide for action in the world. If we know that sodium chloride consists of ions, *and* we know that sodium chloride consists of molecules; or if we know that an insect is an animal, *and* we know that an insect is not an animal; or if we know that energy is always conserved, but we *also* know that energy is sometimes used-up, then our ‘knowledge’ is of limited use. (Of course, sometimes it may be useful to know – for example - that atoms are like hard spheres, *and* to know that they are mostly empty space and have no well-defined surfaces. This is an important complication.)

The nature of science

These examples shift the focus from the general to the more specific context of science education. Science education is charged with teaching learners something of science – of the ways of science and the products.

Science produces knowledge of the world, knowledge that has been labelled ‘reliable’ (Ziman, 1991). That knowledge is expected to be largely coherent. In particular, scientific theories and models are usually expected to be internally consistent. Moreover, the highest status is often ascribed to those ideas which are thought to be fundamental or unifying – seen as having very broad application, or showing how different areas of science can be brought together within a single framework. Science is generally guided by attempts to develop new understanding that fits with existing ideas – in practice it is difficult to see how it could be any other way. In one commonly discussed description of science, anomalies are seen as crucial: indicating that new scientific ideas are needed to bring back coherence. The recognition of an anomaly is the recognition of something not fitting – of something being ‘wrong’. Results that contradict our theories need to be explained, or to be explained away. To ‘save the phenomenon’ is really to save the coherence of our understanding.

Even the most counter-intuitive ideas can be accepted *if* they can be fitted into our conceptual schemes – but lack of coherence is seen as a severe problem. I would suggest that we could contrast relativity and quantum theory here: so there are many popular scientific books on both – arguments over the former were about whether the evidence supported the theories; arguments over the latter were about how to find a coherent interpretation. Finding a coherent synthesis of general relativity and quantum mechanics is of course considered something of a holy grail for science.

I would suggest that any authentic science education would impress on learners both the highly coherent and consistent nature of most scientific knowledge; and how this is a deliberate outcome of the metaphysical commitments of most natural scientists. They expect the world to have regularities and symmetries: to have a 'fundamental' nature, which ultimately explains the patterns we see in more complex phenomena. These scientists expect to uncover 'laws' of nature – so they can talk about the behaviour of gases and the structure of metals – and assume that what they say applies well beyond the tiny region of time and space where they have collected evidence to support their ideas.

Conceptual development in science

If these ideas are taken seriously, then conceptual development in science, perhaps echoing that in science itself historically, should not only involve learning more, or even just learning more sophisticated, science, but should also refer to the way a learners' science knowledge becomes better integrated – more interlinked, and more coherent.

If this is the case, then one focus of research into learning in science should be concerned with such matters as the degree of integration in learners' scientific knowledge; the developing degree of integration in learners' scientific knowledge; and the way such information can inform the teaching of science to better foster such integration.

This would suggest such research questions as:

- how can we explore/measure/describe *the degree of integration* in learners' science knowledge?
- *how integrated* is the typical learner's science knowledge at different stages?

- *how much variety* is there in the degree of integration of learners' science knowledge at different stages?
- assuming the level of integration normally increases with maturation/further study: are there *typical trajectories* in the development of increasing integration in learners' science knowledge?
- *how much variety* is there in the *trajectories* of increasing integration in learners' science knowledge degree?
- can we identify factors which influence the degree of integration, or the rate of developing integration?
- what advice can we give to teachers to help them facilitate greater integration in their students' science knowledge.

I am not aware of a great deal of research into these areas, and I can suggest several possible reasons why:

For one thing, research into learning in science shifted, in the 1970s and 1980s, away from research in the Piagetian tradition which tended to look at overall features of cognitive functioning, to the exploration of learners thinking in specific areas of science – this led to a vast body of 'constructivist' research, but with individual studies often focussed on a particular topic.

This new approach to exploring learner's science – these intuitive physics; their alternative conceptions and frameworks; their life-world knowledge etc., made up a research programme in science education, and within that programme the 'positive heuristic' (using Lakatosian terminology) directed research. The initial areas of research were concerned with familiarisation with this whole new arena for research – and included a great deal of 'natural history collecting' to find out about the types of entities that might be described with these new labels (i.e. alternative frameworks etc.). As the field develops, and theory has become established, researchers are required to move on the next stages of the programme – such as exploring progression and integration in learning from within the constructivist frame (Taber, forthcoming).

I would also suggest that as much of the constructivist research was idiographic in nature, there may well have been a bias (deliberate or tacit) among researchers to avoid research foci of laws and fundamental principles.

More significantly, this new phase of constructivist research is more difficult. It is much easier to explore 14 years olds' thinking about photosynthesis or particle theory than to explore conceptual trajectories over time, or try to find out how learners may or may not link across science topics! In terms of cost-benefit analysis, the days when publishable findings could be based on a talking to students once about a single topic may be largely behind us.

This could explain why constructivism is seen in some quarters as a movement that is running out of steam, or even going out of fashion, and is being questioned as the basis of the dominant paradigm in science education research (e.g. Solomon, 1994).

Personally, I think that if the first phase of constructivist research produced much of interest, then the new direction for the research programme offer even more fascinating phenomena to study. And, whilst talking personally, I think there at least three major areas to be explore. As well as studying integration and progression in conceptual knowledge, there is the major challenge of find a working (i.e. coherent!) synthesis between constructivism and other aspects of work form the cognitive science – memory studies; information processing models etc.

There has been some very interesting work looking at progression in learning that draws upon the constructivist 'paradigm' – in the sense of the common working methods of detailed exploration of the ideas of individual learners. Studies which have looked at conceptual trajectories or learning pathways (e.g. see table 1) have reminded us just how complex the phenomenon/a of learning is/are – and have described their findings in quite distinct ways.

topic	reference
quantum atomic physics	Petri & Niedderer, 1998
the structure of matter	Scott, 1992
atoms, molecules, and chemical bonds	Harrison & Treagust, 2000
chemical bonding	Taber, 1995; 2000, 2001

Table 1: Some examples of studies into progression in learning

On the other hand, little work seems to have been undertaken within science education concerned with the way learners actually link and integrate thinking from different topics[2].

So how well integrated are learners' ideas?

When learners' ideas were labelled as 'children's science' (Gilbert et al., 1982) there were many commentators who criticised this tag. Science, as we have seen above, implies a coherent and well integrated set of ideas of widespread application. Whilst some researchers seemed to find just such characteristics in learners' ideas, others claimed that children's ideas about scientific topics were anything but. The extent to which learners' ideas were theory-like was seen as a major point of difference.

Perhaps it is just with hindsight that this debate seems rather vacuous – surely the question should never have been *whether* learners' ideas were tenacious, stable, coherent, widely applied etc., but rather *to what extent* learners ideas were tenacious, stable, coherent, widely applied etc. We would also wish to know *what degree of variation* there was in the extent to which learners' ideas were tenacious, stable, coherent, widely applied etc., and whether this depended upon age, topic, ability, the nature of teaching received etc.

Whatever, there certainly was a debate that seemed to be presented as if researchers were arguing over a dichotomy more than the profile on a continuum. So, Claxton (1993) mooted the suggestion that children's science was actually more a set of local 'mini-

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[2] It was pointed out during the discussion following the presentation that Engel Clough and Driver had undertaken a study that looked at several topics (Clough & Driver, 1991/1986). This is true, but this study looks at the degree of consistency with which students apply particular frameworks within different contexts: with a topic area – but explored in several different topic areas (they looked at aspects of pressure, heat and inheritance see tables 15.9 and 15.10). This is slightly different from what is being suggested here. I am arguing for research to explore how learners make links across (potentially) associated topics, rather than exploring the range of application of their concepts within topics. I recognise this distinction is not an absolute one.

theories' (although he then seemed to suggest that scientists' ideas may have the same limitations which seemed to rather undermine the argument). Solomon (1993) drew on ideas about the life-world to suggest that there were two domains in which learners of science had to operate, and that their life-world knowledge (like everyone else's) had a different nature to the scientific knowledge that was met in the classroom. Different standards applied in these two realms, and student failures in class were failures to make the transition into the different culture of the science classroom (cf. Aikenhead, 2000).

It might be asked how intelligent people managed to interpret the evidence so differently. I'm sure some of this is down to the biases inherent in the assumptions underlying research questions and approaches. However, my own view is that there is a whole pan-dimensional spectrum of findings to be had: the labile and the stable; the romanced and strongly believed; the widely applied and the highly context-bound; the only truth and the one-alternative-perspective-among-many. Even leaving aside the difficulty of judging the coherence of someone else's ideas from the perspective of one's own ways of compartmentalising and viewing the world, the disparity in findings is not surprising. This seems a bit like two shoppers going to the supermarket, and then arguing later over whether it sells vegetables or cereals – both presenting convincing empirical evidence for their own position (their purchases), and unaware that their neighbour is submitting a paper claiming that what you can actually buy there is fruit juice. Not only that, but apparently the fruit juice always comes in rectangular cartons of one litre capacity, that can be stored for many months before opening. Well, that's what she found there!

Personally, I think you can find all sorts of goods at the supermarket, if you have enough time to explore all the aisles and check out the different shelves.

Compartmentalisation of curriculum knowledge

Although I recognise the value of perspectives such as Solomon's distinction between the life-world and scientific domains, my own work suggested that these approaches could not sufficiently explain all of those aspects of the nature of learners' ideas in science which interest us. Solomon's approach can be applied quite well to such topic areas as force and motion or plant nutrition. In these areas one can see that there is formally codified curriculum knowledge at odds with the ways of talking about thing – balls running out of steam, plant food – that are part of everyday social discourse. Compartmentalising school and life-world knowledge surely happens, but cannot be used as the basis for explaining all the alternative conceptions and frameworks that research has uncovered.

My research into learners' ideas about chemical bonding suggested that there was a very common way of thinking about chemical bonds, chemical structure and chemical reactions which did not derive from the way that children absorb discussion of these issues in the life-world. How many children are exposed to discussions of atoms exchanging electrons and the like in their social hours! Certainly the common 'octet' framework includes ways of thinking that seem to have been imported (directly or through teaching) from social life: what atoms *want* and *need* – how they *try* to get full shells and are prepared to share so they *think* that they have octets of electrons. However, this is not life-world knowledge: it largely derives from schooling, and is better considered the outcome of a deficient set of curriculum models.

So I am aware that one way in which learners' ideas may sometimes lack integration is between those ideas that they have about a topic to use in the everyday world, and the alternative versions they are meant to use in formal school contexts. However, I am more interested here in the way knowledge is structured *within* that 'domain' of school science – the ideas that learners think are what they are being taught in school.

One example of this came when I interviewed A level chemistry students about their understanding of molecular phenonemena. One thing I discovered was there seemed to be a common alternative way of thinking about the forces in an atom that I labelled the 'conservation of force' conception, because students seemed to assign a nucleus with a given amount of force (depending upon the number of protons present) which was *shared* among the electrons available. Ionising an atom led to a redistribution of force as the available force could be shared among less electrons so that they would get more each

Now anyone who has undertaken this type of work will know both (a) that learners' ideas are usually a little more subtle than such a simple description suggests, and (b) that 'common' alternative conceptions and frameworks are not usually held in precisely the same way by different learners. Perhaps we should strictly talk about different learners having individual alternative conceptual frameworks that *have much in common* rather than them 'sharing' *common* frameworks.

These caveats notwithstanding, it was clear that some of the students applying the 'conservation of force' notion were also able to apply normal Coulombic principles when asked about the interactions between charges. What seemed to happen is that when asked about charged particles *in atoms* their thinking is switched to applying a different set of ideas (Taber, 2003). In the same way, students who expected the movement of balls and apples to be related to forces, seemed able to feel that electrons moved between atoms because of the needs of the atoms to have full electrons shells, rather than because of the actions of forces. This is not about having a life-world and scientific view, but rather about applying a range of 'scientific' principles in different contexts that the orthodox scientific view would suggest should be subject to the same considerations. As one of my students told me one day: "I can't think about physics in chemistry, I have to think about chemical things in chemistry."

Perhaps, given all the research on learning in science, we should not be surprised that students do not always make the links we might hope for. It does seem to me that teachers make assumptions in presenting material, assumptions about the way that what they are teaching now will be related to what has gone before. Good teachers make the connections as explicit as possible, but this still seems to be a problematic area in science teaching.

I developed a simple model to synthesise some of the problems that can occur in learning due to the mismatch between the way the teacher expects new material to be related to existing learning and what can actually happen. The original model just had four main categories of ‘learning impediment’, but has been expanded a little (Taber, 2004).

My own assumption is that good teachers present material that they wish to relate to the students’ existing knowledge structures (i.e. meaningful learning), and design their presentation to fit with the assumed prior knowledge. The outcome can be learning as intended, no substantial learning, or learning that distorts the intended meaning in various ways.

Aspects of ‘mismatch’, where learning does not takes place in the form intended, can be due to a variety of ‘substantial’ learning impediments: due to the learner’s model of the world (e.g. plants are not living things); or the learner’s epistemological assumptions (e.g. models are just scaled down versions of reality); or the learner’s interpretation of previous teaching (e.g. everything is made of atoms); or the learner’s interpretations of linguistic features (e.g. neutralisation implies neutral, Schmidt, 1991); or the learners’ analogical thinking (e.g. the atom *is* a small solar system). There are also ‘null’ learning impediments, where either the assumed prerequisite knowledge is not available to anchor new learning, or it is not accessed by the learner who does not recognise its relevance.

Research into memory suggests that once material has been stored it is never actively erased, but that does not ensure it can be recalled when required. In a similar way, even using diagnostic assessment to check the prerequisite knowledge is available does not guarantee that it will ‘brought to mind’ at the appropriate point in teaching. In general we could just advise teachers to be eve more explicit in these matters, but it would be useful to have a better understanding of this phenomenon.

One example of such a ‘fragmentation’ learning impediment I have quoted before (SE) concerned a student who was asked about the possibility of promoting electrons to give excited atoms. When Debra was asked about the possibility of excited atoms in an interview she initially seemed unable to recall any relevant knowledge. However, I was aware that Debra had actually undertaken an experiment to find the wavelengths of spectral lines in her physics classes. When she was specifically asked about this she was then able to describe how “you promote an electron to a higher energy level. And then it falls back and gives out the energy”. Clearly Debra *did* have knowledge of how atoms could be excited represented in her cognitive structure, but this was not activated by the original question, perhaps because she perceived the interview context as ‘chemistry’. When specific probing indicated that knowledge Debra considered ‘physics’ was being sought, *then* her representation of this knowledge was activated.

Now it is not surprising that students compartmentalise their learning according to curriculum demarcations – or at least, that some students sometimes do this. However this is not the whole story. I remember one student who was unsure about the relation of ionic and covalent bonds to double and single bonds. Her inorganic chemistry lecturer (well that was me) went on about ionic and covalent bonds, and in organic chemistry she was told about single and double bonds. She clearly suspected there should be some relationship between these different types of bonds, but had failed to infer what it was. As another chemical example, a student (Carol) described in an interview how, in the structure of the benzene molecule, there was,

> “kind of like a ring [with] like electron thing underneath it, and electron thing on the top…the electron density below and above it…because they’re - bonds…*and* then you’ve got delocalised electrons in the middle, but I don’t know what they look like.”

Carol did not appreciate that rings of electron density and the delocalised electrons were different ways of talking about the same features. This is perhaps an example of what Carr (1984) called ‘model confusion in chemistry’, but again we see that information that was assumed by the teacher to clearly fit into existing knowledge was not linked up in the intended way.

Context and application

Now in one sense there is nothing very new in what I am saying here. Research into learners’ ideas has long indicated that learners often seem to learn and then apply ideas in a very limited range. All principles have a range of application, and we cannot expect learners to know what that range is unless we tell them!

It is quite possible there are three common problems here:

In part, the this may be the general problem that teachers always have in getting down to the student’s level – of seeing the subject matter ‘at the learners’ resolution’. We all know it is very easy to forget just how much our own subject knowledge has developed and consolidated over many years, and so over-assume background when teaching. We can assume it is obvious when some principle does and does not apply, because it *becomes* obvious to someone who has been exploring and using the principle for many years!

A second possibility may relate to conceptual development, in more general terms. Perhaps increased conceptual integration comes with maturity – so the typical 12, or 14, or 16, year old has a lesser tendency to compartmentalise knowledge than adults.

A third possibility concerns epistemological assumptions. As I pointed out earlier, scientists expect scientific knowledge to have a certain form, and so will be looking for principles and laws that have wide ranges of application. Perhaps that’s not what the typical young learner expects. Perhaps they see science as being a large series of 'facts' to be collected (cf. Driver et al, 1996) – a natural history model – and do not *expect* to be seeing how it all 'fits together'.

Whatever the reasons, I think that the issue of conceptual integration is one worth studying, as I feel knowing more about this area could be very valuable for informing effective teaching in science.

The ECLIPSE project

This concern feeds into my own personal research agenda. I am quite keen on Lakatos' notion of Research Programmes, and feel it is useful to conceptualise research into learning science as a Lakatosian Research Programme (Lakatos, 1970). Early constructivist work was often concerned with identifying common conceptions exhibited by learners, but now that there is a great deal of data on this, the research programme needs new directions to remain progressive. These new directions should (on the Lakatosian model) be suggested by the programme so far. I mentioned earlier what I see as three significant 'avenues' for taking forward this area of research: synthesising constructivist approaches with other perspectives; exploring progression to see how conceptual knowledge develops (as in the examples cited earlier); and exploring degrees of (and changes in) integration in learners' science knowledge.

I am actively, if rather slowly looking into this research agenda. On the principle that some sort of public commitment is useful in focusing the mind, I labelled this work 'the ECLIPSE project' and put up a webpage on the Faculty site (http://www.educ.cam.ac.uk/eclipse/index.html). ECLIPSE stands for ***Exploring Conceptual Learning, Integration and Progression in Science Education***. To date my work in these areas has indeed largely been exploratory, but I wanted to briefly talk about two approaches I have been following.

ECLIPSE Understanding Science Project:

The first approach is extremely simple, and possibly even simple-minded. The reason that much of the research in the literature is not suitable for exploring these issues is that the data created with particular learners is often collected at one particular time on a single topic. So, I have been visiting a local school to see a small sample of learners on a number of occasions each. The technique used is ‘semi-structured’ informant interviewing, but with a very modest level of structure. Usually the opening question is ‘what are you doing in science at the moment’, followed up with something like ‘so what have you learnt about that then?’

The intention is to collect comments about a range of topics over a period of time. It is hoped that this will provide a database that can reveal aspects of the way these students relate topics. There are methodological problems here, as students may not mention links they are aware of in the course of discussing topics. I have therefore included some direct questioning about where they see topics being connected – but this of course may lead to the identification of links that would not have been spotted spontaneously. That said, it is probably best to include a certain amount of probing of this type.

This work is at an early stage, and although I have already collected a good deal of data, most of it has not been analysed in any depth. My impression from talking to these youngsters (from across the secondary age range) is that at least some of the students do not seem to expect to find linkage between what are presented as discrete topics, and indeed do not appear to have given much thought as to what kind of things these different science topics might have in common! That said, I was quite impressed by the enthusiastic year 7 student who told me that ‘living things’ and ‘electricity’ had something in common – circles, i.e. that electricity moving in circuits was like life-cycles. I suspect this was a creative act in response to my question, but it none-the-less provided an interesting contrast to some students who seem to miss the most 'obvious' potential connections. More work is needed before I can say much more about this.

I will share with you today, however, a much edited (as it was very long) sample of conversation with one Y11 student (see appendix 1) that I think illustrates my research focus quite well. Here is an intelligent young lady, who is able to remember a great deal from her school science, and offers considerable detail on some points. However, she fails to make the connections that - had I been her teacher – I might have intended and assumed.

My visit coincided with, let's call her Amy, Amy's introduction to electorn beams. Her teacher was going to show her a deflection tube in a later lesson, but had used the first lesson on this topic to introduce the idea. Amy had managed to remember quite a bit of detail, but some of the links that I (had I been the teacher) might have hoped she might make with other parts of her GCSE science course had not been formed. So we see that she is able to describe how the electrons in the beam are accelerated towards the positive anode, and deflected by the charged plates – yet when considering the atom, Amy cannot bring to mind the possibility that electrical forces could be holding the electron in place,

> "erm, there's something like there's a filament, and – erm – as the electrons on the filament get more energy some of them have enough energy to break away, and er, it passes through a grid thing, which erm, - yeah it passes through and then it comes to a positive anode, or something, and that makes them accelerate and pass through, and they get to, is it Y-plates first?, which can move a beam up and down?, depending on which one's positive and which one's negative. And then the X-plates can move it from side to side or something…"
>
> …*So where do you normally find electrons?:*
> erm, around – like in an atom.
> … *And don't the electrons go off free?:*
> N:o
> *why not?*
> because – there's, I dunno, if there's a kind of force of some kind holding it together, or something.
> *Okay, so if this is my atom, with my electrons in it, what kind of force might stop the electrons moving off?*

> erm, I dunno, cause like in atoms there's like shells, as you go out, but I dunno what would hold them in.
> *So you think there might be some kind of force?:*
> erm – probably.
> …What kind of forces do you know about – what kind of forces do we have available?: erm, gravity, erm – friction erm – Oh, I'll go home tonight and I'll think of loads, but – erm, dunno

So was Amy oblivious to the reason the electrons in the beam accelerated, and deflect. It would seem not:

> *So why does a positive electrode make the electrons speed up and accelerate?*
> because the electrons are negative, because in class we thought that they'd stick to the anode because they're kind of positive and negative attract, but apparently they just pass through.
> …*Okay and then there was an X plate and a Y plate?*
> yeah
> *what did they do?*
> erm, they kind of changed what direction the beam's going in
> *and how do they do that?*
> hm, one, well, if you had the Y plates, like one would be positive and one would be negative, …
> *so if this is my beam of electrons, let's say there's a positive plate up there, how does that effect my beam of electrons?*
> so it kind of moves up towards the positive.
> …
> *so why does it get deflected that way?*
> because – the plate is positive, but the electrons are negative, and so kind of, like, I dunno is it kind of attracted[?],

So here Amy is talking about the effect on the electron beam in terms of attraction of opposite charges. So back to the atom:

> … *I want to go back to this atom, because I want to be convinced why these electrons hang around in the atom, because you said you thought it might be gravity, but you didn't seem to be totally convinced, you didn't think it was friction, but you couldn't suggest any other force that might keep them there. So we're going to either have to settle on gravity, or think of a better answer.*
> well if it was me, I'd have said gravity, but I'm sure there is a better answer. I just don't know what.
> …
> *You don't know any other force that might effect electrons?*
> - erm – magnetism, no, … I don't know if that would affect that though…I just never thought of it that way, er –
> … *Have you got [?] any other forces which might influence electrons?:*
> … I can't think right now though.

It seems quite clear that in one context – electron beams – Amy thinks electrical attraction is a feasible mechanism, but this does not come to mind in the context of the atom:

> *…No, okay. I'm going to ask you one more thing to remind me, why did you say the electrons got attracted towards the anode, and bent towards the plates?*
> because they were negative, and the anode was positive, and so kind of, opposites attract.
> …
> *Do you think there's any forces involved there?*
> - erm, yeah.
> *…Final question, you said this negative electron's attracted because there were these positive charges, and then it was deflected by these plates because there were positive charges, is that right?*
> Mm.
> *Is it possible there could be any positive charges holding the electron in the atom?*
> - in the nucleus, isn't there, the – well the nucleus is like the protons and neutrons, but – I don't know if they're positively charged. er – the protons are – aren't they positively charged?

Perhaps this is another example of the compartmentalisation of what is considered physics versus what is considered chemistry knowledge. However, even within part of the discussion that seems unambiguously physics, we find an example of limited conceptual integration. Amy talks about the electrons coming from the filament, which is like the filament in a light. However, she does not seem to have deduced that there are electrons in a lamp filament - despite knowing there must be a flow of electrons through it!

> *So where are the electrons before they are in this beam – where do they come from?:*
> - erm, well Miss said from the filament…
> *So what is a filament?:*
> erm, {moan} don't know how to explain it, it's like, well dunno if it's the same thing, but in like a light bulb you get a filament, and – erm, it's kind of - I dunno how to explain it. E:r – Miss, Miss gave us the example of like in normal physics when we did about the resistance of a wire and it like glowing red when it was, when it got hot enough, and apparently that's the same thing that happens. … Miss drew it like a little kind of coil of wire, {laughs} but, hm. …
> *So in an ordinary filament in a light bulb, are there electrons?*
> e:r I dunno, I never thought about it, erm, yeah I suppose so.
> *Why do we have a filament in an ordinary light bulb?*
> because that's – what kind of – makes it light, doesn't it?
> *okay, good – so why does it do that?:*
> because when it kind of gets hot enough, it gives out light and heat, yeah.
> *And what makes it hot enough?:*
> the current passing through the wire.
> *Okay, and what is current?*
> oh, it's erm – current is the flow of electrons round a circuit, > * >
> < *Okay.* < *So do you think there are electrons in this filament?:*
> I suppose there must be then.

As I say, this approach is rather minimalist, consisting of very open conversations, mostly focused around topics the students are currently learning about in their science classes. That is not to deny that my lines of questioning are not informed by my previous work and reading, and my expectations about where there are links in the science – but I enter these sessions prepared to discussed whatever topics the students report working on.

ECLIPSE Physics Sciences Project

By contrast, I am also developing a rather different approach, with a much tighter structure. This is an interview protocol for sixth form students who are studying chemistry and physics. The interview runs through a whole range of basic topics in the two subjects, and in particular provides opportunities to see if they make the kind of links that I would have hoped for and expected when I was teaching these subjects at that level. I've only tried this out with a small number of informants to date, but it does seem to offer some insights into where students do - or do not - make the connections.

The approach here is deliberately different, as I am approaching the interview from the perspective of my own way of conceptualising the science, and my own expectations and hunches based on previous work. Appendix 2 provides part of my interview with an A level student (about halfway through the course). She had obtained the top grade in her school science examination, and aspired to a career in veterinary science. This young lady, I'll call her Persephone, clearly has a good grasp of a range of topics she meets in chemistry and physics, and applied a number of principles and key concepts across a range of contexts.

That said, there are a number of interesting features of the interview. (For example, this student seems to hold a number of alternative conceptions that have been previously identified in the literature.)

One principle that Persephone applies in several contexts is that of balance between opposing forces:

> *Why do you think that apples do not always fall from trees?…*
> Opposing forces, holding them up in the tree…Tension between the apple and its given tree, or twig, whatever.
>
> *What happens to a parachutist when she jumps from a plane?*
> Erm, starts descending due to gravity… and if she's high up enough, should reach sort of terminal velocity…[because] her downward force is equalled by the like the upward force of air resistance, working against her, so you get a balance.…she carries on at the velocity she's at, so she's not going to accelerate any further.…

However, she applies this to the case of orbital motion, seeing circular motion as the outcome of balanced forces:

> *Why do you think the planets orbit the sun?*
> …gravity again? There's forces between large bodies as in – the sun and planets, I suppose like centripetal force, and…it links in with, objects circling or objects orbiting, keeping something in an orbit. But also the forces opposing that, which I think is centrifugal. Yeah, which would send it out of orbit…to keep it in balance so that it carries on just going round, rather than veering off in either direction, away or towards the sun.…[balanced forces] allows an object to remain either stationary, or at its, doing what it's doing in the same direction at the same speed. Rather than, changing, you know accelerating or decelerating, or veering off either way.…

This is a common alternative conception, and although it is possible to consider this as an inappropriate analogy (transferring a principle to an inappropriate context) the key notion here seems to be classing circular motion as non-accelerated.

There are a number of other interesting features of this interview:

- Persephone seems to hold a 'deviancy' model of ionic charges (i.e. that ions are charged because their electronic configuration is deviating from a full shell, cf. Annie - see Taber, 1995);
- she seems to use the 'conservation of charge' notion ("the effective nuclear charge, which is going to be effecting the remaining electrons…You've got the same number of protons, or positive charge from your nucleus as you have before, but then you've got a different number of electrons that it can effect. And it's fewer, so, it should balance out that each of these electron have got more charge effecting them…");
- she seems to think that sodium chloride contains covalent molecular species.

However, a feature that is particularly interesting for my present focus (i.e. conceptual integration) is Persephone's explanation for why charged balloons might stick to neutral walls:

> *Have you seen the party trick where a balloon is rubbed on a jumper/sweater, and then stuck to a wall?…Why does the balloon stay attached to the wall?*
> There's some sort of, I don't know, interaction if you like with the electrons and things, and you have a positive and negative charge, which allows, a glue effect if you like, attraction between two areas, one of positive and one of negative…
> *And why does it stay stuck to the wall?*
> Because you've got opposite charges, you've got the say negatively charged balloon, and then you're positively charged wall…hasn't had anything done to it as such, but maybe in comparison to your very negatively charged balloon, it's still likely to attract.

Persephone argues that a positively charged balloon will be attracted to a negatively charged wall, and – accepting that the wall is not actually charged – extends this to a wall which is *relatively* negative compared with the balloon. This is not so strange: after all we consider p.d. to be based on relative differences, and so an object at say +10V could easily be the negative pole/plate in a physics experiment. (So this could possibly an example of drawing an inappropriate analogy.)

What is more interesting is that Persephone does not suggest any kind of induced polarity in the wall materials: this is interesting because we know she *is* aware of a similar mechanism in chemistry:

> "well there's van der Waals' forces…you've got if you like an electron cloud between, surrounding each molecule…And as these clouds don't stay in one fixed place, there's always going to be momentary areas of dipole. And that's where you get your positive and negatives attracting each other again"

To my mind, this is a potentially feasible link for an A level student, and in this particular regard we see a lack of conceptual integration: an idea that is applied to explain forces between neutral species in one context is not brought to mind to explain why a neutral species might be attracted to a charged species.

Learning Science and Domain Specificity

One area where research of the type I am interested in carrying out makes strong connections with other (i.e. outside of science education) literature is that about ‘domain specificity’. Although this work seems to be somewhat ignored by science educators, it would seem to be of considerable interest.

The notion that there are ‘domains’ within the mind (itself, hardly an unproblematic concept!) is taken quite seriously in some quarters, and is related to notions about the way parts of the brain may have evolved, at least to some extent, as a set of interconnected but somewhat discrete modules, each being an evolutionary response to a particular ‘problem’ of life.

> "A domain is a body of knowledge that identifies and interprets a class of phenomena assumed to share certain properties and to be of a distinct and general type. A domain functions as a stable response to a set of recurring and complex problems faced by the organism. This response involves difficult-to-access perceptual, encoding, retrieval, and inferential processes dedicated to that solution."
> Hirschfeld & Gelman, 1994, p.21

Perhaps one well-known candidate might be related to Chomsky’s notion of part of the brain acting as a Language Acquisition Device. According to this view some aspects of our responses to environmental stimuli are to some extent hard-wired (brain structures have evolved to recognise and interpret particular types of phenomena), and we ‘naturally’ tend to compartmentalise some phenomena according to which modules are activated by particular perceptions (Hirschfeld & Gelman, 1994).

This area of research would seem to be very pertinent to work in science education considering such notions as alternative conceptions and life-world knowledge. For one thing, it has been suggested that a general property of the structure of human minds is that we have evolved modules that relate to such areas as social psychology, natural history and mechanics. If this is so then just as ‘normal’ human children develop a ‘theory of mind’ to allow them to predict the way other people may think and feel; they may also develop folk biology and naive physics as a matter of course. As part of their folk biology learners assign an essence to living things (Keil, 1992), and recognise ‘natural kinds’ (e.g. Kuhn, 1989). For example, it has been suggested that the category of tree seems to be virtually universally recognised in human societies, even though it is not a significant category within modern biology. Perhaps ‘intuitive’ notions about force and motion, notoriously hard to dislodge, actually reflect some aspect of physical neurological structure (and so even genetic structure)!

In terms of the type of issues have been talking about today, notions of domain specificity could perhaps explain why students who learn about physical forces in physics often do not apply them in chemistry. This could be more than curriculum-based-compartmentalisation but may actually be more deeply ingrained. If ideas met in physics are successfully related to a physics-related-module of mind, then perhaps it is not surprising that these ideas are not applied outside of that domain? This is just a conjecture, of course, but is certainly work exploring.

Another interesting aspect of this area of research is the consideration of how ideas may be ‘transferred’ from one domain to another. It is suggested that this may be based on analogy – an area that has itself been studies in some depth in science education.

> “analogical transfers contribute to conceptual interconnectedness and mental economy. Analogical transfer may in fact represent a means for integrating domain knowledge across domains…But unlike domain structures, transfers can be both idiosyncratic and not functional."
> Hirschfeld & Gelman, 1994, p.23.

This idea has been given particular significance by some workers (e.g. Karmiloff-Smith, 1994). It has been suggested the domain specific modules have a long evolutionary history, and that a substantial step in human evolution was the development of some general purpose feature of cognition that allowed re-representations such that notions from one domain were able to be 'copied across' and then used as templates in other domains.

I find these areas of work quite interesting, as they may well have considerable significance for some of the barriers to learning science that we are all so aware of. Clearly in terms of my own categories of learning impediments, not only does domain specificity suggest why 'fragmentation' impediments seem so common, but the notion of inappropriate analogical transfers is clearly linked to one class of substantial learning impediments where learners make the 'wrong' connections. Whether this area of research is able to provide genuine insights into our own research programme, rather than just re-describing what we all know from within another 'disciplinary matrix' I'm not yet sure – but I for one certainly wish to explore this literature further.

Conclusions

My disingenuous title perhaps promised some sort of conclusion about whether we expect too much from learners in terms of conceptual integration, yet you will now be all clearly aware that I am in no position to offer any kind of definitive answer on this issue! However, after your patience and courtesy, I should finish with some form of concluding comments. So, I would like to offer the following points, that I would like you to take away and consider:

- conceptual integration is, generally, a good thing in life, and is usually highly valued in science;
- conceptual integration, and commitment to it, should be seen as important aims when planning any kind of science education;
- what evidence there is, is ambiguous about the level of conceptual integration in learners' scientific knowledge structures – although there is relative little research

that seems to be focused on this particular feature (i.e., beyond looking at coherence and consistency within a single topic or application of a single concept);
- there are theoretical reasons to expect that learners may be predisposed to compartmentalise their knowledge in ways that may be unhelpful;
- some substantial research into this topic is indicated, and could be very useful in informing aspects of curriculum design, lesson planning and teaching;
- I hope that the work now being undertaken in the ECLIPSE project may contribute to developing our understanding of
    - conceptual integration,
    - the development of conceptual integration and
    - teaching for conceptual integration in science.

Thank you for your interest.

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Appendix 1:

We just had a lesson today actually, we started something new…it's called like an electron beam tube or something…
how do you get an electron beam, do you know?:
erm, there's something like there's a filament, and – erm – as the electrons on the filament get more energy some of them have enough energy to break away, and er, it passes through a grid thing, which erm, - yeah it passes through and then it comes to a positive anode, or something, and that makes them accelerate and pass through, and they get to, is it Y-plates first?, which can move a beam up and down?, depending on which one's positive and which one's negative. And then the X-plates can move it from side to side or something.…
So where are the electrons before they are in this beam – where do they come from?:
- erm, well Miss said from the filament…
So what is a filament?:
erm, {moan} don't know how to explain it, it's like, well dunno if it's the same thing, but in like a light bulb you get a filament, and – erm, it's kind of - I dunno how to explain it. E:r – Miss, Miss gave us the example of like in normal physics when we did about the resistance of a wire and it like glowing red when it was, when it got hot enough, and apparently that's the same thing that happens. … Miss drew it like a little kind of coil of wire, {laughs} but, hm. …
So in an ordinary filament in a light bulb, are there electrons?
e:r I dunno, I never thought about it, erm, yeah I suppose so.
Why do we have a filament in an ordinary light bulb?
because that's – what kind of – makes it light, doesn't it?
okay, good – so why does it do that?:
because when it kind of gets hot enough, it gives out light and heat, yeah.
And what makes it hot enough?:
the current passing through the wire.
Okay, and what is current?
oh, it's erm – current is the flow of electrons round a circuit, > * >
< *Okay.* < *So do you think there are electrons in this filament?:*
I suppose there must be then.
…yeah, so what kind of material might you use to make a wire?
metal
…So if you could see this piece of metal wire at such magnifications you could actually see electrons in it, what might it be like?
erm, - well, apparently {laughs} in physics Mr, * was telling us that metals have electrons which can travel through the metal, but I don't know if that would apply to that.
…and they're free because – in what way are they free…?:
they can move freely through the metal.
So isn't that true of all electrons, then?
erm – apparently not.
…So where do you normally find electrons?:
erm, around – like in an atom.
… And don't the electrons go off free?:
N:o
why not?
because – there's, I dunno, if there's a kind of force of some kind holding it together, or something.

Okay, so if this is my atom, with my electrons in it, what kind of force might stop the electrons moving off?
erm, I dunno, cause like in atoms there's like shells, as you go out, but I dunno what would hold them in.
So you think there might be some kind of force?:
erm – probably.
…What kind of forces do you know about – what kind of forces do we have available?:
erm, gravity, erm – friction erm – Oh, I'll go home tonight and I'll think of loads, but – erm, dunno
…*Okay, do you think it's possible that the reason that electrons stay in the atom, is because there's a gravitational force holding them in place?*
there could be, 'cause like, you know, the sun, and then kind of like, the planets are kind of – held in orbit by gravitational force thing. I dunno if that would be the same sort of thing, but….well I don't see what else it would be but, erm.
What about friction, then. Do you think friction might hold the electrons in the atom?
no
…
Are there any other forces?
erm, there are, but – erm – there are lots, but I just can't think. {laughs} er – I dunno, there are more but I just don't know what.
…*You told me that Mr * told you there's free electrons in a metal?*
yeah
and you told me earlier that erm, you told me that a metal, you told me that a circuit conducts because, or currents a flow of electrons or something?
yeah
is that the same electrons we're talking about or is that something different?
er – I dunno, sounds so never thought of it together erm – erm – well like, in a circuit, erm, like the power comes from the power supply and so the electrons would kind of come from that [sic] but – I don't know actually.
… then there's a positive anode, and so that makes the electrons speed up, and so they kind of accelerate, and then –
So why does a positive electrode make the electrons speed up and accelerate?
because the electrons are negative, because in class we thought that they'd stick to the anode because they're kind of positive and negative attract, but apparently they just pass through.
…*Okay and then there was an X plate and a Y plate?*
yeah
what did they do?
erm, they kind of changed what direction the beam's going in
and how do they do that?
hm, one, well, if you had the Y plates, like one would be positive and one would be negative, …
so if this is my beam of electrons, let's say there's a positive plate up there, how does that effect my beam of electrons?
so it kind of moves up towards the positive.
…
so why does it get deflected that way?
because – the plate is positive, but the electrons are negative, and so kind of, like, I dunno is it kind of attracted[?],

… I want to go back to this atom, because I want to be convinced why these electrons hang around in the atom, because you said you thought it might be gravity, but you didn't seem to be totally convinced, you didn't think it was friction, but you couldn't suggest any other force that might keep them there. So we're going to either have to settle on gravity, or think of a better answer.
well if it was me, I'd have said gravity, but I'm sure there is a better answer. I just don't know what.
…
You don't know any other force that might effect electrons?
- erm – magnetism, no, … I don't know if that would affect <u>that</u> though…I just never thought of it that way, er –
… Have you got [?] any other forces which might influence electrons?:
… I can't think right now though.
…No, okay. I'm going to ask you one more thing to remind me, why did you say the electrons got attracted towards the anode, and bent towards the plates?
because they were negative, and the anode was positive, and so kind of, opposites attract.
…
Do you think there's any forces involved there?
- erm, yeah.
…Final question, you said this negative electron's attracted because there were these positive charges, and then it was deflected by these plates because there were positive charges, is that right?
Mm.
Is it possible there could be any positive charges holding the electron in the atom?
- in the nucleus, isn't there, the – well the nucleus is like the protons and neutrons, but – I don't know if they're positively charged. er – the protons are – aren't they positively charged?
…

Appendix 2:

Could you tell me why you think apples fall to the ground?…
Due to gravity. …
Why do you think that apples do not always fall from trees?…
Opposing forces, holding them up in the tree…Tension between the apple and its given tree, or twig, whatever.
Why does a suspended spring stretch when a mass is attached to it?
The downward force, the weight, overcomes the tension of the spring.
Why does the spring recoil when the mass is removed?
Stored energy is involved in that as far as I know…And the nature of the material itself, and the structure allows energy to be released in the form of movement, forming the spring back to its original shape.
Why does the lamp in a torch glow when the torch is switched on?
It's being provided with the energy from battery or whatever, electrical source, voltage passed through the filament, and that allows it to emit light. -
So why do you think current passes through a conductor…?
Current is movement of electrons and things, is favoured or allowed, by the e.m.f.…There are electrons in there, but they're available, they're delocalised, in the metal structure so they're allowed to sort of have a general flow…[if] there was something providing a if you like a gradient, or a difference to encourage that flow, current…It's been described as before as almost like potential energy…
Why do you think the planets orbit the sun?
…gravity again? There's forces between large bodies as in – the sun and planets, I suppose like centripetal force, and…it links in with, objects circling or objects orbiting, keeping something in an orbit. But also the forces opposing that, which I think is centrifugal. Yeah, which would send it out of orbit…to keep it in balance so that it carries on just going round, rather than veering off in either direction, away or towards the sun.…[balanced forces] allows an object to remain either stationary, or at its, doing what it's doing in the same direction at the same speed. Rather than, changing, you know accelerating or decelerating, or veering off either way.…
Have you seen the party trick where a balloon is rubbed on a jumper/sweater, and then stuck to a wall?…Why does the balloon stay attached to the wall?
There's some sort of, I don't know, interaction if you like with the electrons and things, and you have a positive and negative charge, which allows, a glue effect if you like, attraction between two areas, one of positive and one of negative…
And why does it stay stuck to the wall?
Because you've got opposite charges, you've got the say negatively charged balloon, and then you're positively charged wall…hasn't had anything done to it as such, but maybe in comparison to your very negatively charged balloon, it's still likely to attract.
What happens to a parachutist when she jumps from a plane?
Erm, starts descending due to gravity… and then, she'll be affected by things like uplift, well, air resistance… and if she's high up enough, should reach sort of terminal velocity…[because] her downward force is equalled by the like the upward force of air resistance, working against her, so you get a balance.…she carries on at the velocity she's at, so she's not going to accelerate any further.…
Have you seen the demonstration where someone holds the dome of a Van der Graaf generator, and their hair stands on end?…Why do you think their hair stands on end, why do you think it does that?

Isn’t it static electricity or something… sort of like for like, …they’re forcing the, I don’t know, the hairs apart and away from each other…Do they get the same charge, or something like that, is it a like for like?…
Why do you think magnesium burns in air?
It’s easily oxidised in air, given the heat required…
Why do you think chemical reactions occur?
Erm, there’s interactions between the electrons, of different atoms, or molecules, or ions…So you’ve got either electron transfer, or enabling electrons to be shared…
Why do you think hydrogen reacts with fluorine to give hydrogen fluoride?
Hydrogen which is a positive ion, and then fluorine which is highly negative, so the two are going to attract, and then bond together and form your hydrogen fluoride…in the context of a reaction you can consider [hydrogen] a positive ion…the reaction will take place so you’ve got your hydrogen atoms separating off and your fluorine atoms making their own way, and then combining…they’ve been given that extra bit of energy, if you like activation energy or something to carry out that…when you’ve given them the energy to break the bonds, within these diatomic.…you’re left with two hydrogen atoms…they’ve got one electron in the outer shell…they are ions, you just consider them atoms automatically…I would say they’re ions [because] they’re lacking an electron. They should have two electrons to fill the first shell.…
Why do you think sodium reacts with chlorine to give sodium chloride?
Got images of Na-plus and Cl-minus…It’s an ionic compound, isn’t it…You’ve got the chlorine which is negatively charged, as such, and then sodium which is positively charged, attracted to each other…Sodium[’s] like, metal, it’s a natural positive charge.
Why do you think crystals of sodium chloride don’t fall apart?
They’ve got strong enough intermolecular forces holding things together…Forces between molecules, [the molecules comprise of] atoms, which is, your sodium atom and your chlorine atom.
What holds an individual molecule together, stops that falling apart?
Is it intra-molecular forces…the forces within a molecule - holding the molecule, or its components together itself…you’ve got your electron transfer or your covalent bonding between atoms…[in this case] electron transfer. It’s your ionic…rather than electron being shared between the two component atoms, you’ve got, one being transferred to the other, to complete its outer shell…then you’ve left one atom, lacking an electron, so it’s going to be attracted to the other which has got its electron if you like.
Right, and why does the electron get transferred?
Erm, because you’ve got a stronger pulling force or attraction in one atom…there’s different things that contribute to that…because there’s the sort of make up of it nucleus, as in what kind of charge it has, the number of neutrons and protons and things in there, and also the number of electrons in its outer shell, and the number of shells between nucleus and the outer shell. So you might have shielding and things…
What holds the different ‘molecules’ of N-a-C-l together?
There should be, well there’s van der Waals’ forces…you’ve got if you like an electron cloud between, surrounding each molecule…And as these clouds don’t stay in one fixed place, there’s always going to be momentary areas of dipole. And that’s where you get your positive and negatives attracting each other again…
What holds, what do you think holds a single chlorine molecule together?
… The intra-molecular forces…it’s ‘cause it’s a simple molecule, so that’s your thinking with like covalent bonding…where you’ve got electrons being shared…Well to complete the outer shell of both the chlorine molecules they need to share, they need an electron.

Both of them need, each needs an electron, so by sharing they both have an electron so they're happy…
Why do you think iron crystals don't fall apart?
… it's the sort of nature of the structure of the metal. So you've got an ionic lattice, such with delocalised electrons acting like a bit of a glue between the positively charged nuclei of the atoms happening there…
Why do you think that ice crystals don't fall apart?
… ice crystals, it's another thing of intermolecular forces…water's polar, isn't it, it's a bent molecule, it's polar…You've got your hydrogen, and the negative oxygen [as] it's got more electrons.… in ice you've got if you like a lattice, or repeating structure, where dipoles have lined up, positives to negatives and so forth. And that, holds them together, the structure.
Why do you think ice melts when it is heated?
heat's giving more energy, giving the molecules more energy, and in that allows them to escape the forces holding them together in the ice, more easily…
Why do you think sodium chloride dissolves in water?
water molecules are dipolar, so they are going to attract and pull away parts of the sodium chloride and then you've got different random motion and things, allowing the sodium chloride ions and things from that just to be taken away into the water… they'll be sort of become dis-associated?
What do you think holds atoms together?…what do you think holds a sodium atom together?…
you've got central nucleus, then electrons in orbit, or orbitals. And you have got positively charged protons in that nucleus, so you've got another thing of positive and negative attraction and things going on.
Do you think that a single sodium atom could fall apart? Do you think the outer electron might fall off?
It could do if the outer electron was attracted away from, you need to intervene on most atoms…
Do you think it is possible for a scientist to remove an electron from the sodium atom?
Yes.…Is it using, is it an electron gun and everything in the whole, looking at ionisation energies and everything, mass spectrometer.…
Do you think it is possible to remove a second electron, i.e to remove an electron from the sodium ion?
Yes, but that would require more energy…[because] you've removed an electron, and … there's different things, there's the effective nuclear charge, which is going to be effecting the remaining electrons…You've got the same number of protons, or positive charge from your nucleus as you have before, but then you've got a different number of electrons that it can effect. And it's fewer, so, it should balance out that each of these electron have got more charge effecting them…
Do you think that the nucleus of the sodium atom could fall could apart?
Not spontaneously.
What do you think holds the protons together in the atomic nucleus, atomic nuclei?
That's' a good question…
Why do you think some atomic nuclei are unstable?
Whatever is holding them together in other atoms successfully, may be unbalanced, or, not so effective in that case.