

Can Kelly's triads be used to elicit aspects of chemistry students' conceptual frameworks?

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Abstract:

A great deal of research within science education is undertaken from a 'constructivist' viewpoint, which is grounded in the ideas of George Kelly. Although enquiry into conceptual development in science has drawn heavily on this theory, Kelly's technique of using triads to elicit constructs has been neglected in favour of alternative approaches. This paper argues that although Kelly himself developed and used his technique in a context of psychotherapy, his writing demonstrates that he recognised its wider potential. Kelly did not see the cognitive and affective aspects of personality as distinct, and he did not define his meaning of 'construct' as being very different to 'concept'.

As part of an inquiry into the development of understanding of chemical bonding, A level students have been presented with triads of cards showing chemical species, and then asked to discriminate between them. The type of construct labels elicited are considered, as is the utility of this data.

It is argued that the triads approach, when used as part of a repertoire of complementary techniques, may make a valuable contribution to exploring student thinking about chemistry, and how it changes over time.

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§1. Introduction.

Over the past two years I have on a number of occasions (see Appendix A for details) shown chemistry students triads of cards bearing diagrams from chemistry textbooks and asked them to divide the cards into a pair and an odd-one-out, and then explain the basis for the discrimination. This exercise has been undertaken as part of an on-going enquiry into how student understanding of the bonding concept develops during an A level course (Taber, 1991, 1993b.) The procedure is based on that developed by George Kelly for use in psychotherapy. In this paper I wish to explore the methodological congruity of using the technique in a study into concept development and to consider how useful Kelly's triads have been in my research. I will start out by briefly reviewing how Kelly's theoretical framework (personal construct theory, PCT) has been adopted as a paradigm for science education, then consider the appropriateness of applying the triads technique and the repertory grid to concept development work, before turning to a consideration of the data collected, and how it is being used in my own research.

§2. Constructivism and science education.

Davis *et al.* recently suggested that "science educators overwhelmingly agree that a crisis in science education exists" (1993, p.627). Drawing on Kuhn's terminology they suggest that "this crisis precedes a revolutionary change in paradigms which guides the conceptualisation of teaching and learning" (p. 635). Their candidate for a revolutionary movement is "the emerging paradigm of constructivism" to act as successor to "the commonly held educational paradigm of objectivism" (p.627) which has been described by Tobin (1993) as "the prevailing myth underlying educational thought and practice for more than three centuries" (p.241.) Another recent paper also refers to "the emergence of constructivism as a paradigmatic line of investigation in the field of science teaching" (Marín & Benarroch, 1994, p.1.) This school in science education builds partly on the work of relativist philosophers of science such as (physicist turned sociologist) Kuhn himself (*e.g.* 1970), but perhaps more importantly on the Personal Construct Theory of (physicist turned psychotherapist), George Kelly,

*"We assume that all of our present interpretations of the universe are subject to revision or replacement ... No one needs to paint himself [sic] into a corner; no one needs to be completely hemmed in by circumstances; no one needs to be the victim of his [sic] biography. We call this philosophical position *constructive alternativism*." (Kelly, 1963, p.15, italics in original. Kelly, writing originally in 1955, tended to refer the "man the scientist" whereas now we would prefer a term such as 'people as scientists' or just 'personal scientist'. Throughout this paper pronouns in quotations from Kelly may be understood to refer to people regardless of gender.)*

It has been shown that teachers may have different metaphors for the learning process, and that some of these may be simply described as 'transfer theories' (Fox, 1983). Hennessy reports how a 1990 study

"investigating student teachers' conceptions concerning the nature of science, teaching and learning produced depressing results; almost half of those questioned believed in a transmission model, namely the passive accumulation of a body of knowledge which has independent reality." (Hennessy, 1993, p.8.)

Kelly did not accept transmission metaphors for learning, with teachers pouring their knowledge into passive minds, and failures to learn being due to "poorly motivated, unintelligent, lazy, forgetful students" (Fox, *op.cit.*, p.95),

*"Learning is assumed to take place. It has been built into the assumptive structure of the system.
...
The burden of our assumption is that learning is not a special class of psychological processes. It is not something that happens to a person on occasions; it is what makes him [sic] a person in the first place." (Kelly, *op.cit.*, p.75)*

Although some commentators feel a paradigm shift may be taking place in science education, others could well claim that constructivism has been the predominant viewpoint in science education research

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(if perhaps not amongst classroom teachers) for some time. For example Osborne and Wittrock ground their model of learning in constructivism,

"Generative learning ... is central to the constructivist tradition ... The fundamental premise of generative learning is that people tend to generate perceptions and meanings that are consistent with their prior learning"
(Osborne & Wittrock, 1985, p.64)

The importance of prior experience to learning is a central tenet of Ausubel's theory of meaningful learning,

"The theory of meaning and meaningful learning ... takes as its starting point two phenomena which are well known to classroom teachers. First, a primary assumption which is central to the theory is that the most important factor influencing learning is the quantity, clarity, and organisation of the learner's present knowledge. This present knowledge, which consists of the facts, concepts, propositions, theories, and raw perceptual data that the learner has available to him [*sic*] at any point in time, is referred to as his cognitive structure.
The second important focus is the nature of the material to be learned."
(Ausubel & Robinson, 1971, pp.50-1.)

As a recent paper suggests constructivism might be considered as teaching according to Ausubel's maxim of finding out what the learner knows and teaching accordingly,

"Applied to science education, this constructivist view supports teachers who are concerned with the investigation of students' ideas and who develop ways which incorporate these viewpoints within a learning-teaching dialogue. Curriculum, rather than being considered content to be learned, may be seen usefully as a process in which students are actively involved in constructing a view of the world closer to the scientists' view."
(Trumper, 1993, p.141.)

Or as Pope & Watts explained in an earlier paper,

"Kelly's theory describes people's normal everyday construing of the world around them. Students' interpretations of phenomenon are natural and understandable, not somehow deviant or wilfully misguided. As far as the physics teacher is concerned they may be inappropriate, and even undesirable, but that does not negate the normality and personal importance of the constructs of the students."
and
"Adopting a Kellyan perspective would require the teacher to recognise pupils' or students' scientific constructs as having both important epistemological value and high educational status"
(Pope & Watts, 1988, p.106.)

Whether or not practicing science teachers are following Pope & Watt's advice the label of 'constructivism' has been taken up by the wider research community, such that the work of Guba and Lincoln has been described as,

"an alternative to the conventional positivist paradigm in social science research. At one time known as 'naturalistic inquiry', but now known as 'constructivism', it offers a more 'informed and sophisticated' set of assumptions about the nature of reality (ontology), the relationship between observer and observed (epistemology), and the appropriateness of various tools for inquiry (methodology)."
(Beld, 1994, p.99).

And returning to science education again, Solomon has indeed suggested that the constructivist movement has already past its peak of influence and may already be showing signs of decline (1994).

§3. Constructs and concepts - is the triadic method appropriate to studies of conceptual development?

“Concept. See *conception*.

Conception. That type or level of cognitive process which is characterised by the thinking of qualities, aspects, and relations of objects, at which therefore comparison, generalisation, abstraction, and reasoning become possible, of which *language* is the great instrument, and the product of the concept - normally represented by a word.

...

Construct. A term which some writers, such as Karl Pearson, have suggested as a substitute for *concept*.”

(Penguin Dictionary of Psychology.)

“CONCEPT. An abstraction or general notion that may serve as a unit (or an ‘atom’) of a theory.”
(The Oxford Companion to the Mind.)

§3.1 Can concepts be studied as constructs?

Kelly’s theory of personality deals with ‘personal constructs’ rather than with concepts, and he applied it as therapist: *i.e.* largely in terms of how people construed their social environment rather than the physical world. It is therefore appropriate to ask whether it is methodologically acceptable to apply Kelly’s method of triads in research into scientific concept development rather than psychotherapy?

The process of studying a course such as A level chemistry could be understood as entering a language community. (This is only one metaphor - others will be considered in §5.3 and §5.4) In an examination questions will be asked and answers evaluated according to certain norms established and maintained by the science education community (and in particular examiners.) The students must be able to interpret and respond to questions in such a way that the examiners find sufficient evidence of understanding of the accepted body of scientific knowledge making up the syllabus. Ignoring the statistically small probability (over a whole examination) of producing acceptable answers by chance, passing the examination involves (at least in part) having sufficiently similar meanings for a range of concepts as the examiners. If we accept that knowledge is personally constructed by individuals, rather than transmitted to them, then it is unlikely that any two students, or any two examiners - let alone a student and an examiner - will have exactly the same set of meanings for say ‘covalent bond’: with an exact agreement on examples and non-examples, and appropriate associations with other concepts. Such total agreement is not however necessary for science to proceed, as long as meanings are similar enough for effective communication most of the time. It was this aspect of science that led to Kuhn introducing the term ‘paradigm’ in his thesis on the structure of scientific revolutions (1970),

“I conceived normal science as the result of consensus among the members of the scientific community. Difficulties arose, however, when I tried to specify that consensus by enumerating the elements about which the members of a given community supposedly agreed. In order to account for the way they did research and, especially, for the unanimity with which they ordinarily evaluated the research done by others, I had to attribute to them agreement about the defining characteristics of such quasi-theoretical terms as ‘force’ and ‘mass’, or ‘mixture’ and ‘compound’. But experience, both as a scientist and as a historian, suggested that such definitions were seldom taught and that occasional attempts to produce them often evoked pronounced disagreement. ...

If scientists were not taught definitions, they were taught standard ways to solve selected problems in which terms like ‘force’ or ‘compound’ figured. If they accepted a sufficient set of these standard examples, they could model their own subsequent research on them without needing to agree about which set of characteristics of these examples made them standard, justified their acceptance. That procedure seemed very close to the one by which students of language learn to conjugate verbs and to decline nouns and adjectives. ... The usual English word for the standard examples employed in language teaching is ‘paradigms’, ...”

(Kuhn, 1977, pp.xviii - xix.)

So although terms such as ‘covalent bond’ may be defined in text books and scientific dictionaries, students and practicing scientists have their own personal meanings for the term.

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"In theoretical terms *all* constructs are personal. Even constructs drawn from say science or technology which have highly publicly specified relationships and implications and which have had their predictive validity tested and retested are still personal. They are personal in the sense that each person has to acquire them and integrate them into his [*sic*] total system. ... there might be much of interest to be investigated using grids where the elements and constructs are drawn from areas of high public agreement."

(Fransella & Bannister, 1977, p.117)

Kelly himself, although preferring to use the term construct, did not suggest that he meant something vastly different to concepts,

"...we use the term *construct* in a manner which is somewhat parallel to the common usage of 'concept'.

...

We have included, as indeed some recent users of the term 'concept' have done, the more concretistic concepts which nineteenth century psychologists would have insisted upon calling 'precepts'. The notion of a 'precept' has always carried the idea of its being a personal act - in that sense, our *construct* is in the tradition of 'precepts'. But we also see our *construct* as involving abstraction - in that sense our *construct* bears a resemblance to the traditional usage of 'concept'."

(Kelly, *op. cit.*, pp.69-70.)

As Watts and Pope have commented,

"...Kelly has contributed to a long standing debate about the nature and status of 'concepts'. What Kelly was rejecting was the 'traditional school', or abstractionist view of concept formation in favour of a current appreciation of concepts as personalised organisations of experience. ... The first is representative of the notion that concepts are nature's imprint on a passive mind, the second of the outcome of an active construction of meaning from experience. Given the growing acceptance of this second view, the distinction between a concept and a construct becomes increasingly blurred."

(Watts & Pope, 1985, p.9.)

§3.2 Can Kelly's theory be applied to studies of conceptual development?

There seems to be justification in the literature for suspecting that we may consider the versions of 'concepts' in students' minds as 'constructs' without doing violence to Kelly's original theory. However, Personal Construct Theory was devised in the context of therapy, not education, and as Solomon pointedly comments,

"Kelly was a psychologist who studied patients locked away in the solitary world of the schizophrenic." (Solomon, *op.cit.*, p.7.)

Kelly and his commentators would agree that his theory and methods arose from that particular context, but not that they were limited by it,

"Not only do systems, psychological and otherwise, tend to have limited ranges of convenience, but they also have foci of convenience. There are points within its realm of events where a system or a theory tends to work best. Usually there are the points which the author had in mind when he devised the system. For examples our own theory, we believe, tends to have its focus of convenience in the area of human readjustment to stress."

(Kelly, *op.cit.*, p.12.)

"Kelly had particular terrains which concerned him, such as the understanding of psychotherapy, but he sought to make his psychology comprehensive enough to serve the purposes of those with very different issues in mind."

(Bannister & Fransella, 1986, p.4.)

In order to elicit constructs from a patient, or a student, it is necessary to have a context for the exercise. In the grid method developed by Kelly the context was a list of significant people in the patient's life, and a repertoire of constructs was elicited by comparing these 'elements'. The nature of the 'elements' (i.e. friends, relations, neighbours) and the clinical setting (a disturbed person) meant that the constructs elicited could be emotionally charged, and might relate to attitudes, beliefs and values. Such matters are important in science education, and in science education research, but are

not the main focus of conceptual development studies. But in Kelly's theory (unlike say that of Bloom and co-workers) the distinction between cognitive and affective is not considered appropriate,

"The psychology of personal constructs is built upon an intellectual model, to be sure, but its application is not intended to be limited to that which is ordinarily called intellectual or cognitive. It is also taken to apply to that which is commonly called emotional or affective and to that which has to do with action on conation. The classical threefold division of psychology into cognition, affection, and conation has been completely abandoned in the psychology of personal constructs."
(Kelly, *op.cit.*, p.130.)

"It is argued that Kelly's description of construct systems is purely a description of 'thinking' and thereby deals with only one aspect of the person, the 'rational' aspect. But Kelly did not accept the cognition-emotion division as intrinsically valid ... So a construct is not a 'thought' or a 'feeling'; it is a discrimination. It is part of the way you stand towards your world as a complete person."
(Bannister & Fransella, *op. cit.*, p.21.)

or put even more forcibly,

"The range of convenience of Kelly's theory is still being tested. It would seem to be of potential use wherever the subject (person) imposes meaning on an event."
(*ibid.*, p.44.)

§3.3 Repertory Grid, and the method of Triads.

The Repertory Grid is a technique, or instrument, used to investigate a person's system of constructs. The Grid is literally that, a grid, with columns referring to the 'elements' being considered, and rows the constructs elicited. Fransella and Bannister list characteristics of the grid,

1. They are concerned with eliciting from a person the relationships between sets of constructs ...
 2. The primary aim is to reveal the construct patterning for a person and not to relate this patterning to some established normative data ...
 3. There is no fixed form or content ...
 4. All forms are designed so that statistical tests of significance can be applied to the set of comparisons each individual has made ..."
- (Bannister & Fransella, *op. cit.*, pp.51-2.)

As far as the present enquiry is concerned, I have indeed been interested in the relationships between the constructs that chemistry students have for aspects of chemical bonding, and I am interested as a researcher in the individual conceptual structures, rather than some norm or deviations from it. (Jean Piaget is considered by some to be as much an originator of constructivism as Kelly, but whereas Kelly was primarily interested in the individual person, Piaget's clinical studies of individual children were meant to inform his main concern, the epistemic subject. Piaget's genetic epistemology was concerned to find stages in thinking that were passed through by all people, not idiosyncratic results from individuals.)

It is hoped that such enquiry will be pedagogic value, and whilst valuing the personal constructions of my co-learners, I am interested in helping them enter the language community of 'chemists' that they themselves aspire to join (just as Kelly, as a therapist, wanted to help his patients.) The present research does not involve Grids in the sense of Bannister and Fransella's fourth criterion: there has been no attempt to undertake statistical analysis of data collected. In this sense my enquiry has been limited to using an earlier form of Kelly's technique,

"In its original form the technique was called Role Construct Repertory Test. Here, the subject is asked to name 20 or 30 people they know who fit different role titles ... Those who fit roles ... are called *elements*. Constructs are then elicited by taking three elements at a time. In the Role Construct Repertory Test, the procedure ends there, having provided some insight into the what the person construes their interpersonal environment."
(*ibid.*, p.49.)

The use of presenting three 'elements' (triads) for a comparison was a key part of Kelly's technique,

"The minimum context for a construct is *three* things. We cannot express a construct, either explicitly or implicitly, without involving at least two things which have a likeness and one which is, by the same token, different."
(Kelly, *op. cit.*, p.112.)

Champions of grid technique suggest that it may be an appropriate technique for studies of conceptual development,

"Work in the Piagetian tradition on children's acquisition of constructs to do with the physical world might be richly elaborated using the grid as a way of exploring how these constructs fitted into the more total construct system of the child."
(Fransella & Bannister, *op. cit.*, p.117.)

However those working in science education have preferred other techniques such as concept mapping, word association and - especially - interviewing (see for example, White & Gunstone, 1992, which might be seen as a manual of methods used in the field). One possible reason is touched upon by Osborne & Wittrock who report that,

"The repertory grid technique ... is ... not easily accepted by science teachers. In our experience teachers of physical science in particular are suspicious of research which requires complex statistical analyses to make sense of the data."
(Osborne & Wittrock, *op.cit.*, p.63.)

One reason why physical science teachers may not relate to statistical methods is that they are perhaps largely ignorant of them! Without training in statistical methods how does one critically read such research - let alone be tempted to carry out classroom based enquiry. A related, and perhaps more significant, factor is the teacher's notion of causality. Teachers trained as physicists and chemists have certain expectations of 'explanation' that involve particular types of causation. This is because most physical phenomena are understood by most physical scientists that way. Statistical notions of causality are something altogether different. Statistical thermodynamics is accepted as standing in the place of true physical causality when in practice not enough information may be collected or computed to provide 'direct' causal reasoning, but when physical science appears to suggest that quantum events may only - in principle - be predicted in terms of statistics, then the interpretation becomes the subject of intense philosophical debate (*e.g.* Popper, 1982.)

So science education research within the constructivist tradition has sought to use Kelly's theoretical base to underpin other methods.

"The critical argument ... is that Kelly's theory lends itself to a range of methodologies, some of which are clearly very un-gridlike. The important criterion is whether the basic assumptions that shape the methods are consistent and compatible with the philosophical basis of personal construct theory: constructive alternativism."
(Swift, Watts & Pope, 1983, abstract.)

So what method is suitable?

"The depth of analysis of children's idea and learning required to test the generative learning model in specific situations is likely to require in-depth interview analysis."
(Osborne & Wittrock, *op.cit.*, p.80.)

§3.4 The 'elements' used in the present study.

The use of interviews in constructivist science education research has been extensive, and in particular interviews with visual foci. Decks of cards bearing drawings of various scenes (*e.g.* a 'stick' man playing golf) have been used to elicit students' ideas during interviews. These techniques have been called Interviews-about-events ("what's happening here?") and interviews-about-instances ("is there an example of [concept, *e.g.* force] in this diagram?"). It is suggested that,

“in using, as we have, pictures we suggest that these may overcome one potential hazard of grid work namely their reliance on verbal formulation”
(Swift, Watts & Pope, *op.cit.*, p.23.)

In my own work my main technique has been interviews of this type (Taber, 1993b, c), although the figures have been of atomic and molecular species (“is there any bonding shown here?”) as is more appropriate to my main topic of interest. This methodology has indeed proved fruitful (*e.g.* Taber 1993e, 1994a.) However I have also been trying out Kelly’s method of triads to see if it would be useful as a complementary technique, my intention being to provide triangulation for results based on interview data. As well as the mode of elicitation being different I have deliberately not used the same foci diagrams as those used in the interviews. Whereas those figures were drawn by myself, for the triads I have built a deck of cards from diagrams from text books. In this way the diagrams have the extra face validity from being figures already in the public domain as representing chemical species.

In fact two separate decks of cards were prepared for the work: one based on texts designed for students taking chemistry prior to A level (so that they might be expected to be familiar to students embarking on an A level course) and a second deck from A level texts. (See Appendices B and C respectively for sample ‘elements’.) Pages from books were photocopied (at a suitable enlargement), trimmed, and attached to standard record cards (*c.*100 mm x 150 mm). Reference numbers were arbitrarily assigned to avoid using verbal labels that might be too leading and/or convoluted (“a water molecule with the bonding represented by overlapping circles and electrons shown as dots”?) Diagrams were selected to show a range of types of chemical species (molecules, atoms, ions, parts of lattices), representing a range of substances that should be familiar to the students, in various forms of representation relating to different aspects of structure and associated properties.

In this way it was hoped that Fransella and Bannister’s criteria for ‘elements’ would be satisfied,

“There are two important factors to be kept in mind when selecting the type of element to be used in a grid.

(a) *the elements must be within the range of convenience of the constructs to be used.*

...

(b) *the elements must be representative of the pool from which they are drawn.*”

(Fransella & Bannister, *op.cit.*, p.13.)

Note that in my text I am referring to the cards as ‘elements’ (*i.e.* in inverted commas) to avoid confusion between the PCT term, and the chemical term element. This is because some of the triadic ‘elements’ represented chemical elements, and some of the elicited construct labels included the word element.

§4. Responses elicited from chemistry students.

In this section I intend to present some data from my research to illustrate the types of constructs elicited from students. However, it is not possible to report the constructs themselves, but only the verbal labels elicited, which I will label as ‘construct’s. This is well recognised as a limitation,

“[one] grid-generated problem is the question whether elicited constructs are ‘better than’ supplied construct. This ignores the point that, in construct theory terms, you cannot supply a construct, you can only supply a verbal label to which the person may attach their own construct (their *discrimination*).”

(Bannister & Fransella, *op.cit.*, p.60.)

Turning this argument around, the student may be able to make discriminations according to her own construct, but if she is asked to suggest a label for the construct, it will be just that, a label. More than that, the student may not normally use any label for the discrimination. This is a point that Kelly himself feels the need to emphasise,

“A person may construe his [*sic*] experience with little recourse to words ... Even those constructions which are symbolised by words are not necessarily similar just because the words are similar.”

(Kelly, *op.cit.*, p.92)

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"Many of one's constructs have no symbols to be used as convenient word handles."
(*ibid.*, p.110)

§4.1 A simple classification of students' 'constructs'.

Given this limitation, it is possible to present the elicited 'constructs' in two ways, either in simple lists as they were obtained in the research (as is done in Appendix A), or organised according to some form of classification system that might aid assimilation. Part of the researcher's role is to interpret raw data for an audience. However it must be understood that in producing any form of classification the construct system being presented is that of the researcher - *i.e.* the 'constructs' about chemical species elicited from students are then treated as 'elements' to elicit the researcher's own 'constructs' about the students' ideas.

"There is no such thing as an element that is *only* an element or a construct that is *nothing but* a construct."
(Fransella & Bannister, *op.cit.*, p.11.)

I identified four main types of 'construct' elicited from my A level chemistry students, which I will refer to as:-

1. structural
2. properties
3. classification
4. diagrammatic

1. 'Structural constructs' were those that seemed to discriminate between 'elements' on the basis of structural features of the 'elements' such as molecular shapes, electronic configuration and bond types. (See table 1.)

Table 1: examples of 'structural constructs'.

bonds where electrons are being shared
complete outer shell
contain three orbitals
covalent bonding
eleven protons
lattice arrangement
one or more unhybridised p-orbitals
polar covalent bond
possess octet state
tetrahedral arrangement

2. 'Property constructs' are those that seemed to discriminate 'elements' on the basis of properties that could be inferred about the element, such as chemical reactivity, melting temperature and conductivity. Examples are given in table 2.

Table 2. Examples of 'property constructs'.

can undergo combustion
charged particles
covalency of 4
electrovalency of -2
fairly reactive
harmful to the ozone layer
high reactivity
low melting point
soluble in water
stable

3. 'Classification constructs' were those that seemed to discriminate between 'elements' on the basis of specific classes or categories, such as a named substance, periodic classification or type of reactant. Examples are given in table 3.

Table 3. Examples of 'classification constructs'.

complete atom
ethene
gas
group 1 metals
group 7 elements
hydrocarbon
metal
molecule
period 3
represent sodium

4. 'Diagrammatic constructs' were those that seemed to discriminate between 'elements' on the basis of the way they were represented, rather than what was represented. This category refers to the different conventions used in chemistry textbook diagrams to represent various aspects of the species drawn. Some examples are given in table 4.

Table 4. Some examples of 'diagrammatic constructs'.

got a key
got shading
orbital represented as dumbbells
nucleus shown
represented as 3D shape
show each orbital in atom
show electrons as 'e's
symbol for atom shown
we can know the period
written

(Note that it could be argued that the 'elements' presented were ambiguous: was the 'element' the figure shown on the card, or the species represented? This question is not trivial, for in selecting the diagrams to be used a range of types of representations was deliberately chosen. For example does "O=O" represent a double bond? A student without sufficient background knowledge in cognitive structure may not construe it so; whilst another student might consider a double bond is represented in "O=O", but not in "O₂" which might however imply a double bond to a third student {who knows that the symbol stands for a stable molecule which may be considered to be made up of two atoms which separately have electronic configurations of 2.6, but become stable when they may be considered as having configurations of 2.8, which implies a double bond is present!})

A scheme was developed by making finer divisions within the first three categories, and this is shown in table 5. Again it is important to reiterate that any such scheme reflects the researcher's perceptions of the elicited 'constructs'.

It is also possible to consider the elicited 'constructs' along dimension such as specific-general, analytical-holistic, or trivial-significant - but again to what extent does the researcher understand the student's meaning for a construct? Would 'one electron in the outer shell' be a label for a purely descriptive, enumerating discrimination, or does it also imply a low first ionisation energy, a tendency to form +1 ions, a tendency to form compounds with ionic bonds, part of a material that conducts electricity and has a high reactivity, etc.? Kelly would have an answer to this question, based on his first principle: ('if you don't know what's wrong with a patient, ask him, he *may* tell you', quoted in

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Bannister & Fransella, *op.cit.*, p,57) and in effect that was the procedure that came to be used in the present work (see §6.)

constructs:-

structural:

- molecular:
 - shape:
 - others:
- sub-atomic:
 - nuclear:
 - electronic:
 - c.f. n.g.e.c.:
 - others:
- crystal:
- bond type:
- includes:

properties:

- chemical:
 - reactivity:
 - specific:
 - valency:
- physical:
 - macroscopic:
 - molecular:
 - charge:
 - others:
- environmental:

classification:

- periodic table:
 - electronegativity:
 - block:
 - period:
 - group:
- state:
- reagent type:
- microscopic species:
- type of substance:
- specific substance:
- occurrence:

diagrammatic features:

ambiguous/miscellaneous:

table 5. A scheme that could be used when classifying elicited A level chemistry student 'constructs'.

§4.2 Do the elicited 'constructs' satisfy Kelly's dichotomy criterion?

Earlier I discussed the relationship between constructs and concepts (see §3.1), and in that discussion I ignored one particular aspect of constructs that could seem to distinguish them from concepts, that is their bipolar nature. Kelly set out his theory very clearly and systematically in a series of postulates and corollaries, including the "**Dichotomy Corollary: a person's construction system is composed of a finite number of dichotomous constructs**" (Kelly, *op.cit.*, p.59.) Kelly uses the example of masculinity and points out that

“The notion of masculinity is predicated upon a companion notion of femininity, and it is the two of them together which constitute the basis of the construct.” (*ibid.*, p.60)

The elicited term, masculinity in this example would be called the emergent pole, and femininity would be the implicit pole. In order to investigate the extent to which ‘constructs’ elicited fitted this pattern on one occasion I did ask the co-learner “as opposed to?” each time a ‘construct’ was elicited. (This was not the only time that I asked about the opposite pole, but in general my co-learners tended to have difficulty finding a label beyond “not-[‘construct]”, so I tended not to persist. On this one occasion however I did make the point of asking the question for each of the elicited ‘constructs’.) The results are given below in table 6.

| elicited construct:- | implicit pole:- |
|---|------------------|
| 1. has expanded octet | [hasn't] |
| 2. d-orbitals used in hybridisation | [not used] |
| 3. contains dative covalent bonds | [not] |
| 4. intermolecular bonding (hydrogen bonding) | [not] |
| 5. dimer | [not] |
| 6. delocalisation of electrons | [localised] |
| 7. hybridisation takes place | [doesn't] |
| 8. undergoes electrophilic addition reactions | [doesn't] |
| 9. undergoes electrophilic substitution reactions | [doesn't] |
| 10. acting as bases (accepting proton) | [not] |
| 11. lone pair influence on bond angle | [not] |
| 12. specific arrangement of ligands | [not] |
| 13. intramolecular bonding present | [intermolecular] |
| 14. hydrogen bonding present | [not] |
| 15. resonant structure(s) | [not] |
| 16. van der Waals forces exist in species | [not] |
| 17. sp hybridisation | [not] |

Table 6: implicit poles for a set of elicited ‘constructs’

and as may be seen in only two cases was a specific label given to the implicit pole, rather than it just being not (/hasn't got/doesn't do) the explicit pole elicited. Perhaps such dichotomous labels to discriminations are less common in chemistry than in psychotherapy where couples such as sad / happy, angry / calm, tough / easy-going may be readily brought to mind.

Kelly certainly believed that his dichotomy corollary applied in the field of science,

“Have dichotomous construction systems proved useful in the field of science? ...[yes] in the field of electromagnetism, and later electronics. Here the notion of positive and negative poles and charges has opened the door to many important discoveries and inventions. Yet the notion of *positive vs. negative* is only an assumption which is imposed upon the data; the atoms did not come round to the scientists and ask to be divided into positive and negative aspects.”
(Kelly, *op.cit.*, p.109.)

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But maybe positive charge-negative charge and N pole-S pole are atypical examples? What are the companion notions that predicate the 'constructs' of sp³ hybridisation, group 7 elements, or eleven protons in the nucleus, and together constitute the basis of the constructs?

Kelly was aware that the implicit pole may not have a suitable label,

"When we say that a person has red hair we are distinguishing it from the non-redness of white, yellow, brown or black. Our language has no special word for this non-redness, but we have little difficulty in knowing what the contrast to red hair actually is."

(Kelly, *op.cit.*, p.63)

So in a similar way a student may distinguish sp³ hybridisation from sp², sp, sp³d, sp³d², (*etc.*) hybridisation, without a special word for non-sp³ hybridisation-ness. It would seem therefore that Kelly would recognise my students' 'constructs' as within the range of application of his personal construct theory.

§4.3 Dichotomies and continua

Although Kelly's method of triads leads to discriminations between 'elements' according to dichotomous constructs, the development of repertory grid techniques has led to constructs being seen less as dichotomies, than bipolar scales, and this change of terminology is clear in Bannister and Fransella's interpretation of personal construct theory,

"Kelly is ... arguing that it is more useful to see constructs as having two poles, a pole of affirmation and a negative pole, rather than see them as concepts or categories of a unipolar type. In line with his philosophy of constructive alternativism he is not asserting that constructs *are* bipolar and that they are *not* unipolar. He is asserting that we might find it useful to think about them *as if* they were bipolar."

(Bannister & Fransella, *op.cit.*, p.12.)

The reason for this shift becomes clear,

"When we come to examine Kelly's invention of grid method as a way of exploring personal construct systems we will see that much is gained because we are able, mathematically, to represent a personal construct system by viewing it as made up of *bipolar* constructs."

(*ibid.*, p.13.)

So it seems appropriate to ask the extent to which my co-learners in this study presented 'constructs' which were dichotomous (i.e., where 'elements' either do or do not have the attribute) or bipolar scales (where 'elements' may be assigned to some position on a continuum between the emergent and implicit poles.)

In the work currently carried out the co-learners were only asked to assign 'elements' according to the 'constructs', not to rate them, or order them. Therefore once again I can at this time only present my own interpretation of their 'constructs'. Certainly some of the 'constructs' elicited seem to be open to use as scales on which different 'elements' might be placed according to the extent of having attributes, for example:

stable atoms
covalent bond
non-metals
cube-like structure
all clumped together
simple sketch drawing
pass electric current
difficulty in breaking bonds
low melting point
if dissolves in water, would have acidic properties

are all capable of being used as scales (whether this was what was intended or not.) However, most of the 'constructs' seem to be much less readily used in this fashion, as the following examples show:

solid at room temperature
compounds
atoms
ions
group 1
diatomic molecule
contain oxygen
symbol for atom shown
eleven protons
represent chlorine

and so forth.

The distinction between the two types of construct is certainly important if one wishes to follow Fransella and Bannister in developing grids for statistical analysis. However grids containing 'elements' construed as if according to dichotomies rather than bipolar scales certainly can be analysed (Watts, 1994.) For example one of my co-learners was asked to sort 11 of the 'elements' according to 28 'constructs' (previously elicited from him or his peers.) By a process of comparing rows and columns it was possible to rearrange the grid to put similar columns (i.e. similar 'elements' in terms of how sorted according to the 'constructs') and similar rows (i.e. similar 'constructs' in terms of how used to sort 'elements') together. (See §5.2)

However the distinction is also of a more fundamental importance in the present inquiry, as one of the reasons for focussing on chemical bonding as a topic for research into conceptual development was that,

“during an A level course students are introduced to ... more abstract ideas relating to bonding [such as] covalent-ionic bonding as a continuum rather than a dichotomy”
(Taber, 1991, p.2.)

It is hoped that this aspect of the use of Kelly's triads may be investigated further in future work.

§4.4 Qualities, categories and names?

As mentioned above (§4.1) elicited 'constructs' appeared to make discriminations between 'elements' at varying levels of generality. Some of the 'constructs' elicited certainly relate to properties that many 'elements' could exhibit to varying extents, for example

shows degree of covalent bonding
showing lone pairs
example of expanding the octet
got a ring structure
showing a lattice structure

Other 'constructs' could be called categories, but nevertheless quite general categories such that a wide range of 'elements' could be attributed to the 'construct': for example

hydrocarbons
organic
polymer
metal
acids

Some of the constructs through seem to be so specific as to be names for specific substances or entities:

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phosphorus molecule
represent sodium
represent chlorine
ethene
water molecules

Should such specific categories be 'allowed' as 'constructs'? Kelly would have allowed them,

Are proper names expressions of constructs? Yes. A name is a way of seeing a likeness in on group of events which distinguishes it from another group of events.

(Kelly, *op.cit.*, p.114.)

In section 4 I have presented some examples of the 'constructs' elicited from chemistry students, to give a flavour of the types of responses that the triads procedure may produce. I have also discussed the extent to which the elicited responses satisfy Kelly's notion of personal constructs. Having put my case for (i) the appropriateness of the triad technique, (ii) the validity of the 'elements' used, and (iii) the validity of the elicited responses as concept labels in PCT terms, I consider I have established the congruity of theoretical stance, technique and data. I have yet to discuss whether the data obtained has actually been of any value to my enquiry!

§5. Usefulness and limitations of the method.

§5.1 Quantitative or qualitative research?

As has already been pointed out (§3.3) full-blown Repertory Grid technique involves statistical analysis of the data, and leads to quantitative 'results' relating to the construct systems of the subjects. This has not been undertaken in the present study. This is not unusual for work in this tradition: the 'constructivists' in science education tend to base their work on qualitative techniques (see §3.3), as has fitted the qualitative data collected from interview studies. However some workers have seen limitations to qualitative data analysis.

"These interview techniques promise to give us great insights into how people store and recall knowledge and use it in thinking. They provide so much information, however, that there is a danger of drowning in a sea of uninterpretable data."

(White, 1985, pp.51-2.)

Statistical analyses have been used to make comparisons between groups of students, for example applying t-test to data,

"Using word association tests and concepts maps for evaluation, Moreira found that the experimental groups was better able to interpret key physics concepts in electricity and magnetism, and to show Maxwell's equations with proper concept map linkages."

(Novak, 1985, pp.198-9.)

Data has been analysed to extract dimensions which can be used to plot out the 'proximity' of concepts within some 'average' of group cognitive structure,

"The data from the three group-administered probes (word-association, free sort and tree construction tasks) have been analysed. Proximity matrices have been produced from responses to each of the three tests and scaling methods applied to these matrices to produce representatives of cognitive structure."

(Champagne, Gunstone & Klopfer, 1985, p.178.)

The present research is concerned with individuals, and any averaging of results would not be appropriate. However the following procedure (in the case given applied to data from a group of 38

Brazilian 16-18 year olds) appears similar to that applied with the individual student discussed below (§5.2),

“The questionnaire took the form of a grid, with the nine scientific concepts across the top [c.f. ‘elements’?] and a list of features [c.f. ‘constructs’?] down the side. Students were asked to decide, for each concept, whether or not it possessed each feature ...
... the responses can be interpreted as lying in a four dimensional ‘ontological space’ ...
If frequencies of ‘yes’ responses to a pair of features, across the nine concepts, correlate highly, we may regard these two features as being ‘close’ to one another.”
(Mariani & Ogborn, 1991, p.73.)

Those who have been labelled the ‘alternative frameworks movement’, have primarily preferred to describe aspects of the quality of students ideas, rather than subject them to statistical analysis. Certainly where researchers have had access to large samples (i.e. the CLiSP team at Leeds, working with national A.P.U. data) they have presented descriptive statistics showing the relative popularity of different categories of learner response to questions, which gives an indication of how common some alternative scientific ideas and misconceptions are. However there is qualitative difference between quoting simple descriptive statistics that all physical scientist teachers and science education researchers should be able to understand (e.g. 33% of a national sample of 305 15-year old pupils misidentified a diagram showing diatomic molecules containing one type of atom as representing a compound, Briggs & Holding, 1986, p.41), and using the inferential statistics favoured by some educational researchers, that are only meaningful to those with statistical training (e.g. in the Study referred to by Novak, *op.cit.*, (p.198), the scores on the criterion of ‘identification of general concepts’ from an experimental group and a control group gave a value of t of -1.23 for which $p < 0.05$.)

§5.2 Analysis of a grid.

Most of the work that has been undertaken has involved eliciting ‘constructs’ from students using the ‘elements’ supplied. However, as mentioned in §4.3, on one occasion one of my co-learners was asked to state whether each of a series of ‘elements’ was for him an example of each of a list of ‘constructs’. The set of ‘constructs’ was derived from those elicited from this students and his peers on previous occasions. This allowed the time to be spent on judging each element against the ‘constructs’ and is a recognised procedure,

“For some purposes, it is best to supply construct labels, at least in part.

...

If you are in doubt about what kind of constructs are applicable to a certain group of people, it is common practice to collect a sample of constructs from a comparable group, or the group itself. You are then fairly safe in assuming that the most commonly used constructs for that group will be meaningful to the individual. But as they have been selected from a common elicited pool they are not, in any simple sense, either ‘provided’ or ‘elicited’.”
(Fransella & Bannister, *op.cit.*, p.19.)

By sorting the rows, and then the columns, it was possible to re-arrange the grid to give as much similarity as possible between adjacent rows and adjacent columns. Table 7 shows the data (with ‘elements’ and ‘constructs’ represented by codes) in the order it was elicited, and the final sorted grid is shown in table 8.

So what does this tell us? It gives us information about which of the ‘elements’ were construed as similar (in terms of the ‘construct’s used), and about which ‘constructs’ were used similarly (in terms of the particular ‘elements’ sorted) for this particular student, on that occasion. This information (with the ‘elements’ represented by labels given by the author) is shown in tables 9 and 10 respectively, with the physical distance down the page reflecting the degree of similarity in the grid (and perhaps to some extent their proximity within cognitive structure at the time of elicitation, for the student who provided the data.)

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| | 116 | 126 | 133 | 134 | 142 | 145 | 154 | 315 | 423 | 522 | 621 |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 01 | . | . | . | Y | . | Y | Y | Y | Y | Y | Y |
| 02 | . | Y | Y | . | . | . | . | . | . | . | . |
| 03 | Y | . | . | . | . | . | . | . | . | . | . |
| 04 | . | . | Y | . | . | . | . | . | . | . | . |
| 05 | . | . | . | Y | . | Y | Y | Y | Y | Y | Y |
| 06 | . | . | . | . | . | . | Y | . | . | . | Y |
| 07 | Y | . | . | . | Y | . | . | . | . | . | . |
| 08 | Y | . | . | Y | Y | Y | Y | Y | Y | Y | Y |
| 09 | Y | . | . | . | Y | . | . | . | . | . | . |
| 10 | . | . | . | . | . | Y | . | . | . | . | . |
| 11 | . | . | . | Y | . | . | . | Y | Y | Y | . |
| 12 | Y | . | . | Y | . | . | . | . | . | . | . |
| 13 | . | . | . | Y | Y | . | Y | Y | Y | Y | Y |
| 14 | . | Y | Y | Y | . | Y | Y | Y | Y | Y | Y |
| 15 | . | Y | . | . | . | . | . | . | . | . | . |
| 16 | . | Y | . | . | . | . | . | . | . | . | . |
| 17 | . | Y | . | . | . | . | . | . | . | . | . |
| 18 | Y | Y | Y | . | . | . | . | . | . | . | . |
| 19 | . | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| 20 | . | Y | Y | . | . | . | . | . | . | . | . |
| 21 | . | Y | . | . | . | . | . | . | . | . | . |
| 22 | . | Y | Y | . | . | . | . | . | . | . | . |
| 23 | . | Y | Y | . | Y | . | . | . | . | . | . |
| 24 | . | . | Y | . | . | . | . | . | . | Y | Y |
| 25 | . | . | . | . | Y | Y | . | . | . | . | . |
| 26 | . | . | . | . | Y | . | . | . | . | . | . |
| 27 | . | . | . | . | . | Y | . | . | . | . | . |
| 28 | . | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |

Table 7: a grid obtained from a co-learner (T), before sorting. (Y indicates an element that exhibits/is an example of the constructs, here coded 1 - 28, but see table 10 for details.)

| | 134 | 423 | 522 | 621 | 154 | 145 | 142 | 116 | 126 | 133 |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | | 315 | | | | | | | | |
| 10, 27 | . | . | . | . | . | Y | . | . | . | . |
| 25 | . | . | . | . | . | Y | Y | . | . | . |
| 15, 16, 17, 21 | . | . | . | . | . | . | . | . | Y | . |
| 04 | . | . | . | . | . | . | . | . | . | Y |
| 02, 20, 22 | . | . | . | . | . | . | . | . | Y | Y |
| 23 | . | . | . | . | . | . | Y | . | Y | Y |
| 18 | . | . | . | . | . | . | . | Y | Y | Y |
| 12 | Y | . | . | . | . | . | . | Y | . | . |
| 03 | . | . | . | . | . | . | . | Y | . | . |
| 07, 09 | . | . | . | . | . | . | Y | Y | . | . |
| 26 | . | . | . | . | . | . | Y | . | . | . |
| 06 | . | . | . | Y | Y | . | . | . | . | . |
| 24 | . | . | Y | Y | . | . | . | . | . | Y |
| 11 | Y | Y | Y | . | . | . | . | . | . | . |
| 01, 05 | Y | Y | Y | Y | Y | Y | . | . | . | . |
| 08 | Y | Y | Y | Y | Y | Y | Y | Y | . | . |
| 13 | Y | Y | Y | Y | Y | . | Y | . | . | . |
| 14 | Y | Y | Y | Y | Y | Y | . | . | Y | Y |
| 19, 28 | Y | Y | Y | Y | Y | Y | Y | . | Y | Y |

Table 8.: the same data as in the previous table, after sorting. Note identical rows/columns have been shown only once.

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methane molecule

carbon dioxide molecule (overlapping circles) hydrogen chloride molecule

carbon dioxide molecule (orbitals shown)

nitrogen molecule

hydrogen molecule

tetrahedral lattice (diamond?)

close packed atoms (metal?)

sodium ion

chlorine atom

hydrogen atom

Table 9: the 'elements' presented along a dimension (represented vertically) based on the grid.

lattice arrangement giant structures
pass electric current

period 3 3 shells present in group 7 electrons in K, L & M shells

group 1
atom one electron short of a full outer shell unstable
same number of protons as electrons

nucleus shown

complete outershell
ion
metal ions charged particle
shows metallic bonding

diatomic molecule

shows rough placement of electrons in orbitals

polar covalent bond

compound covalently bonded

stable

molecule

non-metals
neutral species not have noble gas configuration

Table 10: the 'constructs' presented along a dimension (represented vertically) based on the grid.

Chemically the sorting of the 'elements' can be interpreted as along a meaningful dimension - at the top of the page are simple molecules, then giant structures, then ions and finally an atom which does not have a stable electronic configuration by itself. An alternative interpretation is in terms of bonding types: covalent, metallic, ionic, none.

The sorting of the 'constructs' is perhaps more interesting. Some of the 'constructs' which gave similar response patterns have obvious connections - for example period 3, 3 shells present and electrons in K, L & M shells would all be expected to distinguish between similar 'elements', but it may not be immediately obvious why in group 7 should be in the same place on the dimension. However, inspection of Table 9 may explain this: of the particular (triad) 'elements' presented only two contained period 3 (chemical) elements - and one of these represented a sodium *ion* which therefore did not have any electrons in the M shell. The same factor - the limited range of 'elements' presented - explains why compound and covalently bonded are not distinguished in this exercise, and why the 'construct' one electron short of a full outer shell seems to mean the same as atom.

Although of some interest the analysis is flawed by the limited range of 'elements' used. Yet the more 'elements' and/or 'constructs' used to create the grid the longer the process takes, with the chances of boredom and lost concentration on the part of the co-learner (and the researcher?) increasing (see §6.2). The elicitation of the data for this analysis required the co-learner to make 451 judgments! (11 'elements' against 41 constructs, although 13 of the 'constructs' gave a null response across all 'elements', and therefore these judgments did not help in sorting the 'elements', or to any meaningful extent the 'constructs'. These were excluded from the present analysis.)

§5.3 The map metaphor.

The type of analysis which the repertory grid is capable of, and which the limited exercise above (§4.1) gives some flavour of, is very powerful. But is it appropriate? The answer to that question obviously depends upon one's purposes,

"The purpose of grids is to inform us about the way in which our system is evolving and its limitations and possibilities. The results of the grid have often been looked on as a map of the construct system of an individual ..."

(Fransella & Bannister, *op.cit.*, p.3.)

Note the cartographic metaphor in this quotation. 'Mapping out' cognitive structure is a powerful metaphor for the activity that many researchers are undertaking - and a metaphor that leads quite naturally to consideration of proximity matrices and ontological spaces,

"If knowing is making a mental map of the concepts one has learned and if people think with concepts, then the better one's map, the better one can think."

(Wandersee, 1990, p.926.)

It could however be argued that trying to map out anybody's cognitive structure - or any non-vanishingly small part of it - is an activity akin to painting the Forth bridge whilst trying to measure the exact position and momentum of a single electron. Not only will the amount of time required to investigate such structure mean that it has changed by the time one has finished, but the very act of measurement will have provoked at least some of the change. Of course it is poor sport to poke fun at one metaphor without exposing one's own preferred metaphor to criticism.

§5.4 The toolbox analogy.

The nature of learning chemistry is such that it can be argued that conceptual development in the subject is a process analogous to building-up a box of tools, and becoming more discriminating and proficient in their use. The arguments for using this simple model for progression in learning chemistry have been rehearsed elsewhere (Taber, 1993a, 1994c), and I will not repeat them here. However if one conceptualises one's research in these terms then one is less interested in mapping the mental terrain of one's students than in finding evidence for the acquisition and appropriate application of a range of tools. Students may differ in the number of tools in their toolbox, the sophistication of the tools they tend to reach for, and the finesse with which they use them. My research interviews allow me to

explore my co-learners' use of tools, and additional information may come from tests, homework, concept maps - and from eliciting constructs from triads. (Note that concept maps are very useful sources of information, and have the advantage of being of diagnostic and assessment value, at the same time as allowing active construction of knowledge, and the development of metacognition {see Taber, 1994d.} They are maps in that they display the relationship of concepts through detailing the connecting propositions, but perhaps in terms of my preferred analogy I should refer to them as "concept owners' manuals"?)

The tool-box analogy does fit rather well with the idea of learning science as a form of cognitive apprenticeship, described in

"established literature which characterises cognitive differences between novices and experts. This work indicates that predominantly through an interactive process of cognitive apprenticeship, experts spend years acquiring intuitive specialist knowledge and sophisticated mental models of their domain." (Hennessy, 1993, p.1.)

"... learning can be facilitated through a series of processes such as modelling, coaching, scaffolding, fading, articulation and encouraging learners to reflect on their own problem-solving strategies ... These processes are the components of apprenticeship, which essentially involves providing help in developing an appropriate notation and conceptual framework for a new or complex domain and allowing the learner to explore that domain extensively, then gradually withdrawing support." (*ibid.* p.12.)

§5.5 Triad procedures used.

Two decks of element cards were prepared, one using diagrams from books intended for pre-A level study (Freemantle & Tidy, 1983; Gallagher & Ingrams, 1984; Garvie *et al.*, 1979; Groves & Mansfield, 1981; Hughes, 1981; Jackson, 1984: see appendix B for a sample) and the other from A level texts (Andrew & Rispoli, 1991; Hill & Holman, 1989; Liptrot, 1983; Waller, 1985: see appendix C for a sample). Both decks were extensive, intended to provide a large repertoire of 'elements' that could be presented, and only a selection of figures were used on each occasion. The first deck was piloted with a student near the end of his first year of A level, and then used with a cohort of ten co-learners at the beginning of their course. Some of these students repeated the exercise later in their course. The second deck was tried out with an undergraduate chemistry student (who had previously been interviewed as an A level student) at the end of his first year at University, and was then introduced for use with some of the cohort of students during their second year of the course.

Two different approaches to selecting triads was used. At first the choice of triads to present was made in situ during the exercise. This allowed the researcher to try out combinations of 'elements' that might be useful, and to discard some 'elements' as less suitable (e.g. ambiguous) for future use. Just as important it allowed the exercise to be interactive, as the researcher reacts to the students' elicited 'constructs' by offering the next triad.

After some experience of using the technique a standard set of triads was established for use with each pack. Both approaches have advantages. The less structured approach allows the researcher to undertake 'hypothesis testing' about the students ideas, and to follow up immediately responses that seem of particular interest. In a sense the process of the researcher offering a triad to the student, the student offering 'constructs' in response, and the researcher responding with a further triad gives the exercise the form of a conversation, something that has been recognised as inherent in grid work,

"The grid is perhaps best looked on a particular form of structured interview. Our usual way of exploring another person's construct system is by conversations. In talking to each other we come to understand the way the other person views his [sic] world, what goes with what for him [sic], what implies what, what is important or unimportant and in what terms they seek to assess people and places and situations ...

... [the information a grid gives us] is a formalised version of the kind of information we are always seeking about each other, the kind of understanding we are always in a process of gaining about each other."

(Fransella & Bannister, *op.cit.*, p.4.)

or put more succinctly,

“understanding another's perspective requires empathy and a 'conversational' approach.”
(Watts, *op.cit.*)

The advantage of having a standard set of triads is that comparisons become easier. The comparison may be made between different students, or between the same students at different times during their course. Some examples of this will be given below (§5.6, §5.7)

Although time constraints did not allow complete grids to be formed, where each element was considered against each 'construct', sometimes particular 'constructs' of those elicited were selected and used to consider each element. The choice of particular 'constructs' would again be as a result of *in situ* hypothesis testing when uncertain what exactly a particular co-learner meant by the construct label offered.

§5.6 An example of a comparison between students

Five co-learners were presented with the same triad of 'elements' (cards coded 126, 641 and 656, see Appendix B) during the second year of their course. The following constructs were elicited:-

co-learner J (21.10.93):

- ions
- got a core charge of 17+
- got an octet configuration
- in period 3
- in group 7
- tendency to form ions

co-learner K (21.1.94)

- loss of electrons
- molecule
- pure covalent bonding
- electrostatic force
- have full outer shells
- ionic bonding

co-learner N (11.11.93)

- element
- molecule
- pure covalent bonding
- electrostatic force
- how full outer shells
- ionic bonding

co-learner T (24.1.94)

- show all the shells
- shows a molecule
- shows neutral species
- shared, donated or gained electrons

co-learner U (4.11.93)

- individual atoms
- seven electrons in outermost shell

What is the value of such comparisons? Of course it would be possible for the researcher to mark each set of discriminations as 'correct' or not, and to award each subject a score for the number of appropriate 'constructs' applied to a standard set of 'elements' - after all the person supplying the triads is sometimes called the "examiner"! (e.g. Fransella & Bannister, *op.cit.*, p.26.) However such an approach would be inappropriate. For one thing there are much easier and less time consuming ways

to set 'tests' to provide normative data about groups of learners. More importantly such a simplification of the rich data produced defeats the purpose of investigating the idiosyncrasies of individual learners.

"Kelly's emphasis on the study of the individual person highlights a trend in psychology that started gathering momentum half a century ago. Increasingly it was realised that it is not only possible but also in many instances desirable to study the data from one individual (ideography) as well as data from a number of individuals (nomothesis)."
(Bannister & Fransella, *op.cit.*, p.42.)

That is not to say that the data from a group of students should not be compared,

"Methodologically, the grid can be used either to investigate the individual or particular aspects common to many subjects without violating the theoretical assumptions that we are all unique in certain other respects."
(Fransella & Bannister, *op.cit.*, p.54.)

In my own study I am interested in following the development of the unique conceptual toolboxes of my students: so I need to gain insights into the repertoire of tools each co-learner has available at a given time. As a teacher I am aware of the discriminations I would make for a particular triad, but if a student does not construe the 'elements' in the same way that may not indicate the absence of a particular conceptual tool, merely that it was not applied in making a discrimination. Perhaps few A level students would construe those particular 'elements' that way? However if most other co-learners do offer a particular 'construct' in the context of a certain triad but one doesn't, this may be worth following up.

For example consider the sets of constructs offered by two students (K and R) on their first exposure to the technique (note: not with identical sets of triads). In the following tables (11 - 14) the constructs are presented firstly as lists, and then set out according to the simple classification suggested earlier (table 5.)

One of these students found A level chemistry very difficult, and feeling she could not cope decided to drop the subject. Do these sets of 'constructs' give any insight into which student lacked the tools to complete the course? Although 28 constructs were elicited from R many of these related to aspects of the way the diagrams were drawn that were not significant chemically. She made some discriminations based on structural aspects, but did not use 'constructs' relating to properties, or the conventional categories used in chemistry. K's constructs were much richer with a selection of 'constructs' of each of the structural, properties and classification types.

K - 18.11.92

1. possess octet state
2. stable
3. can be present in a noble gas
4. found in group 7
5. found in group 1
6. found in group 8
7. can undergo reaction
8. can undergo reaction to form ionic bonds
9. forms diatoms
10. metal
11. represents an ion
12. charged particle
13. we can know the period
14. represents a type of bond
15. only one element
16. a gain of electrons
17. cannot exist on its own
18. low melting point
19. electrovalency of -2
20. covalency of 4
21. soluble in organic solvents
22. conduction of electricity
23. covalent bonding
24. bond between different elements
25. ionisation
26. soluble in water
27. displacement of hydrogen by reactive metals
28. organic substance
29. ionic compound
30. high energy required to break bonds
31. state of existence is solid
32. high reactivity
33. bond between non-metals
34. can undergo combustion
35. electrovalency of 1
36. lattice arrangement
37. tetrahedral arrangement
38. compound
39. polar covalent bond
40. ionising slowly

Table 11. Constructs elicited from co-learner K near the start of his A level course.

R - 11.11.92

1. one electron short of a full outer shell
2. other shells drawn in
3. electrons as circles
4. electrons as 'e'
5. say what they are
6. got a 17+ charge in the middle
7. three shells
8. full outer shell
9. minus signs on some of the 'e's
10. got orbitals
11. got shading
12. got 'H's
13. symmetrical-ish
14. got structure(s)
15. got brackets
16. written
17. got plus signs
18. two joined together
19. circular
20. say how many electrons are shared
21. got plus signs in the middle
22. all clumped together
23. got charges drawn in
24. double bonds drawn in
25. two different elements in them
26. 3-D drawing
27. simple sketch drawing
28. got a key

Table 12. Constructs elicited from co-learner R near the start of her A level course.

Can Kelly's Triads be used to elicit aspects of chemistry students' conceptual frameworks?

constructs: **K - 18.11.92**

structural:

molecular:

shape: **tetrahedral arrangement**

others:

sub-atomic:

nuclear:

electronic:

c.f. n.g.e.c.: **possess octet state**

others:

crystal: **lattice arrangement**

bond type: **covalent bonding; bond between different elements; ionic compound; bond between non-metals; polar covalent bond**

includes:

properties:

chemical:

reactivity: **can undergo reaction; can undergo reaction to form ionic bonds; cannot exist on its own; high reactivity; stable**

specific: **forms diatoms; displacement of hydrogen by reactive metals; can undergo combustion**

valency: **electrovalency of -2; covalency of 4; electrovalency of 1**

physical:

macroscopic: **low melting point; soluble in organic solvents; conduction of electricity; soluble in water**

molecular: **high energy required to break bonds**

charge: **charged particle; a gain of electrons; ionising slowly**

others:

environmental:

classification:

periodic table:

electronegativity: **metal**

block:

period:

group: **found in group 7; found in group 1; found in group 8**

state: **state of existence is solid**

reagent type:

microscopic species: **represents an ion**

type of substance: **only one element; organic substance; compound**

specific substance:

occurrence:

diagrammatic features: **we can know the period; represents a type of bond**

ambiguous/miscellaneous: **can be present in a noble gas; ionisation**

Table 13. Data from table 11 rearranged according to the scheme of table 5.

constructs: **R - 11.11.92**

structural:

molecular:

shape: **symmetrical-ish; circular**

others: **two joined together; all clumped together**

sub-atomic:

nuclear: **got a 17+ charge in the middle**

electronic:

c.f. n.g.e.c.: **one electron short of a full outer shell; full outer shell**

others: **three shells**

crystal:

bond type: **double bonds drawn in**

includes: **got orbitals; got 'H's; two different elements in them**

properties:

chemical:

reactivity:

specific:

valency:

physical:

macroscopic:

molecular:

charge:

others:

environmental:

classification:

periodic table:

electronegativity:

block:

period:

group:

state:

reagent type:

microscopic species:

type of substance:

specific substance:

occurrence:

diagrammatic features: **other shells drawn in ; electrons as circles; electrons as 'e'; say what they are; minus signs on some of the 'e's; got shading; got brackets; written; got plus signs; say how many electrons are shared; got plus signs in the middle; got charges drawn in; 3-D drawing; simple sketch drawing; got a key**

ambiguous/miscellaneous: **got structure(s)**

Table 14. Data from table 12 rearranged according to the scheme of table 5.

§5.7 Comparisons made over time.

"In general man [*sic*] seeks to improve his constructs by increasing his repertory, by altering them to provide better fits, and by subsuming them with superordinate constructs or systems."
(Kelly, *op.cit.*, p.9.)

The focus of my research is the *development* of understanding of chemical bonding and it is perhaps here that the triad technique has particular value, as the 'constructs' offered to discriminate between 'elements' can give evidence of the stability and lability (Taber, 1993c) of the co-learner's ideas.

'Constructs' were elicited from co-learner T using the same triads on two occasions during the second year of his course. Some examples of the constructs elicited were:-

| 'elements' | |
|--------------------------------------|--|
| 7/10/93 | 9/5/94 |
| 229 / 307 / 349 * | |
| contains phosphorus | has expanded octet |
| all valent electrons used in bonding | d-orbitals used in hybrid |
| shows degree of covalent bonding | |
| contains two or more different atoms | |
| 249 / 338 / 339 * | |
| shows degree of covalent bonding | contains dative covalent bonds |
| shows hydrogen bonding | intermolecular bonding (hydrogen bonding) |
| | dimer |
| 207 / 305 / 400 * | |
| shows carbon-carbon bond | delocalisation of electrons |
| hydrocarbon | hybridisation takes place |
| are bonded metallicly | undergo electrophilic addition reactions |
| contain delocalised electrons | undergo electrophilic substitution reactions |
| contain π and σ bonds | |

Table 15. Constructs elicited from the same student at different times.

* see appendix B

There is evidence here of some stability, similar construct labels being presented after a period of over half a year. There is also evidence of new 'constructs' that were not elicited before, perhaps evidence of the acquisition or development of the range of application of tools. However there are also 'constructs' that are elicited on the earlier, but not the later, occasion. Are these tools that are lost perhaps? This particular student actually explained that in carrying out the exercise he deliberately avoided making obvious discriminations. (He did not feel such discriminations were useful in achieving his purpose of learning chemistry - see §6.2.) This is a phenomena that was present in the comparison between co-learners K and R earlier (tables 11 - 14). K did not provide evidence that he could

discriminate between 'elements' which showed electrons as 'e's rather than in some other way, or that he could discriminate 'elements' which included brackets with those that didn't, whereas R provided these 'constructs'. Either K did not have such 'constructs' available, or he attended to these features but did not feel they were significant enough to report, or perhaps the constructs were available, but the discriminations were not made because he 'saw through' those aspects and was not consciously aware of them. In T's case I would not interpret the data as telling me that he lost the ability to discriminate 'elements' that contained phosphorus from those that didn't, but rather that he did not attend to and/or report this feature as he considered it too trivial. In this particular case it seems very unlikely that the ability to make the discrimination would be lost, but in some instances it would be unwise to make such judgments based on the data from triads alone. In the next section the use of Kelly's triads alongside complementary techniques is considered.

§6. Can Kelly's Triads to be used to elicit aspects of chemistry students' conceptual frameworks?

"Grids are like people. They come in many shapes and sizes; they ask questions and give answers; they can be studied as a group or individually, on one occasion or successively over time; they can be used well or distorted out of all recognition."
(Fransella & Bannister, *op.cit.*, p.v.)

The evidence given above suggests that triads can indeed elicit 'constructs' from students which are useful in following the development of the understanding of chemistry. However it is also clear that the data often raises questions more than providing answers. In my research I have used the triad technique alongside I-A-I type interviews (see §3.4) with the students. The triads provide additional evidence about the student's repertory of conceptual tools to be used alongside the interview data. This provides a form of triangulation which may add to the authenticity of my interpretation of interview protocols.

If the co-learner presents a 'construct' that seems inappropriate to the researcher this could be:-

- i) because the two give a different meaning to the verbal label;
- ii) because the two have different interpretations of which chemical species is represented;
- iii) because of a simple mistake (i.e. a slip of the tongue in reporting which of the 'elements' exhibited the 'construct' and which didn't);
- iv) because the student has a construct system which from the orthodox viewpoint includes a misconception.

It is important to know which of these applies in a particular case, both for the point of view of carrying out research, and for advising the student. (Note that the researcher is also the teacher in this study, and therefore has responsibilities to use the data for the benefit of the co-learners as students: see §6.2. and Taber, 1994b.) The triad data may also be used as material for discussion in interviews, and the interview used to confirm a hypothesis about a student's thinking that has arisen from the 'constructs' elicited.

§6.1 Examples of 'inappropriate constructs'.

Co-learner P used the 'construct' charge of 17+ (12.11.92) to discriminate between three 'elements' - none of which had a charge of 17+. She had misinterpreted the diagrams, reading nuclear charge as overall charge on the species.

Co-learner K used the 'construct' posses octet state but suggested that a number of 'elements' that represented species that seemed to posses this attribute did not. However in a later interview K was able to use the 'construct' in a conventional way. It seems his original use of the 'construct' had a meaning more akin to 'species shown would have octet state when separate atoms'.

A similar 'construct' was elicited from co-learner M, complete outer shell, and again he excluded 'elements' which represented species with full outer shells. However during a subsequent interview M

revealed a different way of construing this idea. For example a hydrogen atom did not have a full outer shell as this would be two electrons and it only contained one ('correct' from a conventional interpretation). But for M the hydrogen molecule, H₂, did not have this attribute either as the electrons were shared so now another two electrons would be needed to give a complete outer shell.

Co-learner U used the 'construct' four hydrogen bonds and included 'elements' representing a hydrogen chloride molecule, a methane molecule and a neon atom as having the attribute. In a later interview he was asked if these substances contained hydrogen bonds. Neon did not (it seems the diagram used was misleading), but methane did. U appeared to understand the term hydrogen bond as being a bond between hydrogen and another atom - so although he had a construct labelled 'hydrogen bond' it was not that of a hydrogen bond as understood in chemistry.

Co-learner P exhibited a similar 'construct' hydrogen bonding which was attributed to 'elements' showing methane, hydrogen (and oxygen - although it would seem P did not recognise this diagram!) A subsequent interview confirmed P was aware of hydrogen bonding which in biology she had learnt joined the bases in D.N.A. together. However she was not able to give a definition of hydrogen bonding, and gave hydrogen and methane molecules as examples of materials with this type of bonding.

P also demonstrated a construct called π-bond present and she ascribed this attribute to 'elements' representing oxygen and nitrogen molecules. However she did not judge other 'elements' representing carbon dioxide, benzene and (a different representation of) oxygen to have this attribute. Although she had acquired a concept of pi-bond she had not yet developed the concept to the point where she could recognise species with pi-bonds unless certain visual cues were present. When interviewed she knew that pi-bonds were something to do with double bonds, and that it was different to a sigma bond. Whereas the sigma bond was understood in terms of its origin - it involved overlap of orbitals - her association for the pi bond was less abstract, and more visual - it was like a hamburger.

Co-learner U presented a 'construct' probably charged, and he attributed this to a whole range of 'elements' in a way which seemed inappropriate. In a subsequent interview he assigned charges to a range of neutral atoms and molecules, thus revealing an important possible source of confusion.

Co-learner M presented a 'construct', molecule in which he included 'elements' representing sodium chloride, calcium chloride, the ammonium ion, and a lattice containing two distinct particles. He was later asked during an interview whether all substances were made of molecules: his response was no, some are made of elements. M used molecule with a meaning more akin to 'compound', and seemed to also think that in their elemental form substances were monatomic.

Finally let's consider some of the 'constructs' elicited from co-learner N. She presented a 'construct' lattice. A figure of a metal did not exhibit this attribution, but a number of simple molecules did. In an interview she confirmed that sulphuric acid, water and benzene would all have lattices. It appeared that N's 'construct' of lattice related to the bringing together of all the elements in a compound, rather than the usual structural connotation. N was a very bright and hard-working student, but she brought with her from school some unusual meanings for certain fundamental chemical terms, and this was revealed through the work with the triads. She applied the 'construct' compound to diagrams showing a range of (chemical) elements, and when interviewed later reiterated that H₂, Cl₂, O₂ and S₈ could be called compounds, but not elements. Despite having this brought to her attention, and continuing through the course very successfully, one year later N was presented with triads and again she gave inappropriate discriminations using the 'construct' compound as well as molecule. She was then asked to use the terms element, molecule, ion and compound with a whole series of 'elements'. Inspection of the data showed that for N these categories were (nearly always) used as exclusive: an 'element':

- could not show a molecule if it showed a compound
- could not show ions if it showed a compound
- could not show a compound if it showed a molecule
- could not show a compound if it showed ions

Three 'elements' representing ionic lattices (124, 311, 553) were construed as compounds, but not as ions;

a water molecule (111) was not construed as a compound;

two representations of ions (313: Ca^{2+} & 2Cl^- ; and 114: Mg^{2+} & 2Cl^-) were considered ions but not as compounds, as was a representation of a polar hydrogen chloride molecule (454);

three representations of discrete molecules (211, 246, 326) and a macromolecule (616: silica lattice) were construed as compounds but not as molecules.

In Kelly's terms N was using these four terms as preemptive constructs,

"A construct which preempts its elements for membership in its own realm may be called a preemptive construct.

...

This is a pigeonhole type of construct; what has been put into this pigeonhole cannot be simultaneously be put into any other."

(Kelly, *op.cit.*, p.153-4.)

The difference between N's discriminations and the orthodox use of the terms was discussed with her, with particular emphasis on the distinction between the molar and molecular levels of studying chemical species - that is that although compound and element are exclusive terms an element may be made of atoms or molecules, and a compound of molecule or ions. One week later her use of the 'constructs' had changed, so that she was generally able to apply the labels in the accepted way (i.e. as constellatory rather than preemptive constructs.) She was now able to construe an 'element' as being both ions & compound (e.g. 313: calcium chloride, previously not construed as a compound), molecule & element (e.g. 145: diamond type lattice, previously not construed as a molecule), or molecule & compound (e.g. 246: methane molecule, previously not construed as a molecule.)

The change in discriminations was significant, but the new judgments were not completely orthodox: the water molecule was now a compound but not a molecule. Also in no longer seeing the constructs as preemptive N now construed the hydrogen chloride molecule (with its bonding electrons shown as completely over to the chlorine) and the sodium chloride lattices as representing ions, compounds **and** molecules: where the orthodox use sees ions and molecules as exclusive categories! (N is in good company - the French scientist Daudel is translated as referring to the "molecular ion symbolised NO_2^+ " as "this molecule" {1990, p.90.}) Construing molecules within an ionic lattice appears to be common among students (e.g. Taber, 1993e, 1994a.)

§6.2 Student reaction to Kelly's triads.

The students who were presented with the triads were all volunteering their time. They were wanting to be helpful, but they also hoped to learn from the experience. Indeed I have described elsewhere how the research interactions involved the teacher-researcher and student-'subjects' coming together with different aims but both aware of the agenda of the other (Taber, 1994b). I have used the term co-learners to describe this relationship, and have discussed how the researcher has a duty to be aware of what the student is able to get out of the research interaction. Such an approach seems totally in keeping with Kelly,

"The relationship between psychotherapist and client envisaged by Kelly was essentially that of co-experimenters."

(Bannister & Fransella, *op.cit.*, p.111.)

In general I have found that A level chemistry students who volunteer to be interviewed find the process useful and interesting (Taber, 1994b, pp.11-14.) However, the response to Kelly's triads was less positive. I do not have any firm evidence to explain exactly why this should be, but my impressions from student reaction and comments allows me to offer some observations:

(i) In interviews co-learners were aware that they were learning from the process (*ibid.*, p.12), whereas they did not seem to feel this about the triads work. (Indeed some seemed rather bemused as to what I could be learning from the sessions!)

(ii) Some co-learners seemed to find the triads work more difficult than being interviewed.

(iii) Whereas in interviews co-learners commented that the time seemed to pass very quickly, this did not appear to be so in the triads work. This was perhaps less of a problem during the elicitation of constructs from triads, as when an attempt was then made to have the co-learner work through a set of 'elements' with one of the elicited 'constructs' (or vice versa) - indeed my impression was that this could become a chore.

I believe partly this response can be explained in terms of my own evolving research processes. Two factors in particular should be mentioned. Firstly in what I now consider to be a naïve attempt at methodological purity I did not give immediate feedback to the co-learners at the end of the research sessions. My own developing line of thought about the dual researcher-subject and teacher-student relationship, and the inevitable effect of any interaction as an intervention led me to change this policy, and make brief contemporaneous notes for feedback purposes (*ibid.*, p.6.)

Secondly, and not totally unrelated, was my wish to use the triads technique as triangulation for the interview data. Again a naïve expectation was that the two sets of data could be analysed separately to some extent to see if they supported the same interpretation. For this reason I wanted to keep the sessions distinct from interviews, and I did not record them, and I tried to ensure that my input was at a technical level rather than a contextual level as much as possible. My intention was to ensure that the 'constructs' elicited were as untainted as possible from my suggestions. However this removed some of the 'conversational' nature that perhaps any technique derived from Kelly ought to embody. One of my co-learners who was particularly keen on being involved in the study, and who was capable of being very forthcoming in interviews, nevertheless found the triads hard-going. The focal diagrams for both types of session were similar, and with the experience of quite a number of recorded interview sessions behind him he was capable of producing detailed and eloquent soliloquies on aspects of chemistry once dialogue was underway: but faced with a triad of cards he was often visibly struggling. He reported not liking these sessions although he enjoyed the interviews (*ibid.*, pp.12-14.) As a form of experiment a slightly different elicitation method was used. I recorded the session, and instead of presenting the triads then waiting for 'constructs' I asked him to pick one of the cards and describe what it represented. He was able to suggest a range of relevant ideas. Only after each of the three cards had been discussed in some detail I asked the co-learner to discriminate between them. This variation seemed to be more successful with this particular learner, but I have not since had opportunity to experiment further with this sort of approach.

§7. Conclusion.

The work I have described today is largely tentative for a number of reasons. For one thing I have been practicing and developing my technique. Secondly the method has been very much a subsidiary technique used alongside and supporting interviews. Also, most importantly, I have been using triads to elicit 'constructs' and to get some idea of their meaning to students, but I have not attempted to explore the potential of using more developed grid technique. I have not (in general) asked students to complete grids, and I have not asked for ratings or rankings. I have not attempted statistical interpretations of the data received. Within this limited framework I believe **yes: Kelly's triads can be useful in eliciting aspects of chemistry students' conceptual frameworks**. When I have further analysed my interview data alongside the elicited 'constructs' I will be in a better position to comment on just how useful! For the time being I am not aware of any other workers using the triads methods as part of a study into conceptual development (rather than attitudes and values) in science, and therefore I hope this paper - despite the tentative nature of the work reported - will be useful in suggesting a potentially useful technique to other workers.

If such workers are interested in studying students conceptual structure by quantitative approaches they may wish to move beyond triads to more developed grid techniques. I can see there could be

much of value in this, but within my own study I prefer a more interpretative approach, which I believe Kelly would respect,

“... Kelly did not think methods of quantification were all there should be in the psychologist’s tool-bag. Constructs can be elicited from an individual in conversation, from essays, from poetry, from Journal papers ... He considered that quantitative and qualitative methods of measurement were equally valid as ways of inquiry into a person’s view of the world.”
(Bannister & Fransella, *op.cit.*, p.48.)

And to collect my data I expect to use Kelly’s triads as part of a ‘pluralistic methodology’,

“... i.e. use a number of different investigative instruments each consistent with an underlying Method, [which] is entirely compatible with PCT, indeed it is implied by Kelly’s writings.”
(Swift, Watts & Pope, *op.cit.*, p.8.)

An important aspect of this Method is that it should to seek to find out what the learner means by her constructs, even if the ‘constructs’ seem obscure, or label different meanings for the researcher (e.g. Taber, 1993c, pp.19-21),

“... the personal-construct psychologist initially deals with [the person’s own abstraction of behaviour] as concretely, from his own point of view, as possible. He [sic] starts by taking what he sees and hears at face value. Our term [for this approach] ... is the credulous attitude.”
(Kelly, *op.cit.*, pp.173-4.)

One way to be credulous is not to begin investigation of a student’s ideas by the researcher asking the learner about the researcher’s constructs, but to use a procedure such as Kelly’s triads to elicit hers. If the researcher suspects that other ‘constructs’ are available, but were not elicited the student could then subsequently be asked to reconsider the ‘elements’ in terms of a set of constructs provided, based on previous research (e.g. for A level chemistry students the data in Appendix A could be used as a resource.) The students should not be assumed to have constructs to give meaning to the provided labels - Kelly’s first principle should be applied:

“If there is some doubt about the meaningfulness of a construct for an individual you can then refer to the individual.”
(Fransella & Bannister, *op.cit.*, p.19.)

For example one co-learner was taken through the set of triads for the first time and was only able to suggest ten ‘constructs’. There were many other discriminations that would have been expected on the basis of the learner’s status (i.e. a good GCSE grade as a requirement to study at A level), and the constructs elicited previously from other students. He was then presented with a list of 35 suggested construct labels and asked which he felt confident to apply. He selected 18. Most of those rejected would normally be acquired later in the course, but some such as ‘cation’ and ‘non-metal’ were surprising - the need for the credulous attitude was required. The discriminations then made with the ‘constructs’ that the co-learner was comfortable with were later analysed, and it was clear that the meanings the student had for terms such as compound, metal, and element (for example) were worthy of further investigation.

Such follow-up investigation can take place in an interview context. Interviews also provide an appropriate means for ‘laddering’: asking ‘why’ in response to each answer, until the student’s chain of explanation reaches the point where ‘that’s just the way things are’.

“This ‘why’ technique can start with any kind of construct ... the end product will be some superordinate construct to do with one’s philosophy of life.”
(Bannister & Fransella, *op.cit.*, p.51.)

or in my research perhaps one’s ‘philosophy of chemistry’. (For example provisional analysis of interview data suggests that the elicited superordinate cause of chemical phenomena might be ‘the need (/desire) to obtain a full outer shell’, or ‘a tendency for ‘stable’ products to form’. The extent to which such superordinate constructs are used as heuristics, or are tautological or anthropomorphic, and at what point the learner ceases to seek reasons as the phenomena is ‘just natural’ are being explored through the research {Taber & Watts, in preparation; Watts & Taber, in preparation}.)

To summarise, an investigation into the development of student ideas in chemistry can be based upon a range of complementary and congruent techniques, and Kelly's triads can be a useful part of the researcher's repertoire.

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Appendix A: Complete set of constructs elicited during the enquiry to Summer 1994.

B - 6.7.93 (chemistry undergraduate, having just completed year 1. A level student 9.90 - 6.92)
specific compounds; contain oxygen; charges; show specific bonds; show interaction between a central positive atoms and negative end of molecule; delocalisation shown; transition metal complex; homonuclear molecules; show named specific atoms; shows double bonds; shows electrons; diatomic; shows electron cloud; organic; inorganic; interactions within a crystal; obviously aromatic; polymer; contains double bonds; sp^3 hybridisation; two central atoms; dimer; clearly showing double bonds; radical; clearly charged; tetrahedral; contains phosphorus; acids; contains hydrogen; contains nitrogen; shows hydrogen bonding; shows shape of molecule; shows electron density; adduct; shows structure of crystal; is a ring; contains electron-deficient bond

E (A level student 9.91 - 6.93)

29.10.92

[deck 1] two orbitals; three protons; no neutrons; noble gas configuration; form ionic compounds; three electron orbitals (shells); unreactive; gas at room temperature; crystalline solid; electronegative; dense; reacts with water; neon; orbital lobes; ions; anions; three-dimensional; multiple bonds; double bond; organic; hybridised; pi-bond; localised pi-bond; stable; eleven protons; metal; one valence electron; simple covalent; single element; ring; macromolecular; tetrahedral; covalent; high melting point solid; dissociates in water

J (A level student 8.92 - 6.94)

04.11.92

[deck 1] ionic bonding; contains metal; solid at room temperature; soluble in water; compounds; metals; high melting point; gases at room temperature; have isomers; forms ions; atoms; ions; fairly reactive; group 1; covalently bonded; electrical current; produce anions; produce cations; electrophile; if dissolves in water, would have acidic properties ;nucleophile; contain oxygen; diatomic molecule; harmful to the ozone layer; helps form free radicals; halogen; oxidising agent; metal ions; inert gas; stable

21.10.93

[deck 1] ions; got a charge of 17+; got an octet configuration; in period 3; in group 7; tendency to form ions; hydrogen bonding; ionic compounds; forms ionic lattices; liquid at room temperatures; have metallic structures; body centred cubic; metallic bonding (delocalised orbitals); overall uncharged substance; consist of just a metal; conduct electricity; conduct heat; diatomic; when aqueous an acid; sodium chloride structure; gas at (room temperature); consists of group 6 element; nucleophile; proton donor; organic substance; compound; shape of molecule in a tetrahedron; sp^3 hybridisation; bond angle 105.28; undergoes free radical attack; exists in natural gas; homologous series alkane; lattice structure; van der Waals forces; double bond; contains carbon; homologous series alkene; undergoes electrophilic attack; decolourises bromine water; soluble in polar solvents; covalent bonding; forms crystals; made-up of metalloid; element; period 2; inert gas; halogen; metal; can form positive ion; s-block element; electropositive; polar bond

28.10.93

[deck 2] have phosphorus in them; have group 7 elements; show lone pair of electrons; carry out nucleophilic substitution; form a complex ion; dimer; hydrogen bond; have aluminium in them; acidic properties; basic properties; metallic bonding; delocalised electrons; double bond; aromatic compound; homologous series alkane; electropositive; organic compound; attacked by free radical (guess); ions; contains oxygen; solvent for acid base reactions; hydrated ions; salt solution (part of); transition metal; dipole shown; protein structure; van der Waals forces; gas; macromolecule; polymer; secondary structure; lattice; contains chlorine; dative bond; diatomic; ionic structure; covalent bonding; can undergo cleavage; high melting point; contains a metal; aids combustion; triple bond; diazonium bond; contains nitrogen; sp hybridisation; sp^2 hybridisation; found in fertilisers; undergoes electrophilic attack

K (A level student 9.92 - 6.94)

18.11.92

[desk 1] possess octet state; stable; can be present in a noble gas; found in group 7; found in group 1; found in group 8; can undergo reaction; can undergo reaction to form ionic bonds; forms diatoms; metal; represents an ion; charged particle; we can know the period; represents a type of bond; only one element; a gain of electrons; cannot exist on its own; low melting point; electrovalency of -2; covalency of 4; soluble in organic solvents; conduction of electricity; covalent bonding; bond between different elements; ionisation; soluble in water; displacement of hydrogen by reactive metals; organic substance; ionic compound; high energy required to break bonds; state of existence is solid; high reactivity; bond between non-metals; can undergo combustion; electrovalency of 1; lattice arrangement; tetrahedral arrangement; compound; polar covalent bond; ionising slowly

20.1.94

[deck 1] loss of electron; ions; group 1 metals; group 7 elements; gain electrons; show sub-shells; show ionic characteristics; 3-dimensional diagram; you can see elements of which group are involved; shows ionic bonding; shows metallic bonding; mobile electrons present; shows cation; shows covalent bonding; shows polar covalent bonding; shows the distribution of electron density; sp^3 hybridisation; macromolecular structure; organic molecule; double bond present; possibility of electrophilic addition reaction; made up of more than one atom; ionic lattice; shows coordination number; consists of a halogen; shows it's a single atom present

[deck 2] shows 3-dimensional diagram; shows presence of lone pair of electrons; trigonal bipyramid; tetrahedral; octahedral; bonds present in equatorial position; uses V.S.E.P.R.T.; dative bonding present; shows dimerisation; shows hydrogen bond; organic molecule; Lewis base; organic acid; metallic bonding; can undergo electrophilic addition/substitution reactions; delocalisation of electrons; shows the presence of sigma and pi bonds; pyramidal molecules; shows the presence of ligands; shows the presence of solvation; complex ions; free molecules; looks like lattice structure; delocalisation of charge; covalent bond present; van der Waals forces; simple molecule; sp hybridisation

L (A level student 9.92 - 6.94)

27.11.92

[deck 1] show each orbital in atom; show electrons as 'e' s; shows a positive nucleus; complete outer shell; symbol for atom shown; name of orbitals shown; electrons shown as negative, protons shown as positive; two atoms involved in covalent bonding; protons shown as positive; can identify which compounds they are (/it is); contain three orbitals; contain two orbital; stable atoms; one electron in outer-shell; eleven protons; seventeen protons; represent sodium; represent chlorine; represented as 3-D shape; involve two atoms combined; show electrons; what we learn at GCSE; what we learn at A level; orbitals represented as dumbbells; shows different types of orbitals; show what elements are involved; compounds in the form of a lattice; ion(s); show ionic bonding; shows the charge on each atom; involve covalent bonding; atoms stuck together; atoms repelling each other; involve atoms of the same element

Can Kelly's Triads be used to elicit aspects of chemistry students' conceptual frameworks?

M (first year A level student 9.92 - c.3.93)

19.11.92

[deck 1] able to form bonds; dealing with electrons and protons; bonds where electrons are being shared; a pair of electrons being shared between two atoms; molecule; show grouping of electrons; show structure when two types of atom are combined; show ions; paper drawn structure of a molecule; show orbitals; complete atoms; complete outer shell; double bonding; same atoms joining; three dimensional structure; bonding of different atoms; both hydrogen and nitrogen; four bonds; zero charge; hydrogen and carbon molecules

N (A level student 9.92 - 6.94)

06.11.92

[deck 1] group 1 metals; lose one electron to become stable; could join with group 7 non-metal 1:1; in form of a bond; covalent bond; stable; show s-orbitals; covalent bonding with one pair of electrons; non-metals; more than one orbital; single bond; use p and s orbitals; involve hybridisation; compound; one or more unhybridised p-orbitals; ion; forms a tetrahedral shape with angles of 109.5° ; neutral; atomic number = 8; period 3; group 7 elements; bonding involving carbon; ionic bonding; lattice; involve two different elements; charged; ethene; one double bond between two carbon atoms; ring shaped structure; alkene; C_nH_{2n} ; can be formed by dehydration; double bonds; hydrocarbon; oxidise to form CO_2 and water; used as monomer to make plastic; exists as S_8 atoms

11.11.93

[deck 1] element; molecule; pure covalent bonding; electrostatic forces; have full outer shells; ionic bonding; covalent/polar bonding; transfer of electrons; sharing of electrons; ions; metal; van der Waals forces; show a form of lattice; one non-metal, one metal; diatomic molecule; compound; two different elements; species shown have same electronegativity; double bond; alkene; attacked by electrophile; will dissociate in water; in period 2; in group 7; species show different electronegativity; alkane; get tetrahedral arrangement; angles are $109^\circ 28'$

18.11.93

[deck 2] showing trigonal bipyramidal structure; involve two different atoms; phosphorus in oxidation state 5; phosphorus molecule; showing lone pairs; showing tetrahedral structure; showing polar bonding; example of expanding the octet; showing a dimer; showing hydrogen bonding; dative covalent bonding; showing metallic bonding; alkene; delocalised; undergoes electrophilic addition reactions; undergoes electrophilic substitution reactions; reacts with bromine water; will undergo alkylation; will undergo acylation; got a ring structure; shows resonance between two canonical forms; shows double bond; aromatic compound; shows trigonal structure; positive charge on hydrogen; ions in solution; showing electrostatic attraction; induced dipoles; ion; intramolecular hydrogen bonding; extramolecular hydrogen bonding; showing an order of two in its bonding; linear molecule; shows slightly charged atoms; resonance hybrid; showing van der Waals; diatomic molecule; sharing electrons; showing a lattice structure; shows triple bond; sp hybridisation; sp^2 hybridisation; alkyne

P (A level student 6.92 - 7.94)

12.11.92

[deck 1] seven electrons in the outer-most shell; first shell is full, *i.e.* contains 2 electrons; second shell is full, *i.e.* contains 8 electrons; three shells present; neutrons present; chlorine atoms present; in group 7; in period 3; charge of 17+; two inner shells; great loss of electrons; great number of initial electrons - before any were lost; number of electrons is the same as value of charge; got four orbitals which help it to bond with four other substances; tetrahedral; hydrogen bonding present; covalent bonding present; double bond present; 2s orbital present; pi-bond present; 2p orbital present; charge present; three dimensional; ionic bonding present; lattice structure; carbon present; chlorine present; two different elements present; a type of tetrahedral structure; cube-like structure; metal and non-metal present; positive charge present; negative charge present; more than two atoms present; shells shown; in transition state; nucleus shown; type of bonding shown; neutral species

Q (A level student 9.92 - 6.94)

5.11.92

[deck 1] one electron outer shell; covalent bonding; atoms; gas; lattice; ten electrons; bond; charged; one type of atom or ion; two hydrogens; one oxygen; single element; contains nitrogen; four covalent bonds; contains halogen; closely packed; dislocation; double or triple bond; orbitals shown; molecular structure shown; elements shown; four bonds; double bond; water; contains pi-bond; four hydrogen; double covalent bond; contains carbon; single atoms; contains hydrogen

R (A level student 9.92 - 6.94 (dropped Chemistry during first year)

11.11.92

[deck 1] one electron short of a full outer shell; other shells drawn in; electrons as circles; electrons as 'e'; say what they are; got a 17+ charge in the middle; three shells; full outer shell; minus signs on some of the 'e's; got orbitals; got shading; got 'H's; symmetrical-ish; got structure(s); got brackets; written; got plus signs; two joined together; circular; say how many electrons are shared; got plus signs in the middle; all clumped together; got charges drawn in; double bonds drawn in; two different elements in them; 3-D drawing; simple sketch drawing; got a key

T (A level student 9.92 - 6.94)

10.11.92

[deck 1] one electron in outer shell; neutral species; ion; atom; electrons in K, L and M shells; unstable; same number of protons as electrons; shows rough placement of electrons in orbitals; molecule; contains bonds; covalent bonds; contain two different types of atom; ionic bonding; solid at room temperature; molecule of water; pass electric current; contains two or more different types of atom; shows s and p orbitals; hydrocarbon; diatomic molecule

18.05.93

[deck 1] shows shells; more than one electron; atom; ion; need one extra electron to have full outer shell; not have noble gas configuration; in period 3; element is magnesium; show noble gas configuration; in period 2; don't have full outer shell; show type of bonding; have full outer shell; contains only chlorine; contains one type of element; shows covalent bond; shows ionic bond; shows diatomic molecule; shows hybrid bonds; shows metallic bonding; shows lattice structure

7.10.93

[deck 2] contains phosphorus; all valent electrons used in bonding; shows degree of covalent bonding; contains two or more different atoms; shows hydrogen bonding; show carbon-carbon double bond; hydrocarbons; are bonded metallically; contain delocalised electrons; contain pi and sigma bonds; contain hydrogen ion; donates both electrons in order to form bond; show attraction for δ -ve part of molecule; metal ion present; show van der Waals forces; contain double bond; diatomic molecule; contains lone pair of electrons

24.1.94

[deck 1] show all the shells; shows a molecule; shows neutral species; shared, donated or gained electrons; shows molecular arrangement in lattice structure; shows delocalised electrons; represents a type of bond; diatomic molecule; shows strong characteristics of ionic bonding; gases at room temperature; can be made in the laboratory

[deck 2] contains phosphorus; stored underwater; to produce an unreactive atmosphere; contains one or more different element; represents dative covalent bond; shows hydrogen bonding; contains delocalised electrons; contains only covalent bonding; shows ions; contains sigma and pi bonds; hydrocarbon; conducts electricity; contains lone pair; shows hydration of metallic element; element hydrated with δ - side of H_2O ; shows van der Waals forces; diatomic molecule

9.5.94

[deck 2] has expanded octet; d-orbitals used in hybridisation; contains dative covalent bonds; intermolecular bonding (hydrogen bonding); dimer; delocalisation of electrons; hybridisation takes place; undergoes electrophilic addition reactions; undergoes electrophilic substitution reactions; acting as bases (accepting proton); lone pair influence on bond angle; specific arrangement of ligands; intramolecular bonding present; hydrogen bonding present; resonant structure(s); van der Waals forces exist in species; sp hybridisation

U (A level student 9.92 - 6.94)

25.11.92

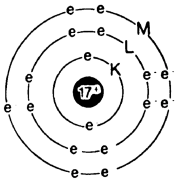
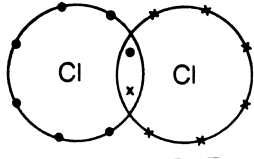
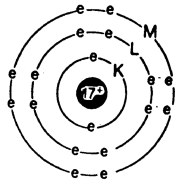
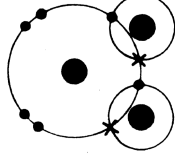
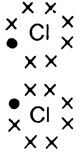
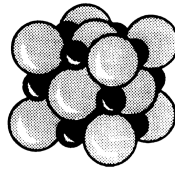
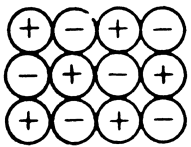
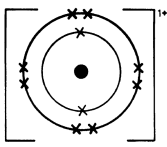
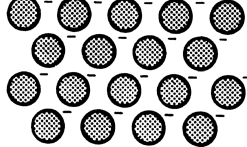
[deck 1] unstable; full shells; one covalent bond; four covalent bonds; three shells; two shells; eleven protons in the nucleus; two covalently bonded oxygens; two covalent bond; water molecules; hydrogen in; giant structures; difficulty in breaking bonds; probably charged; alkane; positive water molecule; ionic bonds; bonds present

V (first Year A level student 9.93-6.94)

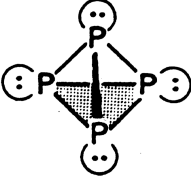
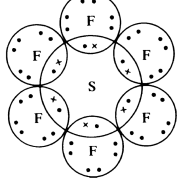
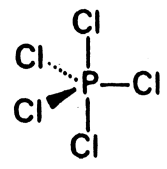
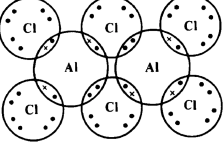
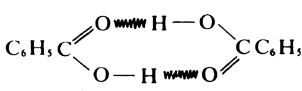
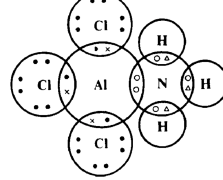
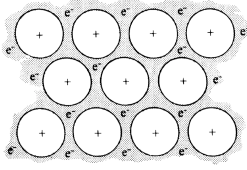
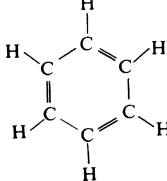
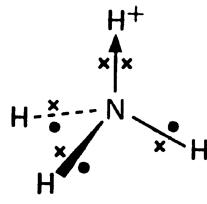
29.9.93

[deck 1] molecule; atom; covalently bonded; valency of 1; lattice; show electrons; contain chlorine; contain hydrogen; double bond; solid formation

Appendix B: Sample of 'elements' used in study (deck 1)

| | | |
|---|--|---|
| <p>126</p>  | <p>641</p>  | <p>656</p>  |
| <p>111</p>  | <p>313</p> <p>Ca</p>  | <p>653</p>  |
| <p>311</p>  | <p>441</p>  | <p>446</p>  |

Appendix C: Sample of 'elements' used in study (deck 2)

| | | |
|--|--|--|
| <p>229</p>  | <p>307</p>  | <p>349</p>  |
| <p>248</p>  | <p>338</p>  | <p>339</p>  |
| <p>207</p>  | <p>400</p>  | <p>179</p>  |