Science Education International
Vol.21, No.1, March 2010, 5-30

International Council of Associations for Science Education

Challenging gifted learners: general principles for science educators; and exemplification in the context of teaching chemistry

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Abstract

There is concern in some counties about the number of able young people entering degree level study and careers in physical science, including chemistry. Too few of the most talented young people are selecting 'STEM' subjects to ensure the future supply of scientists, engineers and related professionals. The present paper sets out general principles to inform science teaching that will engage the most able learners, and hopefully encourage them to select science-based courses in higher education and aspire to careers related to science and technology. The nature of high ability and 'giftedness' is briefly reviewed, and the educational needs of the most able students are considered. It is suggested that chemistry is particularly well placed to offer contexts for the type of educational provision suitable for engaging and challenging the most able students, and examples of how the general principles recommended here might inform the planning of chemistry teaching are discussed.

Key words: *giftedness in science, needs of gifted students, provision for gifted students, challenging the most able students.*

Introduction

Continued scientific and technological progress depends upon sufficient numbers of young people selecting scientific courses in post compulsory education, and aspiring to enter science related professions. Encouraging an increasing level of interest in scientific courses and careers is an ongoing concern of governments in countries with both well-established and developing scientific and industrial traditions. For example, in the UK, there has been extensive concern about 'STEM' (Science, Technology, Engineering, Mathematics) issues, including the limited supply of well-qualified graduates entering teaching to enthuse and educate future generations of science students and scientists (HCSTC, 2002, 2005; HLSTC, 2006).

Whilst the supply of people to join the scientific workforce is important at all levels, the present paper concerns the sub-group who are likely to become the researchers, innovators, academic scholars, and inspirational teachers of the future: the group of students that might be judged highly-able or in some educational contexts labeled as 'gifted'. Whilst both the identification and labeling of the gifted are problematic (as discussed below), the need for developing the interests and scientific understanding of young people who can work in science and technology at the highest levels is not contentious. In many countries there is perceived to be a serious shortfall of suitable candidates for this work. It seems that not enough of those who are high-achievers in school opt to take scientific studies and careers, presumably as other options are considered more attractive.

There may be many factors that contribute to such a situation, and these will at least in part vary according to the 'local' cultural conditions (Sjoberg, 2000). Among those that might be considered are the perception of science and technology in society (e.g. as responsible for meeting human needs vs. causing environmental problems); the perceived status of careers in science, engineering and science teaching compared with other professions; the perceived difficulty of science courses compared to the humanities etc. It has also been argued that science education needs to better engage, *and develop*, learners emotionally as well as intellectually (Alsop, 2007).

Whilst this is no doubt a complex issue, the present paper is primarily concerned with one particular factor: *the perceived intellectual challenge of science*. Traditionally, science subjects have been considered difficult – 'hard' subjects where good grades are not readily obtained - and this has been one factor that has deferred many young people from opting for science in post-compulsory education. Yet research with the most able students demonstrates that those in this group are unlikely to find this off-putting. Indeed, it is reported that gifted students actually appreciate being challenged in their learning, often recognising that work that is not challenging them is not helping them learn, and consequently is not valuable for their education. These students report, or example, being "dissatisfied with over-generalised explanations and inadequate detail" in their science classes (DfES, 2003).

However, 'difficult' and' challenging' need not be synonymous. Where the most able learners may demonstrate tenacity and high levels of engagement with work that requires high level thinking, they are likely to be very easily bored and frustrated by work which requires a lot of time and effort without being intellectually demanding - such as undertaking large numbers of routine questions as 'drill' to reinforce key ideas.

So for science to be attractive to this group of students, it must be challenging as well as being seen as relevant (which may mean in terms of everyday life, society's needs, personal interests, career aspirations, or even just being clearly useful to meet intrinsic learning goals). The present paper draws upon current thinking to explore the characteristics of challenging school and college science.[i]

Moreover, the paper makes a particular case for chemistry as a science that naturally lends itself to developing challenging science education that should intrigue and engage the most able learners. Although the present paper is primarily concerned with secondary and college level teaching and learning, it is clear that many of the same issues arise in higher education, and many of the recommendations made here are applicable in undergraduate courses as well.

The nature of high ability and giftedness

Terms used to describe the most able

Terms such as ‘gifted’, ‘highly able’, ‘exceptionally able’ are commonly used informally in educational discourse without clear definitions (Maltby, 1984), and where they are formally defined (DfES, 2002; Heller, 1996; Montgomery, 2003; Sternberg, 1993), these definitions are often contentious (Taber, 2007a), as of course are the potential consequences of labeling individuals, e.g. as ‘gifted’ or ‘not gifted’ (Rosenthal & Jacobson, 1970). Nonetheless, the notion of gifted pupils in science, and the special provision for this group, are well established. So Fisher describes one project (the ‘Brentwood project’) working with English primary (elementary) pupils in the 1960s where 10-year olds would actively discuss “the factors which affect the pressure of a gas, being treated in a semi-formal manner, and here was a powerful demonstration of the advanced ability to separate variables and exclude variables in the investigation of relationships” (Fisher, 1969).

The most able students (in academic contexts, such as school science) may be those we would describe as having high intelligence, but again this is a construct that has been interpreted in various ways (Gardner, 1993; Sternberg et al., 2000), and the extent to which the most common forms of measurement (e.g. in terms of IQ scores) are suitable for identifying the gifted is subject to ongoing debate (Gould, 1992; Montgomery, 2003).

Howard Gardner (1993), for example, has argued from a diverse range of evidence that human intelligence should be considered as having a number of largely distinct domains, of which only a small subset tend to be stressed and formally assessed in academic schooling. Gardner refers to ‘multiple intelligence’, and suggests that an individual’s intelligence should be understood in term of a profile of strengths and weaknesses across these different faculties,

However, Gardner also acknowledges that those ‘intelligences’ that do tend to be stressed in school curriculum specifications and assessment (e.g. ‘linguistic intelligence’, ‘logico-mathematical intelligence’) do tend to be those that are most relevant to success and progression in academic study. None-the-less, it would seem that, for example, ‘intrapersonal intelligence’ would relate to the metacognitive skills that support effective study habits, and that ‘interpersonal intelligence’ is important in modern science which has a strong collaborative nature with much work done in teams.

Robert Sternberg has also been critical of conventional IQ tests, and has worked over many years to develop alternative, more inclusive, notions of intelligence that better reflect what he has labelled ‘practical intelligence’ and ‘successful intelligence’ (see Taber, 2010). Sternberg (1997) has also written about who learners have different ‘styles’ of thinking and learning, such that a teacher’s evaluation of which students in a class are especially able (or not) can shift dramatically when the style of teaching presentation is altered – that is the same teacher changing their way of developing a topic for their students. This may be very relevant when educational research suggests that what seems a logical approach to developing a topic from the perspective of the subject expert, may be far from optimal from the perspective of the students' current understanding.

These are important debates (see Taber, 2007a for a more developed discussion of these issues), but a key point for the purposes of the present paper is that different ways of defining the most able students have been suggested. Regardless of the academic debates, school systems need to meet the needs of *all* their learners, including those capable of working at the highest levels (however defined).

Discussions of ability may conflate issue of current attainment levels, and a student's potential or aptitude (e.g. to what extent are students from under-privileged backgrounds disadvantaged in the school system, and to what extent can educational environment remediate for early disadvantage?) This is important, as for some scholars giftedness is not a given, it is something that can be developed (Stepanek, 1999). Indeed, whilst current academic attainment may often be a good indicator of future progress, it is by no means the case that all intellectually gifted adults would have been identified as gifted in school – Albert Einstein being a case in point (Pais, 1982).

Scaffolding learning

Whatever view one takes of the desirability and dangers of describing learners by labels such as 'gifted', it is clear that
a) in any class of children there will be a range of current levels of attainments, strengths, interests, motivations to study, learning styles etc.
b) effective schooling has to seek to meet the needs of all students – and so this will include the most able, however defined.

A useful perspective here is that of Vygotsky (1978), who introduced the notion of the ZPD, the zone of proximal development. The ZPD is the 'zone around' the things an individual child can currently achieve alone, and encompasses what they can do when supported by the teacher or a more advanced peer. The zone is not seen as a uniform 'border' on current capabilities, but a more dynamic 'space' that depends upon the learner and the particular learning being undertaken. From this perspective, the teacher should focus not on what the learner can do now, but rather on extending that by supporting learning within the ZPD. For a child learns to develop capability by initially being supported by others, and then gradually taking over full responsibility for a task (as the 'scaffolding' of support is removed, Wood, 1988). From this viewpoint the focus is on *what can be achieved next*.

The task of the teacher of gifted learners then, however we may define them, is (as with all other students) to 'scaffold' them to achieve what is currently just beyond their capability but possible with structured support. A good working hypothesis for a teacher will be that gifted learners can be challenged by scaffolding which assumes these particular learners will need to be provided with less explicit detailed structure than most of their peer group.

A pragmatic notion of giftedness in science

The position taken in this paper then is that although (a) it *may* well be inappropriate to consider some pupils as (permanently, and in all contexts) gifted in science, and others as (permanently, and in all contexts) lacking such ‘gifts’, (b) it is nonetheless important that all students are engaged in activities that are sufficiently demanding to offer intellectual challenge, and (c) notions such as the ‘gifted’ or the ‘highly able’ that are common parlance in education may be useful reminders that work that ‘stretches’ some learners will often offer little or no challenge to some of their classmates.

This pragmatic utility of the notion of the gifted science student, leads to a working definition of such students as those *able to either achieve to exceptionally high levels of attainment in all or some aspects of the normal curriculum demands in school science* or *able to undertake some science-related tasks at a level of demand well above that required at that curricular stage* (Taber, 2007a; Wood, 1988). This is an open-ended definition that is permeable (it admits students being considered gifted in terms of some aspects of school science, but not others; it does not permanently exclude students from being considered gifted in the future based on current judgements) and is focused on the key issue of matching educational tasks to the student’s ZPD.

This permeability even allows students with ‘dual exceptionalities’ to be consider gifted in appropriate circumstances. These are learners who suffer from some specific learning difficulty but also have ‘islands’ of exceptional ability (Winstanley, 2007). For example, students who suffer from difficulties that restrict their level of reading and writing are likely, even if otherwise potentially gifted, to show limited levels of general educational attainment. However, in some science learning contexts these learners may be facilitated to demonstrate high levels of ability (when not judged by their written accounts). Science can clearly offer opportunities for such students to excel, even when their gifts may be masked in most other academic subjects.

Identifying the ‘gifted’ learner

Whilst gifted students are likely to perform well on standard classroom tests, these may not always be the most reliable guides to giftedness. Where such tests are designed to allow conscientious students to perform well, they may be most suited to the hard working students with strong memories, and lack the types of demanding items most likely to challenge and engage highly able students (and so discriminate the ‘gifted’ from others who are performing well in response to an *appropriate* level of challenge in class). If we are to identify the gifted in science, then we need an approach that characterises them in terms of their aptitude for learning from more demanding science instruction, and not just their high scores on existing tests. [ii]

There are various ‘check-lists’ available, that collectively provide a large number of specific indicators suggested as useful for identifying students who should be considered ‘gifted’ in science (e.g. DfES, 2003; Gilbert, 2002; Stepanek, 1999). It has been suggested that these indicators can be organised into four main clusters (Taber, 2007a) relating to cognitive skills, curiosity, metacognitive sophistication, and group-work skills. Only the first of these relates directly to the types of tasks on traditional intelligence tests (Kaufman & Grigorenko, 2009).

Whilst traditional scholastic aptitude is not the only area where characteristics of the gifted should be sought, it is clearly the case that students who are likely be considered gifted in science will demonstrate conventional academic ability (if occasionally masked by limited literacy in some cases). They will understand new concepts quickly and follow complex arguments; suggest novel ideas; adopt technical vocabulary readily; spot connections between concepts, between topic areas and across subjects; make deductions and draw inferences effectively; offer nuanced and detailed explanations; and cope with work that is highly conceptual, abstract and theoretical.

Gifted students are also said to be likely to show high levels of curiosity. They are reported to have hobbies and interests (sometimes highly specialised ones) involving collecting, sorting and characterising; they may spontaneously make observations and ask many questions requiring explanations ('why…?'), and seek the derivations of terms and ideas; they may have a strong motivation for inquiry work, and a propensity for measuring and counting.

These students may also demonstrate a greater tendency to think about their own thinking and learning processes than most students; they often demonstrate high levels of concentration, intrinsic 'epistemic hunger' (i.e. seeking 'deep' levels of understanding, Felder & Brent, 2005); they may often monitor, evaluate and direct their own learning beyond what is normal for the age, and may spontaneously produce their own summaries and overviews.

Finally, it has been suggested that at least some gifted science learners are able to take on roles, and exercise effective leadership, in group-work. As well as showing autodidactic tendencies, sometimes gifted learners make effective peer tutors as they are keen to demonstrate their knowledge and are creative in find ways to explain ideas to classmates.

Of course, students do not need to meet *all* of these these criteria to qualify for being potentially under-challenged in school science, and some such students will more obviously match some indicators than others.

Engaging the most able students

> You sort of research, and I find it quite interesting researching and finding how things work and finding why they happened, and linking them between different…like interpretations, and other things, and at the moment were linking it all together, so yeah, that's quite interesting
> A secondary student explaining why he intends to study history after leaving school (from Taber, 2007b: p.xiii)

Gifted science learners need a curriculum that meets their needs, and challenges them - whether as a special group provision, or as part of the differentiation of provision for a wider group of learners. Teachers will have more opportunities to design lessons to meet the needs of groups of students where the prescribed curriculum allows flexibility in selecting content according to local needs (Coll, 2007). However, there is much that can be done to plan engaging and challenging lessons, even with a highly constrained curriculum.

Provision for the gifted is sometimes divided into that which is considered as 'accelerated learning', i.e. "giving students school work that is in keeping with their abilities, without regard to age or grade" (NDoE, 1997: 56) and 'enrichment', which is "the provision of in-depth multi-disciplinary exploration of content beyond that provided in the regular curriculum" (NDoE, 1997: 32). The UK government offers the following suggestion,

> Provision [for the gifted] should include extension in depth and enrichment in breadth: extension through additional support and challenge, and enrichment through opportunities in the classroom and outside school.
> (DfES, 2002)

Some enrichment opportunities can be found outside the normal school day, such as programmes providing optional science sessions where keen and able students can undertake activities designed to challenge them intellectually (Taber & Riga, 2006, 2007), or through summer schools, schemes to develop students' creativity (such as the CREST, Creativity in Science and Technology, awards scheme organised by the British Science Association) and Olympiads and science fairs.

Another rather specific form of enrichment is that of providing gifted learners with mentors – "experts in a field who may assist a student with his or her understanding in that area" (NDoE, 1997:85). A well-chosen mentor can be a strong influence on a gifted young learner (Ayyavoo, Tzau, & Ngai, 2005). However teaching is organised, it is important that the nature of the learning that is promoted meets the needs of gifted learners, that is that the challenge is matched to what they are capable of. A number of principles of good practice in this area have been proposed (Gilbert, 2002; NDoE, 1997; Stepanek, 1999; Taber, 2007c; VanTassel-Baska, 1998).

According to this scholarship exploring provision for the gifted in science, the most able learners are more likely to be engaged and developed when teaching:

- focuses on conceptual content
- emphasises enquiry and production
- demands higher-level thinking
- supports intra- and inter-personal learning
- offers pace, variety and choice

These principles can be applied widely in the curriculum, and certainly can be adopted to inform the planning of teaching across science subjects. Whilst leading to some overlap, these five themes can be useful in exploring how teaching can be planned to meet the needs of the most able learners.

Chemistry as a context for challenging science education

In the rest of this article, chemistry is used as a context for exemplifying the application of these principles. Chemistry is a subject that presents particular learning difficulties for many students, due to the abstract nature of its ideas (Taber, 2009a); the tendency of students to interpret its phenomena in unhelpful 'intuitive' terms (Taber & García Franco, 2010); and because it requires learners to be able to shift between bench phenomena, a range of symbolic representations, and explanatory molecular models (Gilbert & Treagust, 2009). However, what makes chemistry seem too challenging for many learners, may also make it an excellent context for meeting the needs of the most able.

Focus on concepts

Teaching for the gifted should have significant and deep content, with an emphasis on learning and understanding concepts rather than memorizing facts. Modern chemistry courses seem ideally placed in this regard. Whilst chemistry is undoubtedly a subject where there is an immense 'factual' knowledge base, and some gifted students will take great pleasure in learning atomic masses or melting temperatures, modern courses put emphasis on the understanding and application of basic principles: e.g. the basis and utility of the periodic table, rather than learning the positions of the elements. Fundamental chemical concepts such as 'element', 'compound' and 'reaction' are known to be challenging for many learners (Taber, 2002), but open up a whole new way of understanding the material world, changes in materials observed in nature, and ways of designing materials to solve technological needs. Chemistry is often considered one of the most difficult subjects in the modern school curriculum, because it is based about highly abstract concepts: enthalpy; entropy; oxidation; reactivity; valency, etc.

Indeed one of the key challenges of modern chemistry courses that has been identified as a key barrier for many students is the use of the particle theory: that materials and processes observed in the macroscopic world are best understood by a conjecture that all matter is composed of 'quanticles' (ions, molecules, electrons etc) that have properties distinct from those of the directly observable world, and which interact and combine according to a formal set of rules that can only be deduced indirectly (Taber, 2001). This is just the kind of subject matter that is likely to dishearten many students unless very carefully introduced and supported in their learning (Harrison & Treagust, 2002): but also just the kind of intellectual system of ideas likely to appeal to many of the most gifted learners (Georgousi, Kampourakis, & Tsaparlis, 2001).

Context-based courses

One important development in the chemistry curriculum over recent years has been the move to courses that teach chemistry through contexts: that is rather than teaching the principles, and then applying them, a course unit starts from a key issue, problem or concern, and the pertinent chemistry is then introduced (Bennett, Hogarth, & Lubben, 2003). As with practical work (considered below), it is easy to see context-based courses as providing a way of motivating less able or engaged learners who may find theoretical approaches daunting or dull. However, there is no reason why a context-based approach cannot also be used to challenge the most able learners (Kind, 2007).

Context-based courses move away from (or at least, have to fit other priorities around) one of the well-established principles of instructional design, which is to sequence learning based on the inherent structure of a discipline (Bruner, 1966; Gagné & Briggs, 1974). Conceptual analysis enables teachers to identify which concepts acts as pre-requisite knowledge for other concepts (Herron, Cantu, Ward, & Srinivasan, 1977). This allows the development of teaching schemes where the more basic ideas are introduced early, and then can be used to support further learning.

However, in a subject such as chemistry where many key concepts may seem counter-intuitive (Taber, 2008a), it is may not be sufficient to sequence concepts logically when planning for progression. Abstract ideas may take time to be consolidated, and become sufficiently robust to act as the foundations for further learning (Taber, 2004). So key ideas may need to be introduced early, and then reinforced by being revisited in a range of contexts, before it is assumed that they may be treated as part of the available prior knowledge on which more sophisticated learning can be based.
This presents a challenge for the designer of context-based teaching.

- Does teaching through context need to compromise the most logical approaches from the viewpoint of conceptual development?
- And if so, are there gains in student engagement that can cancel such disadvantages?

These are empirical questions that need to be investigated in authentic teaching contexts. However, it may well be that gifted learners, who are often characterised as acquiring concepts more readily than their peers, would find such compromises much less detrimental than other learners, as we might expect that they are likely to need less reinforcement of basic concepts to fully consolidate them. These points are made tentatively, in terms of what seems feasible based on our current understanding.
For one thing, as suggested above, "gifted learners" should not be considered as a distinct and homogenous group sharing the same set of learning characteristics. Indeed, from the perspective outlined above, giftedness is less a permanent characteristic of an individual student than a useful label that describes the current state of a nexus of considerations (see figure 1). In simple terms: who is judged as gifted will, *in part*, depend upon what we are asking students to learn, and how we set up the context for that learning.

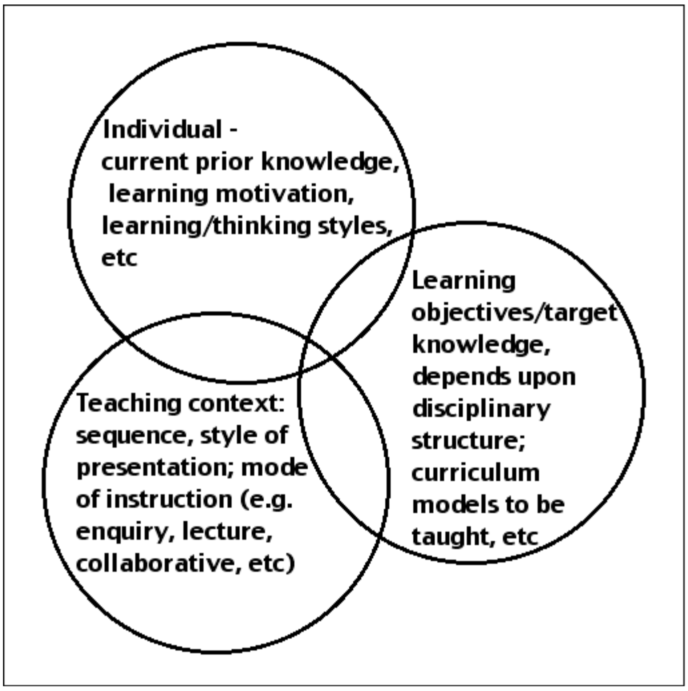

Figure 1: Judgements of giftedness are in part about individual learners, but are made in the context of particular learning and teaching contexts.

That is not to suggest that there may not be some individuals who would be considered gifted in a wide range of learning contexts, whilst many other students would not be likely to be judged gifted in any typical academic setting. However, this does raise the question of whether some students who might be considered gifted when learning a course organised primarily according to an expert view of the logic of disciplinary structure, might seem less gifted when taught through a more thematic context approach, and of course *vice versa*. Clearly more research is needed (a point returned to at the end of this paper) in this area to find out just how gifted learners respond to context-based courses.

Emphasis on enquiry and production

Effective learning for the gifted can be organised around an enquiry approach with students taking the role of active investigators. The context may be laboratory work, but could also be other forms of problem-solving, for example those that depend upon the ability to use mental simulation to ‘run’ thought experiments (Georgiou, 2005). Intellectual puzzles may be highly motivating to gifted learners.

Knowledge discovery and knowledge construction

A personal constructivist view of teaching and learning (e.g. Pope & Gilbert, 1983) sees learning as an active process that takes place *within* the learners’ mind (Taber, 2006). However, teaching is an activity designed to support learning, and a social constructivist view locates important aspects of the learning process in the ‘intra-personal’ plane through interactions: between teacher and student; between students (Scott, 1998). So students with sufficient background learning might be able to ‘discover’ scientific principles when supported by teaching that helped them bring relevant prerequisite knowledge to mind and to structure it in certain ways. (An example of how this might be scaffolded in the case of hydrogen bonding is discussed in Taber, 2002). However, as is well recognised, in the absence of sufficiently strong scaffolding students are likely to 'discover' principles at odds with scientific knowledge (Driver, 1983)!

Whilst 'pure' discovery learning has rightly been criticised for expecting learners to repeat the great intellectual leaps of scientific 'greats' (Mayer, 2004), this of course reflects an extreme position to be contrasted with the (similarly deficient) transmission model of teaching. In other words, good teaching may be seen as the 'guided construction of knowledge' (Edwards & Mercer, 1987; Mercer, 1995). *In principle* gifted learners are no different to other students in this regard: it is the judgement of *how much* can be discovered with *how little* scaffolding which is key here.

Indeed some would argue that learning is best facilitated in forms that approximate the 'natural' processes by which the novice is initially allowed to undertakes 'limited peripheral participation' (Lave & Wenger, 1991) within a community of practice (Hennessy, 1993). This type of model is easy to apply at the highest educational level, the research student working within a University research group (cf. Kuhn, 1996), but more problematic in a typical classroom context where one expert (the teacher) works with a score or more of novices. On the other hand, authentic enquiry potentially provides a context for students to experience something of a cognitive apprenticeship within a community of learners (Polman, 1996). In a school context, this could mean using gifted students as peer-tutors or as mentors for younger students.

Laboratory projects

Practical work is sometimes considered a strong motivator for those students who struggle with theory. However laboratory work is central to chemistry as an empirical science, and also offers a suitable context for devising challenges for learners. Where possible, student enquiries should allow the investigation of real problems and situations, rather than being artificial exercises to produce answers that can be more easily found by asking the teacher or checking a book (and where gifted students may well already know the answers). These latter forms of 'recipe' investigations are both intellectually barren, and tend to undermine any attempts to teach about the nature of genuine scientific enquiry (Millar, 2004; Taber, 2008b). Extended project work, either within the normal classroom context, or as an enrichment opportunity, gives more scope for students to be offered an authentic experience reflecting scientific enquiry (West, 2007). Such projects offer opportunities for meaningful planning based on literature searches, and realistic time scales for producing outcomes, giving meaningful cycles of evaluation and development. Gifted learners will benefit from the opportunities for regulating their learning and the challenge of a complex problem context that does not respond to a simply application of taught knowledge.

Learning products

Where possible, gifted learners can be set tasks exploring genuine problems, and/or producing authentic products where their findings can be reported to a genuinely interested audience (Mackin, Macaroglu, & Russell, 2005). An alternative to laboratory work could be the design and justification of a teaching analogy for use with younger students, or the development of a role-play or simulation (Dorian, 2009) to illustrate a chemical principle.

Authenticity could be achieved by setting groups different aspects of a topic or issue to research and explore, so that the class as whole provides a meaningful and receptive audience for any poster, presentation, model, role-play or other outcome produced by students (Newberry & Gilbert, 2007). The processes of defending a group's product, and offering constructive critiques of the work of other groups can be highly engaging (Yoon, 2005) as well as challenging.

Higher-level thinking

The notion of 'higher-level' thinking in education is often linked to Bloom's taxonomy of 'educational objectives in the cognitive domain' (Taber & Corrie, 2007). Bloom's (1968) original taxonomy has been updated (Anderson & Krathwohl, 2001), but the general principle is that, all other things being equal, there is a hierarchy of task-demand in different types of cognitive tasks required of learners. So recall of information is straightforward. Demonstrating comprehension, or applying ideas, make greater cognitive demands, but are generally still relatively lower level skills. Of course that is *not* to say either that such tasks cannot be demanding in some contexts *nor* that teachers should not set such tasks. However, teaching that sets all or most student demands in terms of recall, comprehension and straightforward application (i.e. in the context of practice exercises, rather than as part of tackling genuine problems) is not likely to challenge students. The higher-level skills are creation/synthesis (appropriate in chemistry!), evaluation, and criticism/analysis.

In chemistry at higher education level this distinction has been championed by Zoller (1993) who refers to LOCS (lower-order cognitive skills requiring algorithmic approaches) and HOCS (higher-order cognitive skills associated with critical thinking and problem-solving). Zoller has strongly argued that traditional teaching approaches in University chemistry often rely too heavily on LOCS, rather than being based around instruction that emphasises HOCS. Similarly, at school level, Zohar has described a project to base science lessons on the teaching of 'higher order thinking' alongside the prescribed science content (Zohar, 2004). Within the context of the English curriculum, which has a series of 'levels' of increasing sophistication to measure progression in learning, a 'levels mountain' has been developed as visual aid to support teachers and pupils in appreciating the type of thinking needed to demonstrate progress (Grevatt, Gilbert, & Newberry, 2007).

Explanations are at the heart of science, and tend to be a strong focus for gifted students, and should feature strongly in chemical education for the gifted (Gilbert & Newberry, 2007). Chemistry teaching offers a great many opportunities for developing skills in building and critiquing explanations, and scope for the most able to work with complex and multi-layered explanations (Taber, 2007d).

Teaching for gifted students in chemistry should emphasise questions that enable the learner to analyze, synthesize (for example, providing opportunities for interdisciplinary connections) or evaluate information. In science, learners should be guided towards 'scientific habits of mind' (Saleh & Khine, 2009), to develop problem-solving skills, and to explicitly apply inductive and deductive reasoning.

This is something the teacher can model through example. Teachers may find it useful to monitor their classroom questions, to ensure that the balance of questions and tasks gives scope for open-ended work, for example by asking questions that promote critical and creative thinking. Teachers can also consciously aim to increase the amount of ‘dialogic’ talk in the classroom that represents genuine debate and exploration of ideas (Scott, 2007).

The nature of science

One recent emphasis in science education that may be of particular relevance to engaging the most able students is that on the nature of science (Gilbert & Newberry, 2007). It is increasingly recognised that school and college courses need to teach students about science as well as teach some science. At one level this links with the scientific literacy agenda (Millar & Osborne, 1998; Roberts, 2007): if science education is to prepare young people to be responsible consumers and informed citizens, then it must equip them to appreciate ‘how science works’ (QCA, 2005): the nature of scientific evidence; how argumentation is conducted in science; how reliable knowledge is possible without absolute proof; why scientific experts may disagree; and so on. Without this understanding the presentation of science in the news and media may lead to naive trust in all claims, or total cynicism about the ability of science to offer any trustworthy guidance.

Yet in practice this means including aspects of the philosophy of science in courses: for example some basic study of epistemology. These are areas requiring sophisticated thinking, and could involve just the sort of material to engage many gifted learners. The philosophy of chemistry is a discipline that has recently attracted a good deal of attention (Scerri, 2000), and could offer useful material here. As one example, the question of the extent to which chemistry is reducible to physics (Scerri, 1993), could be just the kind of esoteric topic to catch the imagination of the most advanced students.

Similarly, there are strong recommendations for including material on the history of science in school and college courses (Matthews, 1994; Niaz & Rodriguez, 2001). Such material can offer case studies to illustrate how science develops in response to new evidence. The history of chemistry, in particular, offers a good deal of material illustrating the role and nature of models used in science: something that is both important in terms of appreciating the nature of science, and useful to help learners appreciate the value and limitations of models they meet in studying the subject. The ways that chemists model matter in terms of particles, and how this thinking has evolved, offers an excellent introduction to modelling in science (Justi & Gilbert, 2000). Involving some historical material in chemistry courses might well appeal to those gifted learners who might otherwise drift away from sciences to more ‘interpretative’ subjects (such as the boy quoted earlier in the paper).

Some development work using ‘the nature of science’ as an organising theme for an after-school science enrichment programme for 14-15 year olds students has suggested that this approach shows considerable promise (Taber, 2007c; Taber & Riga, 2006).

Science-Technology-Society Links

Similarly, the inclusion of more discussion of societal issues (gene therapy; recycling; so-called ‘organic’ foods, etc.) in science courses (cf. Millar & Osborne, 1998) offers another potential area for meeting the needs of the most able (Levinson, 2007). Teachers needs to take care here, because moving away from theoretical aspects of chemistry to talking about opinions is certainly not likely in itself to engage gifted learners. However, exploring the evidence and arguments relating to issues where there is no ‘right’ answer, and where different perspectives have to be respected, and competing views weighted, offers just the kind of mental challenge that can stretch able students intellectually (Taber & Corrie, 2007). This type of thinking moves beyond the attainment of logical operations (cf. Piaget, 1972), to what has been characterised as post-formal operations (Arlin, 1975; Kramer, 1983). In the 1950s and 1960s Perry (1970) studied the evolution of this type of intellectual development among the select undergraduates of Harvard and Radcliffe, and showed that this type of mental maturation was hard-earned even among elite students. The relevance of Perry’s work to chemical education had been highlighted by Finster (1989, 1991).

Chemistry offers suitable foci for this type of work. The siting of chemical industry necessarily involves compromises between different interest groups, and has costs and benefits (that differ depending whether you are a consumer who lives far away, a local resident worried about scenic views or wildlife, someone who is long-term unemployed who may be offered a job, etc.) The use of various additives in food may increase ‘shelf-life’ or taste, but may cause allergies in some, and may encourage long-distance sourcing of food (with attendant pollution costs). There are clearly many other potential examples.

Supporting intra- and inter-personal learning

Self-regulated learning

Metacognition is a term to describe ‘thinking about thinking’, and is related to ‘study skills’ (Gunstone & Mitchell, 1998). Gifted learners are often considered to have advanced metacognitive development (Shore & Dover, 2004), and indeed some of the most gifted students may be autodidacts, i.e. able to ‘teach themselves’ from resources with limited formal instruction.

One aim of education is to produce independent learners who are able to be ‘self-regulating’. To become self-regulating, learners have to develop metacognitive skills – such as being able to evaluate their own work and being able to plan extended studies. Becoming explicitly aware of their own thinking, for example when solving problems (Phang, 2009), is an important step towards students developing metacognitive sophistication.

Teachers can help gifted science students to make explicit their thinking by asking them to cite sources, clues given, and logic used, in drawing conclusions. Open-ended tasks are important, especially those that allow ‘active exploration’, that is providing opportunities for learner-driven exploration of topics. Teachers can help gifted learners develop towards becoming self-regulated learners by looking to offer a choice of tasks and activities that allow gifted learners to work to their strengths, and providing opportunities for self-directed activities such as independent study. Concept mapping is a flexible activity that can encourage students to ‘take stock’ of their learning (Novak, 1990; Taber, 1994, 2002). In chemistry, students can develop concept maps around abstract topics such as bonding or oxidation that have potential to act as synoptic activities (drawing on many parts of the course) as well as those focused on more contained topics such as transition metal or aldehydes.

Such concept mapping techniques can encourage learners to integrate different aspects of their studies, something that even able students may find challenging (Taber, 2008c). Analogical thinking is important in science and has been suggested as focus of science learning in the gifted (Gilbert & Newberry, 2007). An approach that has been explored in a physics-learning context is the use of graphical devices (simple concept maps) to support students in making analogical transfer of knowledge between different topics within the subject (Brock, 2006). There is potential to explore similar ideas in chemistry, for example to reveal underlying similarities within aspects of inorganic chemistry and organic chemistry.

Whilst concept mapping and related techniques (e.g. ‘mind-maps’, Buzan, 2005) can be used in any subject, chemistry offers the potential to develop comparable subject-specific activities in terms of reaction schemes. Aspects of inorganic and organic chemistry are commonly summarised in these schemes in textbooks, but gifted students may be set the task of devising their own reaction schemes to review their studies; to be regular updated as the course progresses.

Working in groups

Chemistry has traditionally offered opportunities to develop inter-personal skills where practical work is carried out in groups. In view of the types of activities that have been identified above as challenging for the most able, this will clearly be most effective in the context of extended and open-ended practical projects (West, 2007). However, group work can be used as the basis for pedagogy for a much broader range of chemistry learning activities. This is particularly so in terms of exploring the social implications of science as discussed above (Levinson, 2007), and group-work has also been used as the basis for activities designed to support learning about the nature of science (Taber, 2007c; Taber & Riga, 2007).

This should not be seen in terms of the gifted learner doing all the thinking, and the other group members taking instructions, but rather that the gifted learner should be encouraged to support peers in taking on different roles within group work.

Indeed gifted learners should be encouraged to take on peer tutoring roles for others in the class, although this needs to be done thoughtfully. This can be seen as extreme case of differentiation by support. Differentiation for different learners in a class may be undertaken by task (setting different work, which can possibly seem divisive), by outcome (only suitable for tasks where learners of all abilities in the group have the potential for some form of success despite very different outcomes) or by support. In this approach the teacher sets work that most students will need help with, and matches the level of support given to the needs of individuals. From what was suggested above, this can only be effective provided all learners are working within their ZPD, and it is unlikely that work that is within the ZPD of the weaker class members in a mixed ability class will also challenge the gifted learner, even when unaided.

However, the challenge for these students will be to support their peers. A cynical view of peer tutoring is that is solves the problem of able students finishing quickly, by enrolling them to do the teacher's work with other learners. However, as teachers know well, finding ways to explain ideas to learners who struggle is very challenging. Teachers also know that having to find ways to answer student questions is a good way of testing and developing one's subject knowledge (Taber, 2009b). Preparing to teach a subject is generally much more demanding than preparing to pass an examination. Used sensitively then, peer tuition is an effective way to help gifted learners develop subject knowledge and interpersonal skills. The teacher should, however, be prepared to support the gifted student in mastering their teaching role, which may not always come naturally (especially when abstract concepts have been acquired un-problematically by the peer-tutor).

Providing pace and variety in learning

A rapid pace is recommended for presenting new material to gifted learners, and it is suggested that any time 'saved' should be used instead to offer more opportunity later for reflection on, and integration of, learning. Such a recommendation is easier to follow when working with a highly able cohort, than when teaching a small number of gifted students as part of heterogeneous group. However, where teaching is often based on an introduction followed by exercises to consolidate learning, gifted students should be given other options.

For example, if a class is provided with a graduated set of exercises of increasing difficulty (so that the students are scaffolding in their learning through the gradual increase in demand), for example mole calculations, the more able students should be asked to initially attempt only the most difficult questions (or less extremely, to work through only odd-numbered exercises). If they complete this without difficulty they could better use their time by leaving the rest of the exercises, and moving on to an activity that encouraged them to integrate the new topic with previous learning (such as concept mapping, discussed above).

Chemistry often offers a wide range of potential examples in topics areas, and the teacher prepared to include the more obscure and challenging examples, as well the standard set of teaching examples, can readily find material to offer challenge. As one example, when asking students to produce balanced redox equations from combinations of half-equations, good teaching practice for pitching task demand for most students would suggest selecting half-equations that will be familiar from their laboratory work and from being met in other course topics; starting from very simple examples; and sequencing exercises so that significant half-equations become familiar by being included in a range of combinations. The student who would find this a pedestrian exercise can be asked to work instead with more obscure, unfamiliar examples in novel combinations.

It is also suggested that it is particularly important to use a variety of teaching approaches when working with gifted students. This is something that chemistry readily lends itself to. The content matter of the discipline is diverse (so that in the traditional division between inorganic, organic and physical chemistry, for example, each branch has a different 'feel'). Calculations, application of theoretical principles, a variety of practical work, discussion (e.g. of societal issues), modelling tasks etc., make chemistry a potentially varied subject to study. The potential importance of both a range of group-work, and opportunities to develop individual independent learning skills will be clear from the discussion above.

Giving students choice

It has also been found that offering students some degree of choice in activities is very motivating for some learners (Taber, 2007d). There are many potential opportunities in a subject such as chemistry to offer students a selection of examples from which to chose. Much of chemistry deals with classes: of elements, or compounds, of reaction types, etc. As just one example, when learning about ionisation energies, groups of students could be asked to prepare a graph and detailed explanation of successive ionisation energies for a different example from a selection of elements. Each example could be posted at a different point around the teaching room as if conference papers, and students could briefly circulate around them, before a plenary session chaired by the teacher. (Alternatively, groups could be asked to present and defend their work, either in paper form or as an overhead transparency or a PowerPoint presentation.)

Such an activity involves each group in detailed work on one example, but allows the discussion of a range of different examples. Whilst allowing groups to select their examples is a relatively trivial level of choice, it does give some sense of ownership over the task. This is important for all students, not just the gifted, but gifted students should be given the opportunity to select more challenging examples (in this case, perhaps a transition element). If students are also given choice in how they present their work (bar chart or line graph?; explanation as continuous prose, or notes labeling the graph?), this can also encourage discussion of broader issues (display of discontinuous data; effective communication of chemical principles). There are many other examples where this approach could be used, for example learning about the shapes of molecules using the valence shell electron pair repulsion theory, or producing a set of charts showing Born-Haber cycles for a range of salts.

Another approach that has been used in university chemistry as well as at school level to offer some student choice, is allowing students to pose questions that will be answered either by the teacher, a visiting expert, or by the individual or group themselves (Watts & Pedrosa de Jesus, 2007). Teaching based around student questions can also encourage metacognition (the student is being asked to explore the limits of their own knowledge) and self-directed learning, as well as giving scope for creativity and lateral thinking.

A case for more research?

This article has considered current concerns about the perceptions of, and attitudes towards, science by many young people, and the particular issues of supplying a well prepared scientific workforce (especially at the professional level) as well as a scientifically literate *populus* allowing members of society to play an informed role in our technologically advanced democracies. In particular the focus has been on the most able learners, those sometimes labeled gifted, who in many countries are not selecting further and higher education courses in the science subjects (particularly in the physical sciences) in sufficient numbers.

The article has highlighted current thinking about the types of educational provision that is most suitable for highly able, so-called ‘gifted’, learners. It is strongly argued that science, and in particular chemistry, can offer an ideal educational context for challenging the most able learners.

This thinking is certainly not anecdotal, as it is supported by a broad literature. However, much of the argument is based on what might be considered ‘circumstantial’ evidence, as there is limited direct research to call upon. In particular science education at school and college level has responded to a wide range of influences in recent years. These include: emphasis on the significance of scientific literary; trends towards focusing on social impacts of science; attempts to introduce more relevance, such as teaching through contexts; recognition of the importance of teaching about the nature of science; initiatives to introduce more recent scientific discoveries and techniques, and on the importance of inter-disciplinary connections; changing views on the roles of ‘discovery learning’, ‘guided discovery’ and the emphasis on enquiry learning; increased stringency in the range of chemicals and techniques considered admissible in classroom teaching; trends towards integrated science approaches, and more chemistry and physics teaching by non-specialist teachers in some countries (e.g. in lower secondary science in England). The significance of these, and other, factors will vary across national contexts.

Chemistry, and more generally science, offers the potential for great intellectual challenge and satisfaction – but it is clear that in some countries not enough of the most able students come to appreciate this through their school experiences. As the present paper has demonstrated, it is quite possible to consider such issues in terms of what is currently understood about ‘gifted’ learners, and to make informed suggestions about how teaching can respond to different pressures and trends whilst best supporting the needs of the most able learners. Such informed advice is useful, but it is not as potent as reliable research evidence such as can be obtained from carefully planned studies of the responses of gifted learners to different science teaching contexts (Taber, 2009c). In view of the serious concerns in many national contexts about the supply of future scientists and science teachers, such a programme of empirical research is much needed.

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[i] I acknowledge a debt to contributors to the seminar series 'Meeting the Needs of the Most Able in Science' which ran in Cambridge over the period 2002-5, supported by the Faculty of Education's Research Development Fund.

[ii] Materials produced for teachers and parents widely reproduce indicators for a distinction, which seems to originally derive from an article by Janice Szabos published in 1989, between the gifted and the merely 'bright' - but there seems little research supporting this discrimination.