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Models, Molecules and Misconceptions: A Commentary on “Secondary School Students’ Misconceptions of Covalent Bonding”

Keith S. TABER[1]

[1] Senior Lecturer in Science Education, University of Cambridge, Faculty of Education, United Kingdom

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ABSTRACT

Learners often find studying secondary school chemistry challenging, and commonly develop alternative understandings of the subject, variously labelled by researchers as misconceptions, alternative conceptions, conceptual frameworks, and so forth. An example of enquiry into this area is provided by Ünal, Coştu & Ayas in a recent paper in the Journal of Turkish Science Education. Ünal and colleagues explored student misconceptions relating to the fundamental concept of covalent bonding, and classified student responses in their study according to both the soundness of student comments, and the presence of misconceptions. Research of this kind is complicated by both the nature of the simplifications used to teach chemistry at this level (which complicate decisions about what is taken to constitute ‘sound’ student knowledge), and the difficulty of appreciating the nature of student ‘misconceptions’, which may actually vary considerably in their significance for progression in student learning. This commentary offers a reconsideration of Ünal and colleagues’ results in the light of previous published research into student understanding of chemical bonding, which suggests that Turkish Secondary School students’ thinking about Bonding seems to reflect a previously reported alternative conceptual framework.

Keywords: Student Misconceptions; Understanding Chemical Bonding; Pedagogical Learning Impediments; The Octet Alternative Conceptual Framework; The Bonding Dichotomy Teaching Model.

INTRODUCTION

Ünal, Coştu and Ayas (2010), have recently published a very interesting study in *Journal of Turkish Science Education* on ‘Secondary school students’ misconceptions of

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Correspondence Author email: kst24@cam.ac.uk

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covalent bondingô. This study deserves note, because bonding is a central topic in chemistry, and one that is commonly reported to be challenging for learners (Hofstein, Levy Nahum, Mamlok-Naaman, & Taber, 2010; Özmen, 2004; Taber & Coll, 2002; Ünal, Çalĕk, Ayas, & Coll, 2006). Students have been found to develop alternative conceptions in this topic in a range of national contexts (Coll & Treagust, 2003; Griffiths & Preston, 1992; Nicoll, 2001; Peterson, Treagust, & Garnett, 1986; Taber, 1998), including Turkey (Nakiboĵ lu, Tsaparlis, & Taber, 2009).

In their study, Ünal et al. (2010) report examples of student comments made in response to their research probes, and characterise studentsô responses according to the soundness of subject knowledge demonstrated, as well as whether student comments indicated misconceptions. In this commentary, I set out to reconsider the analysis presented in this recent research report (Ünal et al., 2010), and argue that whilst the data presented are of great interest, the paperôs findings must be seen to be of limited validity because the conceptual and analytical framework adopted in the paper does not pay sufficient attention to (a) the nature of chemical knowledge and its representation in teaching; (b) the substantial differences between different types of ómisconceptionô. My purpose here is not to criticise these authors, who have produced a paper of considerable interest, but rather to offer a critique that might be helpful for researchers, and inform further research of this general type in the Turkish context and elsewhere.

Scientific models and curriculum models

Part of the challenge for students learning about chemical bonding derives from its abstract nature. Chemical bonds are components of the submicroscopic models used by chemists as the main theoretical basis for explanations in the subject. For many chemists, the molecules, ions, electrons and other such óquanticlesô (quanta of matter at such a small scale that they exhibit wave and particle behaviour) of the submicroscopic world as so familiar they seem as real as the beakers, flasks and test-tubes used in the laboratory. For students, the submicroscopic world is not only unfamiliar, but also largely counterintuitive ï matter seems continuous, and is not obviously made of the tiny fuzzy balls of electrical fields presented by modern science. Molecules, ions, atoms and the bonds that hold them together are not real objects that can acts as referents in the observable world, but conjectured theoretical objects that populate chemistsô explanatory schemes. This is not to suggest that these entities are óonly imaginaryô and have no real *basis*; but rather to stress that it is important to recognise that what chemists (including chemistry teachers) refer to when using terms such as ómoleculeô or óbondô are actually models intended to represent aspects of world as uncovered in scientific investigations (Taber, 2010). This becomes clear if one asks what an atom is actually like: atoms have been described by a sequence of different models historically, all of which offer a useful, but ultimately limited, description of atoms (Justi & Gilbert, 2000; Taber, 2003).

Representing scientific ideas in the curriculum

Research to assess school studentsô understanding of scientific concepts is complicated because many scientific ideas and models are too sophisticated to be taught in schools. So the school curriculum includes *representations* of science (Millar, 1989): that is, curriculum models of the scientific ideas (Gilbert, Osborne, & Fensham, 1982). When well designed, such curriculum models catch something of the essence of the scientific ideas, and provide learners with a suitable basis for progression in learning: that is, curriculum models are simplifications suitable for developing more sophisticated understanding (Taber, 2000b).

Although simplification is necessary, the simplifications we teach should be designed to be óintellectually honestô (Bruner, 1960).

In principle, this is something scientists should appreciate, as many of the models used in science are themselves known to be simplifications, but are still of great value within their range of application. Indeed, it has been argued that the models of molecules and atoms and chemical bonds that are widely used within the chemical community for most purposes, are actually a good deal less sophisticated than the currently most precise available models of molecular structure (Sánchez Gómez & Martín, 2003). So thinking of molecules as atoms linked with bonds comprised of pairs of electrons is some way from the most advanced current scientific understanding, but remains a very useful way of thinking about matter at the submicroscopic scale.

Foundations for further learning versus pedagogical learning impediments

Whilst well-designed curriculum models will provide the basis for progression in learning, poorly designed curriculum models have the potential to actually impede further learning by encouraging ways of thinking inconsistent with scientific models (Taber, 2001). Even if the official curriculum models are sound, teachers develop their own personal teaching models, often based on metaphors and analogies designed to link to studentsô familiar experiences, to help communicate these ideas to pupils, and these teaching models may have elements that are unhelpful in the context of the scientific model (Nakiboglu & Taber, 2010). Well chosen analogies may be a useful tool in teaching and learning, but even these are not always understood as intended by students (Ünal et al., 2006).

Learnerôs ómisconceptionsô can derive from a variety of different sources (Taber, 2009), but in chemistry there are good grounds to think that many derive from aspects of the way the subject is taught, acting as pedagogic learning impediments (Taber, 2009). That is, some of the teaching models used to introduce pupils to scientific ideas may actually work against later progression in the subject.

The bonding typology as an example of a learning impediment

This certainly seems to be the case in the teaching of chemical bonding. For example in secondary chemistry teaching, a common teaching model is to consider chemical bonding in compounds as forming a dichotomy, with two main types of bond ï covalent and ionic (as shown in figure 1), and examples of bonds assigned to one category or the other. Covalent bonds are said to form between non-metals; and ionic bonds between a metal and a non-metal. Students tend to readily adopt this dichotomy.

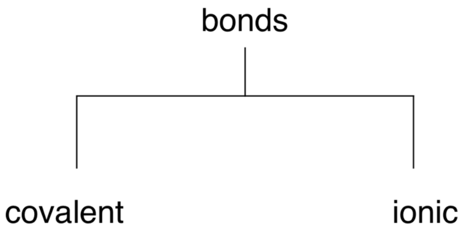

Figure 1. *A teaching model ï the bonding dichotomy*

However, progression in learning requires students to shift from thinking of elements in terms of the categories of metal and non-metal to considering electronegativity; and so from considering bonds in compounds as being either ionic or covalent to instead *having* *different degrees of polarity*, depending upon the pattern of electron density in the bond. Bonding in compounds is then understood as forming a continuum, for which the ionic and covalent cases represent poles (see figure 2). Indeed these may be seen as óideal casesô with no bonds perfectly matching the ionic pole of the continuum. In effect nearly all bonds in compounds are understood as being polar, to a greater or lesser degree.

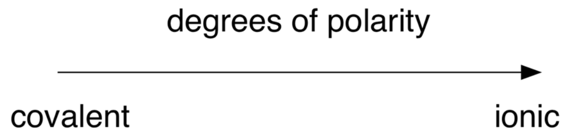

Figure 2. *Bonding in compounds lies on a continuum, not a dichotomy.*

This raises the question of whether a teaching model of there being two types of bond in compounds (figure 1) should be considered a useful simplification. At first sight it seems a sensible way of introducing bond types, which could provide the conceptual basis of progression in learning to a more sophisticated understanding (figure 2).

However research suggests that learning about bonding as a dichotomy can act as a learning impediment, interfering with later learning about bonding as a continuum (Taber, 1998). Students who learnt about bonding as a dichotomy tend to have difficulty shifting to thinking in terms of a continuum. They tend not to appreciate that most bonds are polar, and that there are many graduations of polar bonding between the ionic and covalent extremes, and instead to simply see polar bonds as somewhat distorted covalent bonds (see figure 3).

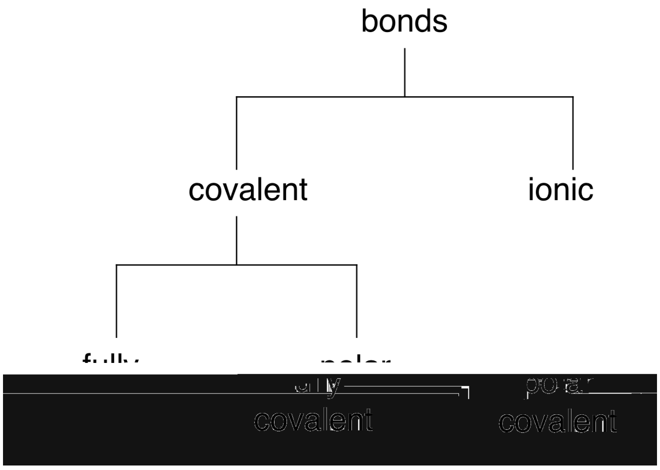

Figure 3. *Common student understanding of polar bonds as a type of covalent bond*

This type of misunderstanding of polar bonding was illustrated by students reported in Ünal et alôs paper (Ünal et al., 2010).

To summarise the argument here, then:

- Scientific models are often simplifications
- Scientific ideas are simplified further in designing target curriculum knowledge
- Teachers find ways to communicate curriculum knowledge using models, analogies, metaphors, that often simplify (or distort) ideas further
- Some simplifications can provide a good basis for building new knowledge, but others may impede understanding and misdirect learning.

The nature of student misconceptions

There is an extensive literature in science education on student misconceptions (Duit, 2009). Moreover, there has been a long and vigorous debate about the nature of learnersô ideas in science, and whether they are best described as alternative conceptions, conceptual frameworks, intuitive theories, mini-theories etc (Claxton, 1993; Driver & Erickson, 1983; Gilbert & Watts, 1983; Solomon, 1993). For example, it has been suggested that ómisconceptionô implies a misunderstanding of canonical knowledge (such as misunderstanding teaching), whereas óalternative conceptionô would also include notions developed spontaneously, for example intuitive notions acquired from direct experience of the world (diSessa, 1993). The term misconception also seems inappropriate for those situations where an individual acquires technically incorrect ideas from another ï for example where teachers themselves have flawed subject knowledge and present incorrect ideas in class (Taber & Tan, 2011). In this situation, the learners do not ómisconceiveô what has been taught, but rather may correctly understand the alternative conceptions presented. The term óalternative conceptionô is also sometimes considered to better fit with the constructivist perspective (Taber, 2009), that considers learning as necessarily an active process of personal knowledge construction within each individual.

For brevity, here I will refer to ómisconceptionsô - a term that has commonly been used to discuss these ideas with teachers, for example in chemistry (Taber, 2002). This debate has considered the nature, and educational significance, of misconceptions, and different positions have been taken about their likely consequences (Gilbert et al., 1982). A recent extensive review of the topic (Taber, 2009) concluded that the evidence suggests that student misconceptions vary along a range of dimensions, with some ï but not all ï being highly influential on the course of likely conceptual change and so progression in learning. This is important for researchers such as Ünal, Coкtu & Ayas, as simply identifying comments students make which are at odds with target knowledge, and labelling them all as ómisconceptionsô ï as in Ünal et al. (2010) ï offers little insight into the implications of research for teaching.

An alternative conceptual framework in chemistry education

Some alternative conceptions elicited in research with learners seem to be especially significant for student learning. A good example is the common way of thinking about force and motion that sees a force as bringing about motion, rather than (as in the scientific understanding) an acceleration, and so a change in motion (Gilbert & Zylbersztajn, 1985). This óimpetusô framework, associating constant motion with a force, is found among the vast majority of learners (Watts & Zylbersztajn, 1981), and is known to be tenacious; resisting correction by teaching (McCloskey, 1983).

In chemistry education, it has been argued that students commonly adopt an equally tenacious alternative conception relating to the behaviour of matter at the submicroscopic level. Students commonly adopt a belief that atoms want to, and act to, fill their shells (or obtain octets of electrons). This simple idea acts as the basis for an extensive (alternative) conceptual framework used to explain why bonds form, why reactions take place, the patterns found in ionisation energies and so forth (Taber, 1998). Students using this principle have considerable success in explaining some aspects of chemistry. They will understand that atoms can obtain full shells by sharing electrons, or by donating them from one atom to another. The availability of these two ómechanismsô for forming bonds, supports the students in understanding that there are two main categories of bond ï covalent and ionic (cf. figure 1). Unfortunately, such ideas are unhelpful when students are asked to learn about polar bonding, electron-deficient compounds, compounds where atoms óexpand their octetô, hydrogen bonding etc. Thinking of bonding in óoctetô terms, acts as an impediment to progression in learning.

In chemistry, there are a range of different types of bonding which are important in understanding structures, and all can be understood to a first approximation in terms of electrical interactions ï whereas thinking of bonding in terms of atoms filling their shells, tend to lead to student excluding anything which cannot be understood in óoctetô terms as bonding. When thinking about covalent bonding, students tend to adopt the ósharingô metaphor, but unfortunately understand this in anthropomorphic terms ï seeing the sharing, not the electrical interaction, as the bond (Taber, 1998). In the ionic case, students tend to see bonding in terms of electron transfer between atoms ï something which is both chemically unrealistic, and leads to misunderstanding the nature of the ionic lattice (Taber, 1994, 1998).

The significance of these ómisconceptionsô can be seen by how pupils will commonly explain chemical reactions as occurring to allow atoms to fill their shells ï although almost inevitably the reactants already comprise of species with stable configurations (Taber, 1998). Despite often having themselves made NaCl by neutralisation of an acid (containing Cl^- ions) and an alkali (containing Na^+ ions), students will claim that the formation of NaCl involves electron transfer. Similarly, students will explain double decomposition reactions in terms of electron transfer, despite the ionic solid being formed by ions already present in the solution (Taber, 2002). In the covalent case, advanced students asked to explain why H_2 reacts with F_2 commonly óexplainô this in terms of the hydrogen and fluorine *atoms* trying to fill their shells (Taber, 2002), even after being taught about the principles of energetics, and bond energies. The octet conceptual framework is not only widespread, but highly influential in student thinking, impeding the progression of learning of the scientific models.

Ünal, Coкtu & Ayasô data on secondary school studentsô misconceptions of covalent bonding

If these ideas are applied to the results reported by Ünal et al. (2010), it becomes clear that these researchers have collected some very interesting data, that are very informative in the Turkish context; but there is a strong case for considering the approach to the *analysis to be sub-optimal*.

Students written responses on covalent and ionic bonding

The first of several questions requiring written responses discussed by Ünal et al. (2010, p. 7) ñinvestigates whether or not students could predict what type of atoms form covalent bonding. It also investigates whether or not students could determine the type of chemical bonding which is formed between the atoms in the given compoundsò. The authors classify student responses here into four categories ï (i) sound understanding; (ii) partial understanding; (iii) partial understanding with specific misconception; (iv) specific misconception ï and report the proportion of responses in each category. Examples of studentsô responses are provided to illustrate the analysis, and this allows the reader to consider how the classification was made. Two examples of responses from each category are reproduced here in Table 1.

Table 1. *Examples of studentsô written responses to a question about covalent bondsï from Ünal et al. (2010).*

Statement	Student response	Classification by Ünal et al.	Note
1	*HCl : It is covalent bond, because it is formed between two nonmetal atoms. They share their electrons.*	*sound understanding*	Uses anthropomorphic ósharingô metaphor
2	*$MgCl_2$: It is ionic bond, because it is formed between a metal and a nonmetal atom. Bonding is formed by means of the attraction between oppositely charged ions.*	*sound understanding*	Explains in electrical terms, but focuses on atoms
3	*$MgCl_2$: Mg: 12, Cl: 17, Mg^{+2} Cl^{-1}. It is ionic bonding. Magnesium and chloride ions bond with each other by means of their opposite electric charges.*	*partial understanding*	Similar to item 2
4	*NH_3 : N: 7, N: $1s^2$ $2s^2$ $2p^3$ Nitrogen share their single electrons with three hydrogen atoms, so that they have full outer shell. Therefore, covalent bonding is formed between nitrogen and hydrogen atoms.ò*	*partial understanding*	Uses anthropomorphic ósharingô metaphor
5	*HCl: It is ionic bonding. While the chlorine atom wants to take an electron to have full outer shell, the hydrogen atom wants to give. So, one electron is transferred from the hydrogen to the chlorine atom.*	*partial understanding with specific misconception*	Wrong label for bond type. Demonstrates electron transfer alternative conception; anthropomorphic language
6	*$MgCl_2$: It is ionic bonding. While magnesium atom is metal, chlorine atom is nonmetal. So, magnesium atom transfers one electron to each chlorine atom.*	*partial understanding with specific misconception*	Demonstrates electron transfer alternative conception
7	*HCl: It is ionic bonding, because both atoms are nonmetal.*	*specific misconception*	Wrong label for bond type
8	*$MgCl_2$: It is covalent bonding, because magnesium is metal, chlorine is nonmetal.*	*specific misconception*	Wrong label for bond type

Consideration of the issues raised earlier in this paper suggests that a simple four-way classification of the data as used by Ünal and colleagues ignores some key points. A significant methodological limitation of this type of data is that of what is not included: studentsô responses reflect what the student brought to mind and thought important to include. For example, consider statements 2 and 3 in Table 1. Both responses identify the type of bond in magnesium chloride as ionic; and both explain that this type of bonding has an electrical basis (ñattraction between oppositely charged ionsò; ñbond with each other by means of their opposite electric chargesò). Presumably statement 3 is considered to only demonstrate ópartial understandingô, rather than the ósound understandingô of statement 2, because the student has not mentioned that this compound is formed between a metal and a non-metal. If Ünal et al. consider this to be an essential part of understanding the nature of covalent bonding, then it makes sense that they judge this answer to only provide evidence of partial understanding. The knowledge may have been available to the student, but if so, it was not elicited. This is an inherent problem with collecting data in written form, and Ünal et al. (2010) are to congratulated on including interviewing to complement their written probe.

However, of more interest perhaps is a comparison between these two responses and statement 1 in the table. Where statement 3 (considered ópartial understandingô) explains the ionic bond in terms of electrical interactions, statement 1 (considered to show ósound understandingô) explains the covalent bond in terms of the sharing metaphor, and does not make any reference to the physical basis for the bond. From the perspective of understanding that will support progression in learning about scientific models, statement 3 (ópartial understandingô) seems to offer a better basis for future learning than statement 1 (ósound understandingô). Statement 4 also uses the sharing metaphor, and seems to imply that atoms share electrons to obtain full outer electron shells ï language that could imply this student holds the octet alternative conceptual framework discussed above.

In describing the responses to a later question about bonding in the water molecule (item 3), Ünal et al. give as an example of a response indicating sound understanding a student answer which includes the statement that ña covalent bond is the attraction of the bonding electrons by the nuclei of both hydrogen and oxygen atomò (p.11), yet in the earlier question seem to consider a reference to the ósharingô of electrons sufficient for a sound understanding.

It is also of interest to see how these authors identify misconceptions within the student data. Statements 7 and 8 are both presented as examples of responses labelled as showing a óspecific misconceptionô. Clearly both answers are wrong. The students respond with the wrong names for the different types of bonding. However, whether that is sufficient evidence of a misconception is not clear. Students may have made a simple mistake in writing their answers, or may have simply not remembered which name went with which type of bonding, and so guessed. In neither situation should this be considered a misconception (Gilbert & Watts, 1983; Taber, 2009), rather just a mistake. We all get things wrong sometimes, without this meaning we have significant alternative understandings of the world. It is also possible, as Ünal et al. acknowledge (p.22), that these responses may result when student has genuinely learnt the labels the wrong way round, and so this would reflect a genuine flaw in conceptual learning. But even in this case, it is questionable whether this justifies the incorrect learning being termed a misconception. The bonding types might be well understood, but the names mis-learnt. If all these types of errors are considered misconceptions, then the term loses its significance.

It is interesting in this context to compare statements 7 and 8 in Table 1, with statements 5 and 6, which are each considered by Ünal and colleagues to demonstrate ópartial understanding with specific misconceptionô. Statement 6 recognises the presence of ionic bonding, but shows little evidence of the student understanding this bond type, explaining the bond in terms of electron transfer. Simply knowing the name of the bond type would normally be considered to demonstrate recall, not understanding (Anderson & Krathwohl, 2001; Bloom, 1968). Just as getting the name of the bond type wrong (statements 7, 8) might be considered insufficient evidence of a misconception; getting it right seems insufficient grounds for recognising understanding.

Statement 5 is of particular interest, as here the student: (a) misnames the bond-type; (b) uses anthropomorphic language to imply that atoms seek full outer shells; (c) considered the bond in terms of electron transfer between atoms. So here there is an error (a), and evidence of two alterative conceptions (b and c) consistent with the student holding the octet alternative conceptual framework. Ünal et al. classify this response as demonstrating ópartial understandingô (with specific misconception), presumably because the student appreciates that compounds between metals and non-metals tend to form ionic bonds. The student applies a simple rule, but seriously misunderstands the nature of the bond.

Treatment of polar bonding

Ünal et al. turn next (p.9) to consider a question that ñinvestigates studentsô ideas about the position of bonding electrons between covalently bonded atomsé to determine to what extent students could predict the position of bonding electrons between two nonmetal atoms whose electronegativities are different from each otherò. Ünal et al. ask students to ñ*determine the positions of bonding electrons between the atoms in the given compounds*ò (p.9).

As explained above, bonding in compounds tends to be polar, to a greater or lesser extent. No ópureô ionic compounds are known. Salts are generally considered ionic, although the ions in salts are ópolarisedô to some extent even when they approximate the ionic model. That is, it is possible *to model* the bonding in salts by considering them to be ionic, to a first approximation, and then considering how the cationic charges would distort the electron density around the anions. This is purely a way of thinking about the bond, just as it is possible to model the bond in HCl or H_2O by considering how a purely covalent bond would be distorted by the different effects of the core charges at either end of the bond. However, if bonds are understood in terms of minimal energy configuration of the charges involved (e.g. as solutions to the Schrödinger equation), which are simply the result of the forces acting, then there is no reason to begin from the ideal ionic or covalent bond models.

Pure covalent bonds are also rare in compounds, only found where two elements have similar electronegativity (SiH_4) or in some cases where there are bonds between atoms of the same element (the C-C bonds in ethane, benzene or cyclohexane for example, but not the C-C bonds in ethanol or ethanoic acid). Interestingly, Ünal et alôs paper, in the question considered above, HCl, NH_3 and CO_2 were used as examples of covalently bound molecules. Two of these three examples have bonds that are polar enough to allow hydrogen bonding to form between molecules. Technically, *all* those compounds have polar bonds rather than covalent bonds, and it is difficult to find a compound with a simple molecule that is familiar from school chemistry that has non-polar bonds.

In their question about the position of bonding electrons in compounds Ünal et al. use the examples of HF; H_2; H_2S and CH_4 and explain that ñthe position of bonding electrons in H_2 compound [sic] were different from those in the other molecules because of the nonpolar covalent bonding formed between two hydrogen atomsò ï although H_2 is of course an element and *not* a compound. In classifying student responses, Ünal et al. report that ñstudents who stated that bonding electrons were shared equally in all covalent molecules and placed the bonding electrons equidistantly to the bonded atoms in their drawings for all of the given molecules were classified in the category of *specific misconception*ò (p.10). This is based upon there being two types of covalent bonds, those with equal ósharingô of the bonding electron pair, and those where ñbonding electrons were not shared equallyò (p.9). In other words, in determining which answers should be considered sound, and which indicate misconceptions, Ünal et al. adopt as target knowledge the notion that polar bonds are a type of covalent bond (as in Figure 3), rather than something intermediate between the ionic and covalent bond models (as in Figure 2).

Misunderstanding hydrogen bonding

Another interesting result reported by Ünal et al. was that some students misunderstood the nature of hydrogen bonding. For example, in item 3 of the written probe, where student were asked about the bonding in water, one respondent wrote: ñhydrogen bonding is formed between oxygen and hydrogen atoms in a water molecule. They bond with each other by sharing of their single electronsò (p.11).

This seems to be an example of an alternative conception that has been reported before, associated with the octet alternative conceptual framework (Taber, 1998). Where pupils think of bonding as the means by which atoms fill their shells, then such interactions as hydrogen bonding, solvation interactions, van der Waalsô forces and so forth do not fit the studentôs criterion for a chemical bond, as they do not allow atoms to fill their valence electron shells. When students hear teachers referring to a hydrogen bond, it seems that students commonly assume this is *meant* to refer to a covalent or polar bond to hydrogen, as the interaction between a Ö+ hydrogen atom and a Ö- atom on another molecule does not fit their notion of a bond in terms of atoms trying to fill their shells.

Exploring student thinking in interviews

It is widely accepted that written probes are a crude means of investigating student thinking. They can be suitable for testing the general level of support for specific misconceptions already identified in a population (Taber, 2000a), but it has long been accepted among researchers in science education that more-in-depth approaches are needed to explore student thinking (Bell, 1995; Gilbert, Watts, & Osborne, 1985; White, 1985). This reflects general understanding of the difference between óexploratoryô and óconfirmatoryô approaches to research ï that qualitative, in-depth approaches to exploring specific learners and contexts are needed to support the identification of suitable items that are valid for use in survey instruments (Taber, 2007).

Ünal et al. used interviews to complement their written probe, and the potential of interviews to investigate student thinking is illustrated in the extract from transcripts presented in the paper. For example, when student S3 was asked about ótypesô of covalent bonding s/he initially responded in terms of there being a difference between nonpolar covalent bonds, where ñtwo atoms of the same element bond to each otherò and polar ócovalentô bonding where ñdifferent atoms bond to each otherò (p.18). Had that been a written response it could have seemed to indicate that this student had simply learnt rote definitions, without any deeper understanding. However follow-up questions revealed that this student was able to go on to explain that in polar bonds ñthe bonding electrons are closer to one of the bonded atoms than the otherò, and that this was because ñone of the bonded atoms which has greater electronegativity than the other will attract the bonding electrons more powerfully than the other atomò (p.18).

Evidence for Turkish secondary studentsô thinking reflecting the octet conceptual framework

This potential for using follow-up questions allowed Ünal et al. to provide more convincing evidence for why students should be considered to have ósoundô or ópartialô understanding in the interviews, where in the written responses absence of evidence cannot be considered strong grounds for assuming absence of understanding.

In their paper, Ünal et al. do not review the previous research suggesting that English students commonly conceptualised covalent bonding in terms of the Octet alternative conceptual framework (Taber, 1998). However, the interview data they present offers a range of examples of student comments that would suggest Turkish students think about bonding in very similar terms to that found among English students in the earlier study. Some examples are presented in Table 2.

Table 2. *Statements from data presented in Ünal et al. (2010) reflecting the Octet Alternative Conceptual Framework*

Aspect of the Octet Framework	Examples of statements from Ünal et al.ôs interviews
Bonding seen as driven by attainment of full outer shells/octet/noble gas configuration	S3: é ñnonmetal gains electrons, so that they have more stable configuration as noble gases.ò S2: ñ Hydrogen needs an electron to have two electrons in its outer shell. Oxygen needs two electrons to have eight electrons in its outer shell. Each hydrogen atom shares one electron with oxygen. So, all atoms have full outer shell and they bond to each other.ò S4: ñ Sodium atom gives an electron and chlorine atom takes this electron, because they want to have noble gas configuration. Each of them has full outer shell.ò S7: ñ Oxygen atom tends to take two electrons to have full outer shell, while hydrogen atom tends to take one.ò S9: ñ They must share their single electrons, because both of them need one electron to have full outer shell.ò S10: Hydrogen and oxygen atoms... tend to gain electrons to have stable configurations. They share their single electrons, so they have full outer shell.ò
óSharingô metaphor seen as a sufficient description of covalent bond	S2: ñ Each hydrogen atom shares one electron with oxygen. So, all atoms have full outer shell and they bond to each otheré I just know that they bond to each other, because they share their single electrons. Bond is... it must be shared electrons. They are also called bonding electrons. Thus, shared electrons must be bond. They hold the atoms together.ò S3: ñWhen two nonmetal atoms react with each other, they form molecules by sharing of their single electrons.ò S7 ñThey share their electrons and form water moleculesé They shared their electrons, so they bonded together.ò S9: ñ[covalent bonding is formed between atoms] By sharing of their single electronsò ñ They must share their single electrons, because both of them need one electron to have full outer shell. So, they form covalent bonding.ò S10: ñ They share their single electrons, so they have full outer shell. Thus, they form covalent bondé . They share their single electrons, so they have full outer shell. Thus, they form covalent bond.ò
Bonding described in anthropomorphic terms: what atoms ówantô, óneedô	S1: ñthey want to gain electrons to resemble stable noble gases configuration. They want to have a full outer shellé Metals want to lose electrons, while nonmetals want to gainé metals want to lose electrons, but nonmetals want to gain. If so, they are able to think and wantò S4: ñSodium atom gives an electron and chlorine atom takes this electron, because they want to have noble gas configurationé Both of them meet the needs of each otherò S5: ñmetals want to give electron while nonmetals want to takeé We learned that metals wanted to lose electrons, while nonmetals wanted to gain.ò

Table 2. Continued...

Ionic bonds identified with electron transfer	S1: ñthe metal atom gives its electron to the nonmetal atom. They form ionic bonding.ò S4: ñSodium atom gives an electron and chlorine atom takes this electron, é Therefore, they form covalent [sic] bondingé sodium gave one electron to the chlorine atom, and the chlorine atom took the electron. Both of them meet the needs of each other, so that they bonded to each otheré [bonding] must beé the electron which transferred from the sodium to the chlorine atomé They bonded to each other by means of the electron that sodium gave and chlorine tooké An electron is transferred from sodium atom to chlorine atom. They are hold together by this meansò S5: ñMetal atoms transfer some electrons to the nonmetal atoms. So, they bond to each other.ò
Ionic bonding considered to result in molecules or molecule-like entities	S1: ñ a metal and a nonmetal atom will form a molecule,ò
Polar bonds seen a type of covalent bond	S3: ñ [types of covalent bonding are] polar and nonpolar covalent bonding.ò S7: ñthere are two types [of covalent bonding]. These are polar and nonpolar covalent bondingé There is no more difference between polar and nonpolar covalent bonding. They are covalent bonding in anyway. They differ from each other only according to being formed between different nonmetal atoms or the same nonmetal atomsò S8: ñthere are two types of covalent bonding. These are polar and nonpolar covalent bondingé Scientists have differentiated covalent bonding according to being formed between different nonmetal atoms or the identical onesò
Hydrogen bonding is interpreted as covalent/polar bond	S9: ñ Hydrogen bond is formed within HCl moleculesé it is both covalent bond and hydrogen bondé Because chlorine atom bond to hydrogen atom, we could say that they form hydrogen bonding as wellé . it is the same with covalent bonding. It is formed between hydrogen and chlorine atom by sharing of their single electronsé There is no differenceé [hydrogen bonding] is covalent bonding. But, it is also hydrogen bonding because it is formed between an atom óchlorineô and hydrogen atomé Hydrogen bonding is formed within molecules comprising of one hydrogen atom with other atomsò.

There is much evidence here that Turkish students adopt aspects of the Octet conceptual framework that was found to be common among English students.

CONCLUSIONS

Ünal et al.ôs paper presents evidence from a written probe and interviews, which they use to demonstrate that Turkish secondary students show evidence of misconceptions in this key concept area of school chemistry. This is an important finding. However, it has been suggested here that Ünal and colleaguesô study has used an analytical framework that does not do justice to the complexity of the phenomena explored. Ünal et al. do not give sufficient weight to the way their judgement of what comprises sound understanding is tied to their adoption of particular teaching models. So whilst they rightly recognise that identifying the ionic bond with electron transfer reflects inadequate understanding, they appear to consider that descriptions of the covalent bond as ósharingô of electrons constitutes the basis for sound understanding. Similarly, Ünal et al. adopt a dichotomous notion of chemical bonding in compounds which sees polar bonds as a sub-category of covalent bond. This teaching model has been criticised as being a poor basis for progression in learning, and clearly judgements of which pupils demonstrate sound understanding would be quite different had Ünal et al. made a different choice here.

An observer (such as the author of this commentary) who disagreed with the decisions made about what constituted appropriate target knowledge for these students will not accept the findings ï the claimed proportions of the sample displaying sound understanding, for example.

However, despite this, Ünal et al.ôs study is of value because it follows good practice in reporting research, by being open about the basis of the researchersô decisions, and offering good examples to illustrate this from the data - which allow readers to make their own judgements. It also offers some extended extracts from interview transcripts, which reflect the kind of data that have been used productively by many other researchers to explore student thinking in depth. This data allows the researcher to move beyond the rote responses students give based on learnt definitions, to find out something about the coherence, depth and logic of student thinking (Taber, 2008). So, for example, both students S1 and S10 associate covalent bonding with sharing of electrons to allow atoms to fill shells. Yet the interactive potential of interviews allows researchers to probe further and we discover that for S1, this is the extent of understanding, based on anthropomorphic notions of atoms that act on their needs (Taber & Watts, 1996), whereas S10 is able to appreciate how the sharing metaphor stands in place of a physical explanation in terms of the electrical attractions between bonding electrons and nuclei.

In their study, Ünal et al. identify apparent evidence of student misconceptions, but as they concede in the discussion section of their paper, the analytical approach they adopt does not readily distinguish between simple confusing of terms and the holding of alternative conceptions with significant potential to impede further learning (Taber, 2009). Considering that Ünal et al.ôs paper only presents a selection of extracts from their interview study ï intended to illustrate how they assigned students to their four categories ((i) sound understanding; (ii) partial understanding; (iii) partial understanding with specific misconception ; (iv) specific misconception) - it is intriguing that these extracts provide so much evidence of student thinking aligned with the octet alternative conceptual framework (Table 2), suggesting that in some important respects the thinking of secondary students in Turkey may be similar to what has been reported in the English study (Taber, 1998). It might be conjectured that a more detailed analysis of the full data set could offer a useful comparison with the results of the research from the English context.

Ünal et al.ôs study attempts to classify student understanding of a key chemical concept area, in terms of a small number of categories. In doing so it illustrates to Turkish science educators that Turkish students, as those in other countries, experience learning difficulties in this topic. However such coarse-grained evaluations offer limited insight into how to modify curriculum and teaching approaches. Yet, the data presented in Ünal et al.ôs paper also illustrate the potential for more in-depth studies to provide more detailed accounts of the nature of Turkish studentsô thinking. These could be a starting point for understanding why Turkish school children come to think about the topic in this way, and so how teaching needs to be modified to better support progression in student learning. Ünal et al. provide a good example of the kind of data that researchers can obtain, but one suspects that a more nuanced analytical framework could have revealed many more insights about the knowledge and understanding of their student informants.

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