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An explanatory gestalt of essence: students' conceptions of the 'natural' in physical phenomena

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Abstract.

Comments like "it's natural", "it's normal", "it's obvious" or "it's common sense" are everyday occurrences in the responses students make in their descriptions of physical phenomena in school science. This paper explores some of the meanings students attach to these terms and the ways in which they are used, within both orthodox science and 'children's science'. The common use of "it's natural" leads to a discussion of experiential and explanatory gestalts of meaning, and their relationships with 'alternative conceptions' and 'alternative frameworks'. In essence it is a study of the 'taken-for-grantedness' that lies within both scientific explanation and students' 'alternative conceptions' in school science. The final section explores some examples taken from the contemporary research literature and from interview discussions with students conducted by the authors.

Introduction

In an Assessment of Performance Unit survey of 15-year-olds in the U K (quoted in Brook *et al.* 1984:101), the following question was posed:

> On a frosty day, Sally noticed the metal part of the handle bars of a bicycle felt colder than the white plastic grips. What is the reason for this?

One student's answer begins with the domain of 'school science'.

> Because metal is a conducter and plastic is a sort of insulater [original spelling]

but instead of any causal explanation (i.e., what is a conductor beyond something that feels cold on a frosty day?), this student adds the common sense observation,

> Metal feels cold anyway.

Of course it is important not to over-interpret a single datum, but this young person seems to understand this phenomenon as simply being natural and, there- fore, not in need of further explanation. Bliss and Ogborn (1994) argue that learners come to science having tacit knowledge of patterns that recur in their environment, patterns that have repeatedly been verified in their experience and form the basis of apparently successful explanations about their world. Such tacit knowledge provides a taken-for-granted, natural, explanation of events in the world. This paper explores the expression 'it's natural'. The reasons for doing so lie in the domain of research pertaining to constructivist theories of conceptual development, and to the process of learning science in schools. Of interest is the quality of learners' 'alternative conceptual frameworks' and the ways in which learners substantiate their conceptualisations of phenomena in science. In particular the focus is on the generally implicit baselines against which they work, what Lakoff and Johnston (1980) have called 'experiential gestalts'. This paper examines the notion of 'explanatory gestalts of essence' to complement somewhat Anderson's (1986) 'experiential gestalts of causation'.

“It's natural” is a term used in many contexts so that, in some cases, it has a quality of being 'obviously-the-case' (the natural state of affairs), and of the 'essence of things' (a natural tendency). So, for example, a student might respond to the question “Why do objects fall to the ground?” less with a description of gravitational forces than with the phrase “Well, it's natural”—and then consider the matter closed. The term can also indicate worldliness (so that natural is opposed to the super-natural) and, of course, be a reference to nature itself, where it is often contrasted with things artificial or manufactured.

The examination of 'it's natural' takes place in two domains: that of orthodox science and that of children's science. The first is a brief exploration of nature in science. The latter draws upon data from a range of research reports in the field, along with data gathered by the authors through extended interviews with learners in the years of secondary schooling and further education (ages

11 to 19). Of primary interest is how these two domains relate to each other and the clash that can occur when students are asked to move from one to the other. The overall structure of the paper is as follows:

1. An initial discussion of the terms 'conceptions', 'frameworks' and 'gestalts', leading to
2. a distinction between 'experiential gestalts' and 'explanatory gestalts'.
3. Then follows a brief history of 'natural states' in science.
4. A consideration of commonsense perspectives is followed by
5. a discussion of how 'natural explanations' are generally used in explaining and undertanding phenomena.
6. Then, an examination of some examples from recent research in school science, and
7. a summary discussion of some implications for science education.

Conceptions, frameworks and gestalts

Constructivism and children's alternative frameworks have come under increasing criticism of late (for example, by Solomon, 1994). This paper aims to contribute to a continuation of the work in progress and leave critical rebuttals and counterpoints to papers elsewhere (for example Watts, in press).

There are now catalogues of 'children's science' documented, for example, by Gilbert and Watts (1983), Driver et al. (1985), Carmichael et al. (1990) and Pfundt and Duit (1994). The term itself has many nuances, the expression being used sometimes to highlight the differences between learners' and 'scientists' science' (to distinguish between 'lay theories' and formal, scientific theories) and, at other times, to suggest some parity of status with orthodox, text-book science (in that they are simply 'alternative to' orthodox science). In general terms, children's science can be pictured as an amalgam of largely tacit explanatory ideas, often quite situation specific and highly context-dependent. These ideas 'work' because they satisfy an immediacy of description, explanation and logic; they are usually confirmed by everyday experience and social convention, and posses a greater degree of intuitive commonsense than the seemingly high-blown, abstract and wholly unnatural explanations of science. Wolpert (1992: 9) makes the point that it is science itself that is unnatural, and that it is entirely different from everyday commonsense thinking:

The way in which nature has been put together and the laws that govern its behaviour bear no apparent relation to everyday life. The laws of nature just cannot be inferred from normal day-to-day experience. Even that the earth goes round the sun is accepted more by authority than by genuine understanding—to provide the evidence is no trivial matter. As Bertrand Russell pointed out, we all start from a 'naive realism', believing that things are what they seem. Thus we think that grass is green, that stones are hard and that snow is cold. But physics teaches us that the greenness of grass, the hardness of stones and the coldness of snow are not the greenness, hardness and coldness in our own experience, but something very different.

The 'naive realism' of school science is commonly couched in terms of alternative conceptions and conceptual development. An 'alternative conception' is a specific elicited belief that is contrary to accepted scientific views, and which appears to be relatively discrete within the learner's cognitive structure. An example might be the view sometimes expressed by children that condensation is produced by the mixing of 'heat' and 'cold'.

> 'When something is hot and it touches some thing cold it forms a Reaction and forms Water.'

or

> 'Heat and the cold make condensation.'
>
> (Second year secondary ['Year 8'] pupils. Taber, 1987.)

An example of a common 'alternative framework' is the naive mechanics based around the idea of impetus: where it has been found that children and adults may demonstrate a range of coherent—but technically incorrect—ideas relating to the presence or otherwise of forces, their magnitudes and their directions, acting on stationary and moving objects. Research grounded in constructivism does not suggest that this is a single framework that is identical in all learners, but rather that there are enough common features between learners for it to be useful to reify 'the impetus alternative framework' when discussing these ideas and their consequences for learning.

Nor does any one individual only have access to one complete and consistent framework in any particular area: for example, a physics student may hold in his or her conceptual structure aspects of a developing Newtonian framework of mechanics alongside her 'intuitive' impetus views. If she proceeds with her study of the subject she will be expected to also acquire a new relativistic framework which is (in parts) incommensurate with the Newtonian version. If successful she will know when and how to apply each. Another example of plural frameworks would be the alternative 'molecular' framework that has been proposed to explain student comments about ionic bonding, and which it is suggested has three related components (the 'valency' 'history' and 'just forces' conjectures, Taber, 1994). Again students may show evidence of having aspects of both the molecular and 'official' electrostatic frameworks available.

The suggestion here is that research should consider a third, more fundamental level category of 'alternative' thinking. Whereas an alternative conception relates to a particular phenomena, and the alternative framework concerns a web of ideas within a particular scientific topic, there is a case to be made that learners acquire broad and general patterns of thinking about the word (gestalts) which they come to use in explaining wide-ranging phenomena that they experience. As with alternative conceptions and frameworks, these gestalts may often have common features from one person to another: it is what is taken to be 'obvious', 'common sense', to be generally accepted or understood.

Experiential and explanatory gestalts

Lakoff and Johnson (1980: 91) introduced the idea of 'experiential gestalts', where a given gestalt is composed of several elements which together comprise a whole which is greater than the simple sum of its parts. They describe an 'experiential gestalt of causation' and maintain that the notion of causation is constructed at a very early age when, for instance, an infant pushes and pulls things, throws the feeding bottle off the high chair, or shakes a rattle. Many notions, such as agent, object, cause and effect are common to a wide variety of actions and come to constitute an overall causal gestalt. They say:

> [These properties] characterise a prototype of causation in the following sense. They recur together over and over inaction after action as we go through our daily lives. We experience them as a gestalt; that is, the complex of properties occurring together is more basic to our experience than their separate occurrences.

In Anderson's (1986) work he considers causation in the context of school science and discusses examples from mechanics, electricity, light and thermodynamics. This is very much of the same perspective as Bliss and Ogborn (1994), noted earlier. The crux of the matter lies in differences between what orthodox science sees to be a proper cause—and what young scientists see to be responsible for particular effects. Herein lie the problems for science teaching. The suggestion here is that learners have what might be called an 'explanatory gestalt of essence'. As might be expected, there are considerable differences between what scientists take to be unexplainable (or simple given) and what students take for granted as obviously 'natural'. The term 'explanatory' has been chosen to suggest that, for some phenomena, there can be no direct sensory experience—and yet the ideas involved can still be taken as basic and taken for granted. 'Nature' is a term used as part of a conceptual framework to explain a range of physical (and social) phenomena, but as itself cannot be experienced directly.

It is important for those in science education to take heed of such gestalts, else they risk trying to teach abstract explanatory frameworks for phenomena for which learners already have explanations in the more concrete terms of its 'essence'.

Natural states in science

Science is synonymous with the study of nature: it is 'natural' philosophy, 'natural' science, the search for the laws of nature, a search that itself reveals ontological assumptions, presumably based on the sense of regularity and pattern that humans perceive in the world. The derivation of the Greek word *physis* is 'growth' or 'nature', though when Aristotle first used the expression physics the subject of discussion might today best be described within biology or philosophy.

There have always been a number of interwoven meanings for the terms 'nature' and 'natural'. At one level nature relates to the properties, inherent characteristics and intrinsic qualities of animate and inanimate objects. The notion of essence is a very old one that has permeated philosophical debates since Aristotle, partly because it helps to capture the common intuition that many naturally occurring phenomena exhibit a kind of duality between underlying structures and surface features. This allows talk of things being apparently different while remaining essentially the same (like all triangles, for instance).

Nature also refers to those creative and regulatory systems which cause the occurrence of particular phenomena termed 'acts of nature'. Nature like this causes seasonal changes, weather, organic growth and all the developments that occur within this. 'Natural disasters' in the wake of volcanic eruptions, typhoons and earthquakes are commonly juxtaposed with humanly contrived ones resulting from, for example, wars, social conditions or pollution.

While Marchant (1980) points out that ancient cultures have traditionally portrayed nature as feminine, personified as a female-being in both western and non-western societies, there are clear differences in quite how to give expression to the term 'nature' in different cultures. The Japanese term 'shizen', for example, carries a broader meaning than that in the West, in that it also encompasses notions of intuition, inevitability, personal consciousness and understanding (Kawasaki, 1990). This clearly carries implications for the study of western science and for science education.

Platonic and Aristotelian metaphysics developed the famous ideas based on the notion of an intelligent natural world that develops according to some deliberate design. Aristotle conceived of the universe having a spherical boundary with the Earth resting at the centre. Around the Earth was a series of concentric shells, the three closest to the centre containing water, air and fire. The purpose behind this structure was to explain, for example, why flames 'naturally' rose while other objects, like stones, always fell to earth. The outer shell of fire was encompassed by a succession of seven solid and crystalline spheres: they carried the Moon, Mercury, Venus, the Sun, Mars, Jupiter and Saturn, and finally the fixed stellar background.

The seventeenth century in Europe saw a gradual change from an organic to a mechanical world picture—the opinion that an entity which generates life must therefore of itself be alive steadily receded in the wake of the manifest success that flowed from the mechanistic paradigm. Darwinian 'natural selection', for example, can be seen in this light. It was a direct theoretical counterpoint at the time to the then well developed technology of selective breeding. Darwin (1968/1859) was aware that his thesis was couched in the language of metaphor—“I use the term Struggle for Existence in a large and metaphorical sense” (p.116)—and saw the narrative value in comparing his novel idea of selection by nature with the more familiar selection by man—“Can the principle of selection, which we have seen is so potent in the hands of man, apply in nature?” (p.130)—and personified Nature to emphasise the analogy.

> Can we wonder, then, that nature's productions should be far 'truer' in character than man's productions; that they should be infinitely better adapted to the most complex conditions of life, and should plainly bear the stamp of far higher workmanship? It may be said that natural selection is daily and hourly scrutinising, throughout the world, every variation, even the slightest; rejecting that which is bad, preserving and adding up all that is good; silently and insensibly working, whenever and wherever opportunity offers (p.133)

While aware of the traps, Darwin certainly expected his audience to see Nature as an active causative agent in the world. Other examples of scientists' expectations of nature abound in the history of science. For example symmetry is an important aspect of science, with some theories of fundamental physics derived in accordance with ontological assumptions about nature being symmetrical. New fundamental particles have been predicted—and then 'found' (discovered/created?)—according to schemes based on symmetry; the difference between the four fundamental forces has been explained in terms of symmetry—breaking at the 'low' temperatures of our cosmological epoch; and the discovery of the lack of conservation of parity in some interactions went against the expectations of some physicists. Assumptions that nature is symmetrical, like Occam's razor, and indeed the expectation that the laws of nature will be the same tomorrow as today are part of the working scientist's explanatory gestalt of essence for the Universe as a whole. Thus it is 'the nature of nature' to be explainable by being regular, by having certain symmetries (or conservation laws—which amounts to the same thing), by tending to be best explained by simple rather than more complex theories (i.e., the smallest number of ad hoc assumptions) and perhaps even by being beautiful. Consider as a brief example, some selected quotations—with our emphasis—from Watson's personal account of the discovery of the structure of DNA,

> From our first conversations we [Watson & Crick] assumed that the DNA molecule contained a very large number of nucleotides linearly linked together in a very regular way. Again our reasoning was partially based upon simplicity. (Watson, 1980:34)
>
> I tried to decide between two- and three-chain models . . . by the time I had cycled back to college and climbed over the back gate, I had decided to build two—chain models. Francis [Crick] would have to agree. Even though he was a physicist, he knew that important biological objects come in pairs . . . Francis, however, drew the line against accepting my assertion that the repeated finding of twoness in biological systems told us to build two-chain molecules . . . Since the experimental evidence known to us could not yet distinguish between two— and three-chain models, he wanted to pay equal attention to both alternatives ... I would of course start playing with two-chain models. (99-101)
>
> The objections could be raised that, although our idea was aesthetically elegant, the shape of the sugar-phosphate backbone might not permit its existence. Happily, now we knew that this was not true, and so we had lunch, telling each other that a structure this pretty just had to exist. (120)

It is this backdrop that forms the ground within science as to what is natural and what is not: scientists have the responsibility for making discriminations, for example, about what falls within science and what does not, what is pseudo-science or supernatural—the demarcation problem of such interest to so many philosophers of science.

'Naturally so' and commonsense

People commonly inhabit a world of everyday reality, a taken-for-granted world. Schutz (1966) has asserted that to live a normal life in society then reality must be taken for granted as such, to allow people to live without too many traumas, shocks or troublesome questions. The constructivist view is that individuals develop commonsense knowledge and theories through their experiences in the world— both the social and physical environments they inhabit. Their 'common' knowledge and 'lay theories' accumulate through life and are confirmed and validated through constant interaction with bodies both animate and inanimate. As Wolpert (1992) comments:

> Common sense is not a simple thing: it reflects an enormous amount of information that one has gained about the world and provides a large number of practical rules— many of them quite logical—for dealing with day-to-day life. It is so much part of everyday life that one seldom thinks about it. (16)

Phenomenological terms for common sense are the 'natural attitude' or 'the life-world perspective'. As Giorgi (1990) says, the natural attitude refers to the normal pre-reflective attitude within which we do our daily living. It would also include the host of 'taken for granted' assumptions underlying most of our activities. What is seen to be common sense can (after Fletcher, 1984) be said to be:

1. a set of fundamental assumptions about the nature of the social and physical world. They are never questioned, justified or even articulated. One such example might be that we are the same person from day to day.

2. a set of shared cultural maxims. These are often in the form of proverbs, allegories or fables and are quite common across and within cultures. An example might be that 'severe punishment deters criminals'.

3. a set of ways of thinking about the social and physical world, involving explaining, interpreting and understanding the behaviour of self and others.

This set of assumptions has certain characteristics (Furnham, 1990). They are rarely explicit, rarely consistent, are generally confirmed (rather than falsified) by experience (and where not, they are the source of surprise), are inductivist, often confuse cause and effect, are content orientated, are mostly general and are quite weak. Some notable philosophers (for example, Polanyi, 1959; Merleau-Ponty, 1962) have taken this line of thought, making a distinction between tacit and explicit knowledge and suggesting that explicit knowledge rests on a framework of tacit knowledge.

The work reported here takes the view that "it's natural" signals a response by students to awkward questions—posed by self or others in science lessons. There are two broad possibilities:

- the learner needs to invoke an answer to a problem which is familiar but where novelty or conceptual obscurity prevents an easy explanation, and the basis for the phenomenon is difficult to divine or explain;
- there is an absence of any perceived novelty.

The question is awkward because the students are being asked to solve (what for them is) a non-problem. That is, the uses of "it's natural" embrace both situations which are seen to be evidently the case ("it's natural", or "it's obvious"), and those for which they have no empirical sense data or evidence, and which relate to scientific theorising and modelling rather than the nitty-gritty of the here and now. In the second case, learned models which have a satisfying completeness about them soon become the norm and this then commutes to being 'natural'.

Explanation and understanding

To answer some of the issues raised is to consider the explanatory value of scientific language. Elster (1983) distinguishes between three kinds of explanation: causal, functional and intentional. He maintains that causal explanation is the unique mode of explanation of physics and physics is the standard instance and model of a science using causal explanation. Functional explanation involves notions of anticipation, benefit, adaptation, selection and evolution and in this case biology is the paradigm for functional explanation. Intentional explanation is hardly advocated by scientists in the 'natural sciences' at all. While there have been some teleological explanations within biology, intentional explanation is much more characteristic of the social sciences.

As Lemke (1990) suggests, scientific explanations tend to be most valued when presented in terms of causality: effects are explained by their causes. Good theories explain a large range of phenomena in terms of a small number of fundamental causes. Often a sufficient 'cause' at one level of explanation is itself a phenomenon that needs to be explained at a more fundamental level. For the active scientist, explanation is likely to be in terms of mechanism and logical reasoning. Few scientists (cosmologists excepted perhaps!) are searching for the ultimate cause, and this is often illustrated with the view that the biologist uses the ideas of the chemist who in turn uses the ideas of physics. If put without qualification, such remarks could encourage a view that, for example, chemistry is 'nothing but' an application of physics—and this would be unfortunate (see for example Scerri's (1993) work on quantum theory in chemistry). However, despite being an extreme simplification there is undoubtedly some truth in such an idea: when Crick, Franklin, Wilkins andWatson 'solved' the DNA structure 'problem', they became widely celebrated, Francis Crick and James Watson especially. Crick and Watson were no less scientists for having to take 'as given' a considerable amount of knowledge about keto-enol tautomerism, X-ray diffraction techniques, hydrogen bonding, etc.,without deriving such ideas from 'first principles'. Perhaps what mainstream scientists (but not necessarily our students) do is think at several levels at once (DNA as a functioning unit carrying a code in heredity; DNA as a macromolecule composed of sub-units of bases and sugars; DNA as comprised of atoms bonded together; DNA as a structure which can be investigated by physical techniques; DNA as a substance found in chromosomes, etc.), and use descriptions at one level to explain a phenomenon at another.

In school science the concern is with developing understanding. Ultimately, students are required to explain phenomena in a logical manner—but understanding is not an all-or-nothing process. The learner constructs meaning, and construction tends to be a piecemeal process that requires good foundations, and may require the use of temporary scaffolding and supports—to be removed later when the structure is complete. Understanding may often begin at a 'descriptive' level and, only when the description is familiar, can causes be considered (or different levels of explanation be developed—in the terms of the paragraph above). Teachers (and scientists) communicate meaning through the use of analogy and metaphor, to compare novel phenomenon with ideas familiar to the audience.

Some examples from research

This section explores the 'nature of naturally' through five concepts within school science. These are force, energy, heat, light, and atomic phenomena. This is clearly not an exhaustive list but will suffice to capture the sense of the discussion. Essentially there are two parts. These relate to what requires explanation, compared to that which can be taken for granted. In this sense, 'natural' is often counterposed within students' statements with those occurrences which seem to be forced, deliberate or intentional. For example, as part of a study on sound, one 12-year-old (Watts, 1994) was discussing the production of echoes. "An echo" she said, "just happens. I mean, it's nature, isn't it. We don't make an echo happen, we don't force it to happen, it just comes back to us naturally".

Force

It is an interesting parallel with historical explanations that many school students (Watts and Gunstone, 1985) and teachers (Kruger, 1990) describe a state of rest as needing no explanation—it is a natural state where no forces are seen to be acting on a body. It is the 'natural' state for an object to be in. Wind, running water, objects falling, are all examples of natural forces, whereas motor cars, machines or a person pushing something along means it is a 'man-made' force. For example, one 14-year-old student was shown a series of pictures depicting situations where forces might be involved (Watts, 1983). One was a picture of a person on a sledge sliding down a hill and the student was asked to describe the forces associated with this. The sledge, she said, was moving

> quite naturally, nothing is forcing it to go down, it just slides down the hill. In this case you aren't forcing something to do something, it's a sort of natural force. Then you've got the other kind of force—when you are forcing something—like trying to cut a tough steak, you are actually forcing that to be cut. If the boy [in the picture] pushes the sledge back up the hill for another ride down, then that would be a man-made force.

Cessation of motion may also be seen as obvious and natural in certain circumstances and not requiring a scientific explanation. As Twigger et al. (1994) note regarding their interview study of 10- to 15-year-olds, when asked about the abrupt deceleration of a parachutist on landing, 'the motion is most often explained as ending simply because the earth got in the way' (224).

To suggest that forces are needed for some objects (tables, floors) to support a massive item is counter to intuition, after all part of the essence of being a table or floor is to provide such support. As Brad (quoted by White and Mitchell, 1994: 34) points out,

> I mean if you stick the books on the table they're not going to push the table under the ground.

Energy

There have been many studies of students' conceptions of energy, currently reviewed by Driver et al. (1994). In some studies (for instance, Watts, 1983) students made a distinction between natural energy (from the sun, wind, clouds and stars) and man-made energy (from batteries, power stations and turbines). 'Good' food has natural energy—it contains natural goodness, it is said, in the vitamins, minerals, glucose, sugar. Oxygen is natural food energy, too, both for animals and for plants. In this vein:

> Plants and flowers have natural energy, but a nuclear power station is man-made.
> The smell from a nice flower is natural energy.

Within this distinction, man-made energy is re-chargeable while natural energy is not—once the goodness is taken out of it, then this cannot be recovered. In this same study, students were asked to describe the energy associated with a melting ice cube. A typical response in this direction is:

> Well, since a 'fridge is man-made energy, and a cold winter's day is natural energy,
> it would depend on how the ice was made, and how it is being made to melt.

Another learner distinguished between energy and force,

> Student: I don't think that's energy . . . I think that's force
>
> Interviewer: What's the difference?
>
> Student: Force . . . is something natural.
>
> (Watts and Gilbert, 1983.)

Heat

Many student descriptions of phenomena are anthropocentric, using themselves as human beings as the main point of reference. So, for example, 'hot' and 'cold' are measured in respect of self and normal body temperature. This temperature, on the whole, does not need explanation, it is just a natural measure. This reference point can also mean room temperature, where this is not noticeable, where it is a normal temperature of human comfort. Comments from two 14-year-olds illustrate this (Watts, 1983):

> There's a sort of natural heat—body temperature—and there's unnatural heat, sort of from the sun, electrical fires and so on.

and

> Ice melting happens naturally. But, pepper and chili powder are artificially hot—not like the sun or a fire.

Light

There are three parts to descriptions of light. First comes the lack of any need to explain the obvious. For example, Osborne and Freyberg (1985) in their study of children's ideas about light found that some 35% gave no explanation for vision. It seems that vision is not a problem for these children and the fact that 'we see with our eyes' is sufficient explanation to deal with the phenomena. For many students, light has a normal, natural standard. This, again, is anthropocentric and is that level of light which we commonly experience (although gradual variations within a wide range are not perceived due to accommodation within the visual system). It might best be represented by a continuum stretching from 'very light' to 'very dark', with normal, natural, everyday 'room daylight' in the middle. This midpoint is the daylight one might get on a slightly overcast day such that while the sun is not visible, neither is there a heavy cloud layer to make a room darker. This kind of light is not associated with the sun or any other light source (probably because nothing is very obvious) but is seen as 'natural daylight'. As one student said (Watts, 1985):

> There are no shadows in natural light, or in darkness. You need strong light for that.

Similar statements showed a distinction between 'natural light' and 'artificial light':

> Light is a natural substance that allows you to see. It's the opposite to darkness.

In this category, a candle light is natural:

> I mean it's a sort of natural source of energy. I mean it's just there, you don't have to make it. I mean, in a light bulb, or a fluorescent tube you have to make the light, but the candle and sun are sort of natural. It's like the way that plastic is artificial and leather is natural.

Atoms and molecules

Research into A-level students' understanding of chemical bonding in the UK has revealed examples of situations that the subject does not feel the need to explain as they are 'natural' (Taber, 1993.) Bonding is a complex topic which can be understood at a variety of degrees of sophistication (Taber, 1995) but even the simplest discussion takes place against the abstract assumption that matter is composed of minute quanta referred to as atoms.

The atomic hypothesis is so much a part of a scientist's training that it is a component of the theoretical core that seems beyond question. This makes it difficult for the trained scientist to reflect on the question 'to what extent does it seem natural for matter to be quantised rather than continuous?' Andersson (1990: 65) discusses how Pfund's students 'conceived of the atom as the final link in a process of division, not as a primary building-block that exists in matter all of the time': i.e., matter is naturally continuous until it is acted upon by being divided. Even when students know about particle theory, they may not consider it to be a natural phenomenon, as in this example from a 14-year-old quoted by Johnston and Driver (1991: 3).

> I think that some things are made up of particles and some aren't—for example I think that sand is made of particles and other powders, but I don't think that things such as paper is made up of particles because it is a naturally grown object.

The atomic scale is so different from that familiar to young learners that transfer of macroscopic features onto the microscopic world has often been noted in student comments. One example is the confusion between the hypothetical particles of atomic theory and the macroscopic particles of crystal grains, soil crumbs and the like. Some learners indeed seem to think it natural to 'abhor the vacuum' between sub-atomic particles. As Johnston and Driver comment, they believe there must be something in the space between particles, often more of the material itself! The atomic theory has been enormously successful in explaining the properties of matter, but is of less value for a learner who does not have any need to explain these properties as they are 'just natural'. Two further examples may be presented from Johnston and Driver's paper,

> It seemed that, for many students, it was taken as read that air was squashy, and that no further explanation was required. (40)

and

> Even when learners accept that atoms can explain phenomena, they may replace the properties of matter as the basic natural (i.e., given) phenomena that do not

themselves need explanation (Taber, 1996). This may explain comments of the type 'an element is a natural matirial [sic] unlike a compound made up of elements' (reported by Briggs and Holding, 1986: 30). If atoms are in the natural state, then how could sub-atomic particles have separate existence? As one A level student suggested to one of the authors (KT), an electron 'can't exist by itself'.

Although students starting an A—level course know about bonding in compounds they may not see a need to invoke the bonding concept for an element such as iron.

> Teacher: Do you think those atoms [of iron, shown in a diagram] will hold together?
>
> Student: Yes
>
> T: Why do you think that is?
>
> S: Because they're all the same sort.
>
> T: Does that make them hold together?
>
> S: Yeah.
>
> T: Do you think there is any kind of bonds between the atoms?
>
> S: No, because they're all the same and they don't need to be bonded.
>
> (In Taber, 1993)

It would seem that atoms of some elements just naturally cohere. In the macroscopic world no two objects are absolutely identical, and some students seem to find the idea of entirely identical particles, such as two electrons, contrary to what seems natural. One A-level student reported (Taber, 1993) the learnt fact that all electrons are the same size, but "it sounds stupid put like that". She could not suggest any way of distinguishing an electron that had been part of a carbon atom from one that had been part of a chlorine atom, but "I reckon there must be [a] way. 'Cause what I've said is, I dunno, it just don't seem right". A similar belief was revealed when another student was asked what would happen to the electrons in a covalent bond when the bond was broken. He thought the two electrons would 'go back to their original shells' and identified which electron (on the diagram) would go to which atom.

The idea that electrons originate in, and therefore belong to, particular atoms contributes to the alternative 'molecular' framework for understanding ionic bonding (Taber, 1994) in which the strength of the interaction between two adjacent ions is considered to depend upon whether electron transfer has taken place between them or not. In this context the learner suggests an asymmetry in the interactions between one ion and its (symmetrically arranged, and identical) neighbouring counter ions.

Does this student, ignoring the symmetry in sodium chloride, suggest that young people do not expect nature to be symmetrical, or were such expectations in this case over-ruled by what had been learned about covalent chemical bonds? (Taber, 1994:102). It is interesting to compare this example with that of another A— level student who, when presented with a diagram meant to represent hydrogen fluoride—with alternate covalent and hydrogen bonds—resisted the suggestion of different interactions between the same types of atoms:

> But that don't make sense, really, because when [the bond] is in the molecules there's hydrogen and fluorine, and when the molecule joins another molecule there's hydrogen and fluorine, and you can't say one has got covalent and one has got another type of bond. Because it just doesn't make sense.

Final thoughts

Scientists apply ontological assumptions about nature each time they choose to draw a smooth curve through a finite set of empirical data points that 'seem' (think of the assumptions behind this word) to lie on a smooth curve, but would fit as well on an infinite number of more complex curves. This paper follows the authors' ontological hunches in attempting to find common patterns in the comments of many students about many topics collected over an extended period of time. Such commonalities have explanatory and ultimately pedagogic value in the complex field of research in student conceptions.

Strike and Posner (1985) have suggested that learners will alter their conceptions under the conditions that the new replacement concepts are seen to be intelligible, plausible and fruitful. It seems unreasonable to try to understand these conditions without appreciating the background of experience and explanation students bring to science. Just what do they take for granted? What do they expect of a scientific explanation? What laws of nature do they feel are plausible? What do they think are laws of nature?

This study arrives at a notion of 'natural' tangentially through interpretations of students' responses, producing a line of inquiry with several off-shoots. Areas of further research work might address a number of issues:

1. 1. The suggestion of 'gestalts' must be developed further. If there appear to be gestalts of causation and gestalts of essence, what other gestalts—tacit webs of background interpretation—are possible and plausible? There are the important questions of 'How are such gestalts engendered?' and 'By what means are such patterns revealed?'

2. While a discussion of such gestalts allows some understanding of the broad backdrop against which students begin their understanding of science, of what they take to be the 'taken for granted' or 'obvious' (Larochelle and Desaultels, 1991) within the science of everyday phenomena, more needs to be known about what they see to be permissible and plausible arguments and explanation. It is necessary to tackle head-on what students see to be the nature of 'nature', thus contributing to discussions on students' views of the nature of science.

3. Although this paper proposes a mapping of conceptions onto frameworks onto gestalts, with some sense of defining features in children's science and some direction to learners' thinking, there is still a need to take up further White's (1994) challenge to substantiate dimensions of cognitive content. Conceptions of nature can open the door to discussions of 'openness to common experience', 'abstraction' and 'complexity' in students' thinking, along the lines that White suggests.

There is, too, a pedagogic agenda which opens up. What is it that can safely be taken for granted when beginning the teaching of a topic? How common is com-mon sense, and what are the 'first principles' which might underlie the teaching of, say, light or heat to 14-year-olds? What can be taken as “naturally the case” in classroom discussions? It is entirely possible that a teacher will use the expression “it's natural” or “it's nature's way of doing things” as an explanatory device, or will intimate that “that's just the way things are” as justification for particular phenomena.

To this extent, classroom research and curriculum development might address a number of issues:

1. The most secure ways to discuss 'nature', its meaning in classroom science and its role as an explanatory mechanism in teaching. Such research might explore some of the basic underlying arguments that support the teaching of science in schools—rather than launching a topic like atomic bonding at students from 'mid-air'—to examine the ontological basis for some of the assumptions made en route.
2. Such research would focus the place of 'nature' and 'naturally so' in the science curriculum. This might draw together and re-invest in work which has explored teleological explanations in the classroom—those arguments that see design and immediate benefit in nature because laws of causality suggest order and purpose.

Needless to say, there is considerably more work to be done.

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