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The secret life of the chemical bond: students' anthropomorphic and animistic references to bonding.

A paper to the

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by

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Abstract. This paper discusses students' use of anthropomorphic language in science, and in particular calls upon some examples from on-going research into student understanding of chemical bonding. We argue that anthropomorphic language is common amongst scientists as well as science learners. A simple classification of such

instances is suggested to distinguish those examples that are useful in aiding communication and understanding, and those which merely stand in place of such understanding.

Introduction.

I: [Does this diagram represent] a stable atom?

J: If it was on its own, I mean even if it wanted to form a more stable compound, it would have no means of doing it, so yes.

I: So is it fair to say that atom wants to, form compounds?

J: Yes, wants to, yes.

I: How much does it want to?

J: If you had another force in contact with it, and that force could have a significant effect on it, then I think this, atom would want to lose an electron and become an ion, but on its own, no, I think it's just happy on its own.

I: You've said that erm, this particular atom, although it's stable in certain situations, wants to form compounds. So could I change that and say this atom likes to form compounds, would that be true?

J: Yes.

I: That this atom desires to form compounds?

J: Yes.

I: This atom enjoys forming compounds?

J: {laughs} Yes.

I: This atom gets its kicks forming compounds.

J: [short pause] Erm, yes.

I: This atom after due reflection and consideration, decides it would be a good idea to form compounds.

J: Mm.

I: You think those are fair statements? How does it know it wants to form compounds, has it been told, has it worked it out for itself?

J: At the moment because it's on its own, I don't think it knows that it wants to form a compound. I think this is sodium, and if there was a chlorine atom quite near it, I think the sodium atom would realise that it could form a more stable configuration by giving one of the electrons to the chlorine and forming a bond, and so it would be at a lower energy level.

Extract from a conversation between one of the authors (KT) and one of his students. Edited for readability (Taber, 1993b.)

In the extract above a young chemistry student, let us call her Jas, uses language which implies that a sodium atom has conscious awareness and human feelings. Does Jas really believe that a system comprising eleven protons, twelve neutrons and eleven electrons is capable of perceptions, desires and decision-making? Jas was a first year Advanced Level (A level) student taking biology, chemistry and maths when the discussion took place. She had previously obtained good grades at 16+ before entering College and, a week after the interview quoted went on to easily pass her end-of-year chemistry test.

Some science educators may consider such beliefs about atoms to be both rare and ridiculous, though previous articles in this Journal (for example Watts & Bentley, 1994) have highlighted the prevalence of animism and anthropomorphism in school science. In that article we explored the extent to which such language is widespread in science texts, and whether it is to be valued, or discouraged. This kind of work builds on a tradition of such explorations which received considerable prominence with Piaget's (for example 1929) study of childhood animism, and was reviewed by Looft and Bartz (1969). At that point they noted that animistic and anthropomorphic notions were present in populations of all age ranges and great cultural differences. Our belief is that this is still the case today and here we look at a particular instance, not in everyday situations, but at the very core of science - the models, meanings and metaphors surrounding chemical bonding. First we need to rehearse the nature of animism and anthropomorphism.

Anthropomorphism and animism in science.

Anthropomorphism is the imbuing of non-humans with human feelings and desires, and animism is a tendency to regard inanimate objects as if they were living things. Anthropomorphic and animistic language may be used in a quite explicit way, as when Millikan refers to an oil drop having an electron “sitting on its back”, or by virtue of using words such as ‘want’ and ‘need’ which we associate with human desires. When Robert Boyle referred to two slabs of marble falling apart in a vacuum “wanting that pressure of air, that had formerly held them together” he presumably did not literally intend to suggest that minerals had preferences, any more than Millikan meant to imply that electrons can literally sit down, or that an oil drop has a backbone (both quotations are taken from Wolpert, 1992; p.96 and p.95 respectively.) These examples are historical, but Wolpert himself refers to cells in the developing embryo which “make the decision to become a humerus” (op. cit., p.137), and in another recent ‘popular science’ book - with the anthropomorphic title of ‘Taming the Atom’ - von Baeyer refers to “the intimate act of molecular mating” (1992, p.121.)

We might guess that many of these kinds of uses are intended metaphorically and that scientists, writers and teachers take liberties with the language of science, knowing that they are ‘breaking the rules’. Lemke (1990) argues that science has a series of stylistic norms that are serious and correct, and must be adhered to in order that discourse might be properly scientific. They are norms such as the avoidance of colloquial forms of language, the consistent use of technical terms, serious and dignified expression (avoiding sensationalism), using causal forms of explanation (avoiding narrative and the dramatic) etc. He also argues that scientific language decries the use of personification:

> Avoid Personification and the use, specifically or usually, of human attributes of qualities (e.g. "fat and skinny"), human agents or actors (as grammatical subjects or objects) and human types of action or process (as verbs, e.g. "like to have") (p.133)

Avoid it, that is, unless the teacher knows what is happening and is conscious of rule-breaking. He gives the following example of the use of Personification relating to electrons and energy levels:

> An electron comes to town, wants to go into the cheapest hotel. It goes into the cheapest one that's available. If the 1s is there, if it's empty, fine. If the 2s is there, empty, fine. 2p? Great. What's the next lowest?

Lemke suggests that this is acceptable anthropomorphism, even though (or rather because) both teacher and student understand that it is contrary to scientific orthodoxy. Lemke goes on to describe a lesson where a student has asked a question about electron pairs. The teacher, trying to regain the attention of the class after a period of individual work, says "When we are discussing bonding, it'll be important to know they are in pairs, because they like to have these opposite spins." A student calls out "They like to?" Lemke says:

> The teacher is being chided for Personification, though these students know perfectly well that *like to* here is a more humanising, slightly humurous metaphor for *tend to*.

Anthropomorphism in learners' explanations of phenomena studied in science.

A reading of two case studies of 13-14 year olds in classes learning about the particulate nature of matter (Wightman, Green & Scott, 1986) reveals a number of examples of anthropomorphic and animistic language. In the first case study class: one particle “jumps away from the rest” (p.32), gas particles “might be reproducing” (p.138), air is “trying to” move because “it wants to go as far as it can” (p.142), “oxygen gas particles” are “moving anywhere they want to go really” (p.149), and “when it’s warm, particles don’t want to be all squashed together you know, all hugged together” (p.152.)

In the second group reported on: atoms “hold hands” (p.277), “gas would be crawling round the room” (p.310), and the teacher asks the class to imagine the atoms “going ooh - ow - as you try to rip these neighbouring atoms apart right down the middle aagh - aagh!” (p.214.)

These examples are from students at Key Stage 3 in the U.K. system. One of us (KT) is undertaking research with post-compulsory students, undertaking advanced level work (A levels) in a Further Education College. The primary enquiry technique used is an extended interview approach (Taber, 1993a.) The work has an action-research flavour in that:

> 1) there exists a dual role for the teacher-researcher in his relationship to the young people, and
>
> 2) that the ‘subjects’ are aware of the research agenda, but have their own interest in attending the interviews.

Intelligent students in this age range have enough metacognitive sophistication to recognise that our interviews, ‘conversations’ or ‘tutorials’ allow them to explore and develop their own ideas quite extensively. To reflect this action-research flavour the students are referred to as co-learners (Taber, 1994.) The co-learners are older than the secondary pupils quoted above, are more familiar with atomic ideas, and are both self-selected for interest in chemistry, and sufficiently well qualified to be enrolled on an A-level course. Anthropomorphism is still present in their language. Indeed some of the following examples seem similar to those quoted above:

• two positive charges always “repel each other” “because they’re the different charges and they just don’t like each other”;

• a sodium atom “is lending chlorine” “one of its electrons”;

• “fluorine’s being greedy trying to grab two electrons”;

• “when you heat it or boil it, the atoms, of argon are free to move around if they want”;

• “they [carbon and nitrogen atoms] want to fill up, like electrons on each one [orbital], to become like, stable” whereas neon has already got “what it needs”;

• “the first shell, it needs two electrons to become stable ... it joins with another hydrogen, and it shares, the other hydrogen’s electron, so it, it thinks that it’s got er, two electrons”;

• delocalised electrons “can help, you know, do things like conduct electricity, and, things like that”;

• “what an atom is trying to do is become stable ... in the case of metals it’s easier for them to become stable by losing electrons”;

• the atom “wants to get a lower enegy level”:

• electrons [shown shaded differently] “belong to different atoms”.

So here we find atomic and sub-atomic species disliking, grabbing, helping, lending, thinking, trying, needing, owning and wanting. There is also reference to atoms ‘sharing’ electrons, although this is a term that is ubiquitous in chemistry texts and teacher talk, and it is hardly surprising it is taken-up by pupils and students. Similarly atoms ‘donate’ and ‘accept’ electrons. This usage has become acceptable. However, let us stay on the fringe of acceptability and explore an example of the notion of ‘belonging’. A number of the co-learners in the research exercise referred to electrons in bonds ‘belonging’ to particular atoms. One such co-learner (L) was asked what he meant:

I: There are 32 electrons [in the diagram being discussed]. Are these electrons all the same?

L: No. Because, I think the electrons that are shaded in belong to chlorine, and the electrons that are shown as a circle belong to the carbon atom.

I: You said belong to. So do they actually own them?

L: Er, originated from. But now they're being shared, between the carbon and the chlorine.

It would appear that this co-learner was aware of his use of the term 'belong', and meant it in a metaphorical sense. However in the following extract the co-learner (P) also uses the term 'belong' to explain why two electrons in a bond are shown differently, and is then confused when asked to clarify her meaning:

P: [The shading in the diagram] is just to signify that the dark ones are the chlorine electrons, and these clear ones are the carbon electrons.

I: So what's the difference between a chlorine electron and a carbon electron?

P: Well they're different because they belong to different atoms.

I: How does an electron belong to an atom?

P: What do you mean?

I: What do you mean by 'belong'? These two electrons seem to be about equal distance from the chlorine centre and the carbon centre, but you're saying that this dark one belongs to the chlorine, and the light one belongs to the carbon. In what way do they belong to them?

P: I think it's because like, certain elements, they have different number of electrons. And chlorine has seven electrons in its outer shell, and carbon has four electrons in its outer shell, and you can tell from those characteristics that it's chlorine [tapping the diagram] and that's carbon.

I: But what's the difference between the electrons? I mean if I was to take one of these electrons out of the molecule, and said "right, this is an electron, it's been taken from a molecule that has carbon and chlorine in it",
how are you going to distinguish?

P: I don't think you can tell.

This co-learner does not seem to understand the point of the question: “So how does an electron belong to an atom?” Perhaps in this case “belong” was used to indicate the electron had a “natural place” rather than in a deliberately anthropomorphic sense (see Watts & Taber, forthcoming.)

Black (1979) describes metaphoric language and considers the classification of metaphors being ‘live’ or ‘dead’. In the case of chemical bonding, perhaps the scientific community is in the process of watching the ‘human bonding’ metaphor in its death-throes, moving from being ‘pregnant’ and vital with meaning, to being rendered un-metaphorical by common usage. Language is fluid, and when we use metaphors on a regular basis they cease to be metaphorical, and become literal, as word meanings themselve change. So atoms **do** share electrons, and language **is** fluid! Perhaps neither of the co-learners quoted using the term “belong” mean it teleologically?

Using animism constructively.

The language of students’ explanations quoted can be taken to imply that electrons, atoms, nuclei, ions and molecules have intentions and are causal agents. Is this necessarily a bad thing? It is certainly not our intention to criticise all such language use. Indeed it has been argued that anthropomorphic and animistic thinking can be very valuable in increasing the appeal of school science, especially amongst girls and young women (Watts & Bentley, 1994). It is well established that, in general, boys and girls already have different science interests on entering secondary education (e.g. Taber, 1991a) and gender-related attitiudes to science are believed to be at least partially concerned with different preferred modes of relating to the world (see Smail’s analysis of ‘characteristics of children and science education’, 1987, p.83). The under-representation of women in science is a serious matter, and anything that can be done to make science curricula better match the interests, cognitive styles, and aspirations of females is to be encouraged (Taber, 1991b), even if it means challenging the 'masculine' nature of science as it is normally practiced (Bentley & Watts, 1987). Watts and Bentley (1994), working from a constructivist persepctive, have discussed the merits of anthropomorphic and animistic language in humanizing and feminizing school science. So should we celebrate Jas' sodium atom that has 'needs', but is quite 'happy' on its own, until it 'realises' its situation?

An example of using animistic explanatory power might help. After the discussion presented at the start of this paper the interviewer turned to protozoans, whose behaviour was familiar to Jas through her own observations (unlike atoms and bonds!), and might act as bridge between human feelings and actions, and her apparently sentient sodium atom:

I: You study biology, don't you? Do you ever, do you ever do experiments with single celled protozoans?

J: Yes, we've looked at them under the microscope.

I: Have you carried out experiments where you put salt on the microscope slide and maybe it moves away from the salty side, or towards it? Or you put acid on there and it moves away from the acid? Or you heat it?

J: Oh yes, taxis.

I: Hve you come across the idea that the protozoan is an irritable creature, in the biological sense, that it responds to its environment and its behaviour shows evidence of that response to stimulus?

J: Yes.

I: Do you think this atom is undergoing similar processes?

J: Yes I do.

I: Now do you think the protozoan has conscious awareness, like you and I do? It actually thinks about things?

J: No, it's just the effect. I mean if you heated it or put acid near it, then effect has to happen first before the protozoan realises 'oh, this is a bad thing', and moves away.

I: But I mean is there that sort of thought process going on, maybe not in words, where it says "I'm getting hurt, this isn't good, I'll swim over there."

J: No, I don't think so, I think it's more like instinct, sort of, I think it's 'built in'. I think when the protozoan evolved, that basic instinct was actually built into it, that it had to keep away from acid. I mean the acid would be a chemical, that the protozoan would naturally repel, sort of thing. I don't think there's a thinking process involved.

I: And the atom, do you think it stops and thinks, "chlorine atom coming this way, get involved there, form a bond"?

J: No I don't think it thinks. I don't think it stops and thinks, I think it just happens.

In the extract given as a prelude to this paper, Jas certainly seemed to be referring to atoms teleologically. However by this point in the discussion Jas seems to have decided that atoms are inanimate: they don't think things through, bonding just happens. One advantage of the extended interview technique used in this research is that the interviewer can return to themes, and allow the co-learner to approach ideas in different ways. Indeed it is fair to suggest that the interviews are learning experiences for the co-learners as they can actually think through the consequences of their ideas. Some minutes later though questioning shows that she has not completely abandoned an anthropomorphic framework for explaining atomic events:

I: Does the atom really want to form a compound? Has it desires in that direction?

J: Yes.

I: Do you think it gets lonely if it can't form a compound?

J: {laughs} No, I don't think it gets lonely.

I: Do you think it gets jealous of other atoms that can form compounds?

J: It depends on how reactive that particular atom is compared with the other atom that has formed a compound.

I: Let's say there were three sodium atoms, just three, and a chlorine molecule came along, and some sodium chloride was formed, and two of the sodium ions were involved, with the two chlorine atoms from the molecule, and they form sodium chloride, and this is the one left over. Do you think it gets jealous?

J: It probably does but it can't do anything about it, because it's as reactive as the sodium that's formed the compound. If it was more reactive then I think if it got close enough it could displace the sodium. I mean if it was a more reactive element it could replace, displace the sodium and form a compound with the chlorine. Because it's as reactive as the [other] sodium, it can't do anything about it.

I: Do you think it feels envy?

J: If you can say that about an atom, yes.

I: Do you think it would hate the other atom?

J: No, I don't think it's got feelings like that. No.

I: What kind of feelings does it have then?

J: No, nothing. None.

At one level Jas will explicitly state that the atom can not experience feelings, yet she talks <u>as if</u> does have feelings in contradiction to this principle. Is this inconsistency a sign of confusion, or a deliberate device to emphasise meaning through 'rule-breaking'? Lemke (1990) describes a systematic calculation of talk in the classroom, and suggests that where the language is in its 'high science' register, the level of the class' engagement with science is about 20-25%, but rises to 80 or 90% when it moves into a rule-breaking, personified style. Lemke says:

> This means that we can be quite confident in saying that students are three to four times more likely to be highly attentive to 'humanised' science talk as they would be to 'normal' science talk in the clasroom.

Do learners tacitly understand this point and use rule-breaking in a similar way? Or does Jas use anthropomorphism because she does not have access to the appropriate ‘high science’ register? Perhaps she knows that the anthropomorphic framework for explanation is not valid, but does not have a suitable alternative explanatory framework to call upon.

Explanation and understanding.

In order to answer some of the questions raised here we must consider the explanatory value of scientific language. As Lemke (1990) suggest, scientific explanation tends 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 idea that the biologist uses the ideas of the chemist who in turn uses the ideas of physics. Despite being an extreme simplification there is undoubtly some truth is this idea: when Crick, Franklin, Wilkins and Watson ‘solved’ the D.N.A. 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 (D.N.A. as a functioning unit carrying a code in heredity, D.N.A. as a macro-molecule composed of sub-units of bases and sugars, D.N.A. as comprised of atoms bonded together, D.N.A. as a structure which can be investigated by physical techniques, D.N.A. as a substance found in chromosomes, etc.), and use description at one level to explain a phenomenon at another.

In school science we are concerned with developing understanding. Ultimately we want our students to be able 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 start 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 the novel phenomenon with ideas familiar to the audience.

Lemke (op. cit.) argues that the products (theories and processes) of science illustrate that it is, in fact, a very human activity involving human actors and judgments, rivalries and antagonisms, mysteries and surprises and so on. The language and stylistic norms of science, however, are so dull, dehumanising and redolent of mystique that they actually impede good communication. He says:

> Because of this, all good science teachers find it necessary to break the rules and violate these stylistic norms, humanising science as they communicate it. (p.134.)

It is in this metaphorical sense that Millikan's electrons sat and von Baeyer's atoms mate. It is in a metaphorical sense that the learner's knowlege has foundations and scaffolding. When Darwin presented natural selection in anthropomorphic language he was not suggesting that nature **is** alive in the same sense as an individual ape: it was an extended metaphor, and he believed that "everyone knows what is meant and is implied by such metaphorical expressions" (quoted in Beer, 1986). Similarly Lovelock's Gaia (1979) is an organism in a metaphorical sense: it is by definition supra-organismic. When Rose refers to bacteria collecting near a source of glucose behaving as if they knew the glucose was there, he believes this analogy will communicate his meaning effectively (1992, p.164.) The philosopher and chemist Michael Polanyi once commented that “our conception of science should not be one which strives at the logically impossible, self-destructive ideal of completely explicit statements” (Kirschenbaum & Henderson, 1990, p.163-4.)

Two classes of anthropomorphism?

Metaphorical anthropomorphism, or perhaps ‘weak’ anthropomorphism, is seen as a virtue. We think that L’s notion of ‘belonging’ in the extract presented earlier, is an example of weak anthropomorphism. If Jas (in the extract above) is well aware that atoms do not ‘want’ ‘realise’ ‘feel’ or experience happiness, but simply uses such terms to communicate her ideas about the sodium atom in analogy with a social being, then this is a healthy stage between ignorance of the atomic world and being able to express her ideas in the more physical (and alas perhaps less poetic) language of energy and forces, and solutions to the Schrödinger equation. But what if Jas thinks a sodium atom literally experiences its world through feelings and emotions much like hers? If this were her belief then it is but a short step to explaining chemistry through the feelings of atomic species: sodium atoms react with chlorine molecules because they want to. Schrödinger himself once asked “do electrons think?” (Moore, 1989, p.448.) For him it was a rhetorical question, the idea was ridiculous and showed (in his view) the inadequacies of the Copenhahen interpretation of quantum mechnics. Perhaps such questions are not rhetorical for some students. This ‘strong’ version of anthropomorphism is teleological, in that it allows phenomena to be explained in terms of the (non-existent) desires of atomic species to achieve the end-state. Perhaps this is related to the use in secondary level chemistry of the ‘full outer shell’ heuristic . The noble gases have relatively stable electronic configurations, and as a rule of thumb when elements react to form compounds they ‘achieve’ or ‘attain’ a nogle gas electronic structure (often decribed as having a full outer shell, although this is not strictly correct except for the helium and neon structures.) Some students interpret the 'full outer shell' as a sufficent explanation for chemical reactions - atoms react to form molecules or ions because they want, or need, to acheive a full outer shell. If the student considers that such teleological anthropomorphism can be a sufficient cause of chemical change, then she has no reason to seek other levels of explanation (say in terms of potential energy and electrical fields.)

In the case of chemical bonding this is certainly likely to be problematic: the student who studies chemistry beyond KS4 (age 14-16 in the UK system) will soon find that the 'full outer shell' heuristic is little help in discussing bond polarity, hydrogen bonding, van der Waals forces and many other important bonding phenomena. For this reason we wonder whether such 'strong' anthropomorphic thinking could actually be an impediment to further learning. Conversely, perhaps strong (teleological) anthropomorphic language is the first stage in developing understanding, allowing the learner to obtain a descriptive level of understanding of atomic-level phenomena through mental role-play and empathy. Maybe as the abstract atomic world becomes familiar through such 'social' modelling the learner is able to move past the descriptive level: perhaps retaining anthropomorphic language to be used metaphorically, or simply as habit.

If strong anthropomorphism is just a stage in developing understanding, then one might expect anthropomorphic language to diminish as other levels of explanation become available. It is possible to imagine transitions as the learner becomes more confident in using mechanistic explantion, and can 'dismantle' anthropomorphic 'supports' to understanding. Consider the following extract where another co-learner (signified N) attempts to explain van der Waals forces in terms of electrostatics:

I: Do you think there's any bonding shown in diagram seventeen?

N: It's covalent bonding between the two iodines, and, van der Waals forces between the molecules.

I: What are van der Waals forces caused by?

N: By induced dipoles.

I: What are induced dipoles?

N: It's when you've got an electron say, in an atom, and it, it could be that at one certain time all the electrons in that atom are towards one side of the atom. So, at that time, the side which all the electrons are on would be slightly negative, and the other side would be slightly positive. And because of this, <u>and because the iodine molecules want to attract, want to be joined together in the lattice</u>, the positive charge would induce a slightly negative charge. The area which is slightly positive would erm, induce a slightly negative charge in another atom, because that positive charge would repel [sic] the electrons in that area, of another atom. So they would move away, and so, a dipole would be induced in another atom, and then the positive and the negative ends of both would join together to give a weak force, which is van der Waals, I think.

Although the account becomes a little confused during her answer as she tries to keep in mind which charges are located where, her otherwise good 'scientific explanation' is marred by the inclusion of the anthropomorphic phrase we have underlined. Ignoring that segment one might deduce that this co-learner has passed beyond explanation through teleological anthropomorphism. Of course it is dangerous to draw conclusions from such limited data. Constructivist theory (in particular Kelly's fragementation corollary, see for example Watts & Pope, 198?) might perhaps warn us that the learner may retain the use of apparently incommensurable explanatory frameworks, and be able to apply different arguments depending on context, cues and so forth. N's inclusion of an anthropomorphic phrase such as this may simply indicate a moment of carelessness. It may, though, be a window into an equally powerful but momentarily eclipsed animalistic explanatory framework. Perhaps a student not yet fully confident in the mechanistic 'belt' of explanation might use teleological 'braces' as well?

A continuum of responses.

This raises the possibility of a spectrum of responses rather than our first simple dichotomous categorisation. If the two categories discussed so far are spread to represent the poles of the continuum, we can speculate on some of the points that might lie between. For example, there must be a point on this continuum which allows for simple carelessness or commnality of expression, of the 'tools live in the garage' variety.

There is a real sense, too, in which students may 'try out' language structures in different ways so that they neither intend rank anthropomorphism nor a complete and complex metaphor. There must be a point which represents this tentative talk, which includes the 'is like', 'so to speak', 'as it were' and the 'as if' - when he or she is not committed to a formulation as a fully figurative expression. That is, the stage at which the elements are portrayed more as a simile than an elaborate metaphor.

Further research work.

In this paper we have juxtaposed samples of dialogue between researcher and science learner with some of our 'thinking aloud' about aspects of the relationship between meaning and language. The empirical data is presented less as research results, and more as illustrative material: illustrating, in our view, an important facet of the way the leaner makes sense of science through the use of language. As long ago as 1934 Vygotsky discussed the role of language in the learning of scientific concepts and proposed a model involving the simultaneous development of spontaneous and scientific (i.e. taught) concepts: the former having origins in personal experience but not initially being capable of formal representation through language, the later being acquired in through instruction in verbal form and initially being purely abstract (1986.) The path of conceptual development, Vygotsky suggested, involved the spontaneous and scientific concepts approaching and merging along a concrete-abstract dimension,

> "In working its slow way upwards, an everyday concept clears a path for the scientific concept and its downward development. It creates a series of structures necessary for the evolution of a concept's more primitive, elementary aspects, which give it body and vitality [sic!]. Scientific concepts, in turn, supply structures for the upward development of the child's spontaneous concepts towards consciousness and deliberate use. Scientific concepts grow downward through spontaneous concepts; spontaneous concepts grow upwards through scientific concepts." (p.194.)
>
> "starting far apart, they move to meet each other" (p.192)

It is our contention that further study of learners' anthropomorphic use of language could be most revealing in following the development of scientific understanding. Our illustrative data is taken from talk about atomic phenomena, and in particular chemical bonding: an area that is understood in terms of a series of mental models of varying abstraction and complexity (Taber, in press.) We consider this to be a fruitful place to start our investigations, as the more abstract the concepts, the further (in Vygotsky's terms) from the concrete spontaneous concepts available to the learner, and the more scope there is for the mediation of language as the abstract is made concrete.

We suggest that further work should be undertaken to investigate children and young people's use of anthropomorphic language to find out the extent to which it is used in a poetic or teleological sense, and in particular to answer the questions:

- how aware are learners of their anthropomorphism, do they realise the implications of their language, and what do they intend such terms to convey?

• do most (all) learners pass through a ‘strong (teleological) anthropomorphic’ stage in understanding atomic phenomena?
• do some learners not pass beyond such a stage, being limited to understanding the atomic world in terms of the intentions and deliberate actions of atoms etc.?
• does weak (metaphorical) anthropomorphic language develop from strong (teleological) anthropomorphism, or is it a separate phenomena?

We believe the ideas duscussed in this paper are important and look to a programme of research established to consider such questions. How would this be done? We would suggest such a programme would have these three features:

1) it would include the collection of examples of learners’ anthropomorphic language - such as those presented above from the CLiSP case studies, and the on-going work we are involved with;
2) it would involve asking the learner what she intends by her words: how deliberate was the choice, and what does she mean to communicate?
3) such studies must be longitudinal, following the development of student use of language over an extended period of time: perhaps as they are first formally introduced to particle ideas, or during their learning of the elementary chemical ideas of molecules, ions and bonds, or during the development of these ideas during an A level course; or if possible over the whole of this progression.

These are the next phases of the research enterprise.

We leave the last word with the scientist John Desmond Bernal (1967) who humourised that:

Life is a partial, continuous, progressive, multiform and conditionally interactive self-realisation of the potentialities of atomic electron states.

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