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CONSTRUCTING CHEMICAL CONCEPTS IN THE CLASSROOM?: USING RESEARCH TO INFORM PRACTICE

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ABSTRACT: There is now a considerable literature on the ideas that learners bring to classes, showing that pupils and students hold a wide range of 'alternative conceptions' about aspects of chemistry. This body of research is potentially of great interest to practising teachers in schools, colleges and universities. Yet is has been suggested that this research does not have the effect on actual teaching practice that would seem justified. Indeed it has been argued that there tends to be a discontinuity between the work of the educational researchers uncovering 'misconceptions', and those charged with developing the curriculum and actually teaching the learners. This paper discusses a project established by the Royal Society of Chemistry (in the UK) to attempt to bridge the gap between research and classroom, in order to encourage teaching practice informed by current chemical education research. [*Chem. Educ. Res. Pract. Eur.*: 2001, *2*, 43-51]

KEYWORDS: *learning chemistry; alternative conceptions; conceptual development; constructivism; research-practice divide; the Royal Society of Chemistry (RSC);scaffolding learning*

INTRODUCTION: MISCONCEPTIONS, ALTERNATIVE CONCEPTIONS AND ALTERNATIVE FRAMEWORKS

There is now a vast literature on learners ideas in science, that shows that school pupils, college students, and university undergraduates often hold technically incorrect ideas about scientific concepts related to their curriculum (Pfundt & Duit, 1991; Driver et al., 1994). These ideas may be present before any teaching of a topic commences, and are often also found after teaching has taken place. Sometimes the learners' alternative ideas that are found after tuition has occurred are unchanged, or are amalgam versions of the existing ideas and the content presented by the teacher (Gilbert, Osborne, & Fensham, 1982), but sometimes new erroneous ideas are formed during lessons (Taber, 1995a, 2001). Although much of the early work about learners' ideas in science derived from physics topics, there is now a considerable body of research discussing learners alternative ideas in chemistry (Griffiths, 1994; Garnett et al., 1995; Barker, 2000; Taber, 1999a, 2000a).

Much of the literature about learners' ideas in chemistry refers to 'misconceptions' (e.g. Schmidt, 1997), but this term is considered (by some authors) to imply a minor misunderstanding of the teacher's words that is readily put right, whereas many learners' ideas have been found to be tenacious and stable over long periods (e.g. Taber, 1995b, 2000b). The terms ‘alternative conceptions’ and ‘alternative frameworks’ are often preferred because these terms are seen to express something of the status that many of these alternative ideas are seen to deserve from a constructivist perspective.

The constructivist research programme

From this viewpoint learners are like scientists (Driver, 1983) - albeit untrained and sometimes sloppy scientists - who construct models of the world based on the best evidence available to them. These constructions can therefore have significant epistemological status for the learner, and may not easily be brushed aside. Much of the early pioneering research into learners’ ideas was informed not only by constructivist Piagetian ideas of how learning occurs (by assimilation to the existing mental models, followed by some degree of accommodation), but by the Personal Construct Theory of George Kelly. According to his ‘constructive alternativist’ view, each individual has a unique system of personal constructs (Kelly, 1963), which acts like a pair of distorting glasses through which the world is seen and interpreted (Pope & Watts, 1988). As we each have our own, individual and unique, pair of distorting goggles, we each see the world slightly differently: and science might be seen as the quest to hone our lenses until they are optically perfect - a difficult task as no one has seen how the world would look without the distortions.

‘Radical’ constructivists might demur from this metaphor: and argue that the world does not *objectively* exist as an *independent* entity, and so the notion of the perfect lens is invalid (e.g. Glasersfeld, 1989). However, in practice, most constructivists working in science education take a more pragmatic stand: learners’ alternative conceptions and frameworks are of importance because of their significance in the learning process: not because they are equally valid alternative views of the world!

Learners’ alternative conceptions may sometimes be relatively isolated pieces of misinformation, that are readily corrected (imagine a pupil had heard an older student report that sulphur was a metal) and such labile ideas do not offer a major problem to the teacher. However, some critics of the research into learners ideas have made the logical error of assuming that as alternative conceptions may be of this form, they all are (e.g. Kuiper, 1994). In fact learners’ conceptions can vary on a range of dimensions - such as complexity, consistency, context-dependence etc.

In-depth research shows that learners’ conceptions may sometimes be developed into integrated structures of inter-related and mutually supporting ideas, which have become reinforced over months and years as more and more chemical knowledge has been fitted into the complex of ideas (Taber, 1997a). Sometimes some knowledge has to be slightly reinterpreted to fit into the existing pattern: but this is not fundamentally different to the approach often taken by practising scientists. It is these alternative conceptual frameworks which are likely to prevent learners understanding the teacher’s intended meaning in science classes. For example, the ‘octet’ framework has been presented as a relatively consistent conceptual framework which students use to understand bonding, aspects of chemical stability, aspects of mechanism (e.g. bond fission), rationale for reactions occurring, patterns in ionisation energies etc., etc.: and which produces significant distortions in the way college level chemistry is understood (Taber 1988). Once established, this particular alternative framework has been found to be relatively stable, despite learners meeting increasing numbers of counter-examples that can not be readily fitted into its scheme (Taber, 2000b). Indeed, some evidence of ‘octet’ thinking has been found among science graduates training to teach (Taber, 2000c).

The constructivist research programme has been a major ‘paradigm’ in science education for the past two decades, and has uncovered vast catalogues of learners’ alternative ideas. The significance of this research has certainly been recognised in the UK where government standards for initial teacher training require new teachers to show they take learners’ likely ideas into account in their teaching.

Some critics have suggested that this research programme is in decline, having effectively run out of good ideas (Solomon, 1994), but it has also been suggested that a synthesis of research at the dual levels of learners’ conceptions and how information is processed in the brain will provide an agenda for a developing progressive research programme (Taber, 2000d). Current constructivist research does not just look at the alternative conceptions pupils possess, but also how conceptual development occurs (Taber, in press).

HOW RESEARCH SHOULD INFORM TEACHING

The vast catalogues of research into learners’ ideas in science should be a fertile resource for any teacher. Before teaching a topic, such as redox for example, the teacher should be able to check the research literature to find out what is known about both the alternative conceptions that many learners bring to class, and how (the intended) conceptual development is likely to be best brought about.

The body of research that exists not only provides insight into the most common alternative conceptions at different ages, but suggests *which* ideas might be best seen as barriers to further learning - and therefore need to be challenged - and *which* might be viewed as acceptable ‘staging posts’ in the learning process: and seen as acceptable ‘intermediate conceptions’ to be built upon. The literature provides ideas about the factors which are likely to influence conceptual change (Strike & Posner, 1985, 1992). There are also insights into how learners may use multiple frameworks (Taber, 2000b), and how this may even be *appropriate* in a subject such as chemistry (Taber, 1995c) where so much of our theoretical understanding is based on the use of multiple models (Carr, 1994; Harrison & Treagust, 1996, 2000).

The gap between research and teaching

Yet in practice many chemistry teachers continue to teach their subject as if none of this research has been undertaken. As de Jong (2000) points out chemical education research has not been applied in the way that the researchers had hoped. de Jong highlights a key problem here: teachers expect research to be presented to them in a form they can readily apply, and are too busy doing *their* job (teaching) to read the research literature; researchers expect teachers to interpret reported findings before applying them in the classroom, and are too busy doing *their* job (researching, and publishing in research journals) to communicate directly to teachers.

Some teachers may undertake small scale action research, but generally such work is not given status, and is usually not disseminated widely (Taber, 1996). As far as research undertaken by professionals is concerned, they may share their ideas with their own students (often trainee teachers), but it is largely aimed at peers. It does not seem to be anyone’s job to translate research into classroom practice, and as good professionals, teachers and researchers are busy getting on with their own jobs!

BRIDGING RESEARCH AND TEACHING: THE RSC PROJECT.

To the extent that de Jong has highlighted a major 'systems failure', what is needed is someone to bridge between research and teaching practice, and this in turn requires suitable funding. Clearly government initiatives, and established curriculum bodies might be among possible backers for this type of work. In Britain educational charities, such as the Nuffield Foundation, have a history of supporting this type of curriculum-related work. Another possible source of support is the range of professional bodies and scientific societies that often put a high value on their educational work.

The Royal Society of Chemistry (RSC), the professional body for chemists in the U.K., supports a wide range of educational activities relating to school science and college/university chemistry teaching. One of the RSC initiatives is to fund for a Teacher Fellow each year. This is someone who is employed (or seconded from other employment) for a year to work full time on an educational project. Each year a different project is selected. The outcomes of these projects are usually materials to support teaching in schools and colleges, and are distributed free along with a range of other useful material that the RSC funds or produces.

The Teacher Fellowship project for the 2000-2001 academic year (i.e. September 2000-August 2001) is concerned with the area of learners' misconceptions in chemistry over the secondary age range. (In the U.K. this means ages 11-18: so from starting secondary education, up to university entrance level.) The Teacher Fellow (i.e. the author) has been seconded from work in initial teacher education to produce classroom materials and supporting documentation aimed at helping teachers diagnose and challenge learners' alternative conceptions in chemistry topics.

There is clearly a limit to the amount that can be achieved in one year, and with the literature being so vast there will clearly need to be some selection of the topics to be tackled. The main criteria will be those areas that are seen as most central to the conceptual structure of the subject, and where research evidence suggests learners may commonly hold extensive and well integrated alternative conceptual frameworks that are likely to be tenacious and act as barriers to further learning. Perhaps if the initiative is judged as successful it will encourage sponsors to provide further funding for this kind of work, and the RSC project will lead to effective translation of research into practice becoming more commonplace.

Diagnostic assessment tools for teachers

The constructivist literature emphasises that the teacher always has to teach from where the students are (in terms of knowledge development) rather than where the teacher would *like* them to be, or where the curriculum suggests they *should* be. It is therefore recommended that at the start of the teaching sequence learners' ideas need to be made explicit to teacher and student alike (e.g. Driver & Oldham, 1986). Clearly there are many ways that the teacher can attempt to do this (White & Gunstone, 1992), but the teacher needs to select methods than can be used effectively in classroom contexts within the time limits available: the types of research interview common in the literature (Gilbert, Watts, & Osborne, 1985) would not be a suitable approach!

Although applying an approach such as concept mapping or word association as part of teaching does not require specialist methodological knowledge, it is still the case that diagnosing alternative conceptions from learners' responses does presume a sensitivity that is unlikely without some knowledge of the types of ideas learners have been shown to have. In other words, the teacher needs to have read about the research findings, and - as has already been pointed out - most do not have the time for this, even assuming that they have ready access to a good library.

Yet some published research clearly uses diagnostic instruments that could be readily modified for use in teaching if they were to be presented with suitable documentation in a teacher-friendly form. Some of these instruments are already reported in the practitioner literature (e.g. Taber, 1997b, 1999b), but these examples tend to be exceptions.

This is clearly an approach that can be built upon in the RSC project. For example, research shows that many 15 years olds in the UK may have difficulty classifying particle diagrams as representing elements, compounds or mixtures (a distinction rather fundamental in chemistry, and usually assumed to have been understood earlier in the learners' school career). The questions used in the original research (Briggs & Holding, 1986) are being used as the starting point for writing a suitable probe for use in a teaching context.

In the RSC project it is intended to present teachers with a simple probe (to help teachers see if their pupils can make the distinction) that can be photocopied for classroom use, along with documentation: explaining the types of alternative conceptions that research suggests pupils are likely to hold, advice about what to look for in learners' responses to the questions, and how best to respond to take pupils' ideas forward.

Conceptual scaffolding tools for teachers

Indeed, it is likely that some of the materials that will eventually be included in the resource pack distributed to U.K. schools and colleges will be of just this type: materials to help teachers elicit and identify learners' alternative conceptions. However, it is hoped that at least some of the materials will go *beyond* diagnostic assessment, and will actually be seen as teaching materials. It is intended to prepare follow-up exercises for teachers who apply the elements/compounds/mixtures probe, and find that their pupils have alternative conceptions in this area. Whereas some of the project materials might primarily be seen as useful in identifying alternative conceptions, it is hoped that other components will be valuable in helping learners construct new chemical conceptions, and move their thinking on.

The aim here is to apply research about common alternative conceptions, alongside current thinking about how to encourage conceptual development, to try and provide classroom exercises which challenge learners' ideas, and help them to develop more scientifically acceptable notions. An example would be a draft probe which is designed to elicit (if present) a common conception of carbon as being a monatomic species at the molecular level (as it has the symbol C c.f. O_2, S_8 etc.), and then present a challenge to this in terms of carbon's high melting temperature.

It is intended that all the materials produced will be trialed in schools and colleges before final publication, and it is possible that the specific materials I have referred to will be modified or eliminated if they are not found to be useful in classrooms: however, these examples provide a taste of what the project is aiming to achieve.

A research aspect to the project

Whilst the RSC project is primarily about translating research findings into useful practice it will also have something of a research flavour. The testing out of materials in real classrooms will provide an opportunity to collect further data about learners' ideas, and - perhaps more significantly - how they respond to attempts to challenge and develop their conceptions. During the year that the project runs, returns from schools and colleges will be scrutinised to inform decisions about modifying, adopting or eliminating materials from the set to be published and distributed by the RSC. However, the data set acquired in this process might well provide further more general insights on later analysis.

The project also provides an opportunity for a type of dialogue that some feel is somewhat lacking among science teachers these days. In the U.K. in recent years there have been moves to standardise school curricula, to ensure examinations boards have very similar syllabi and examination specifications, and to emphasise performance against standard tests at several points in the school system. Although all these developments have been prompted by a genuine concern for the learner's school experience, they have considerably reduced the opportunity for teachers to show individual flair and creativity.

Indeed, many of the decisions that school departments used to make (in this country) about when to teach topics, and how to order key concepts, have been significantly curtailed by the need to meet specific targets by certain ages. Many of the discussions about how to better help learners cope with the high theoretical and conceptual nature of a subject like chemistry are now much rarer, because in practice the teacher has much less flexibility to try radical teaching approaches.

It is hoped that the RSC project will be able to use existing research findings, and the experience of school trials of project materials, to promote a dialogue between teachers, and other interested parties, about key issues relating to the appropriate depth and ordering of chemistry topics to bring about optimum understanding for learners. Perhaps the outcomes of a project sponsored by an esteemed body such as the RSC will actually carry some influence with the curriculum and examination authorities.

An international perspective

This brings me to consider the apparently insular nature of the project. The RSC has a world-wide membership, but is primarily a UK organisation. The materials that are prepared will be published in the English language and will only be widely distributed within the UK.

To the extent that alternative conceptions develop from the individual's experiences, these are partly mediated through cultural and linguistic norms. Some alternative conceptions certainly have origins in the way the same words are used for distinct technical and everyday meanings: and this will vary from language to language. Some alternative conceptions have been reported to derive (at least in part) from the way in which topics are presented in the curriculum: and this will vary between different countries even when the same language of instruction is used. Comparative studies therefore offer a way of exploring the extent to which the incidence of particular alternative ideas is bound to specific social, linguistic or bureaucratic contexts, rather than being largely a function of, say, general human cognitive functioning.

The RSC project is basically a British initiative. However, the RSC as a body encourages mutually beneficial co-operation with colleagues in other countries (for example, through FECS). It is hoped that lessons from the RSC project will prove valuable to colleagues in other education systems, and may perhaps lead to useful international collaborations.

A number of colleagues from schools and universities in other countries (mostly, but not all in Europe) have expressed an interest in being kept informed with the work as it develops, and even trying out or adapting materials for use with learners in their own countries.

CONCLUSION

In this paper I have referred to de Jong's (2000: p. 29) description of the 'gap between research and teaching' that has often prevented the findings of chemical education research being widely adopted by practising teachers. If we accept de Jong's critique, and in particular his conclusion that neither researchers or teachers have the time, nor see it as their responsibility, to translate research findings into classroom practice, then this leads us to perceive the need for someone to bridge the 'gap'. I have described the RSC initiative to appoint a Teacher Fellow to start work on constructing that bridge - at least as far as research into alternative conceptions is concerned. Clearly one such initiative alone would be papering across the chasm: which makes it even more important that this project is judged a success, and a worthwhile target for financial support.

I have outlined the plans for the project in terms of the type of material that it is hoped to produce. The project is managed by the Education Manager (Schools and College) at the RSC, and management's main concern will be that quality (well informed, clearly written, teacher friendly) copy is produced ready for editing into a coherent publication. However, the presence of a file of resource materials in school science labs. will not be proof of the real success of the project.

Any eventual evaluation of the worth of the project will have to be against wider criteria. In particular: *has the initiative enabled classroom practice to be better informed by chemical education research, without asking teachers to make unreasonable efforts to familiarise themselves with the research literature?* If the answer is 'yes' then this project will have done something worthwhile to help bridge the gap between chemical education research and practice.

Any reader wishing to receive further information about the work should contact me at the Institute of Education in London.

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