Affect and meeting the needs of the gifted chemistry learner: providing intellectual challenge to engage students in enjoyable learning

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Abstract: Meeting the needs of gifted learners is normally considered from a cognitive perspective – a matter of incorporating sufficient higher-order cognitive tasks in learning activities. A major problem in the education of gifted learners is lack of challenge, which is needed to ensure such students are able to make progress. Lack of challenge can also influence learner motivation, and even lead to boredom. Meeting the needs of gifted learners is therefore a matter of matching task demand to their abilities to meet their emotional as well as their cognitive needs. The present chapter suggests that an aim in teaching should be to engage learners in activities that offer an experience of 'flow', which is achieved when learning demands offer sufficient, but not insurmountable challenge. Flow is an inherently motivating experience but requires a suitably high level of task demand to maintain deep engagement. The chapter draws on an example of a science enrichment programme that offered activities that were demanding for the 14-15 year old learners because they drew upon cognitively challenging themes (related to aspects of the nature of science), and required a high level of self (or peer) regulation of learning to provide high task demand. An example of one of the activities, concerning the role of models in chemistry is described. Students recognised that learning activities offered greater complexity, open-endedness and scope for independent learning than their usual school science lessons. The features that students reported in their feedback as making the work more challenging also tended to be those they identified as making the activities enjoyable.

Keywords

Gifted; Affective domain; Flow; Metacognition; ASCEND project; Nature of models in chemistry

Introduction

It is widely accepted that 'gifted' learners can be considered to have 'special needs', even when giftedness is understood as simply being at one end of a normal distribution of ability, intelligence or achievement (Reis and Renzulli 2010). From a cognitive perspective, students who are more advanced in their knowledge and understanding of a subject clearly need to be offered teaching that allows them to develop further conceptually, and which is therefore often likely to be too demanding for many of their less gifted peers. From an equal-opportunities standpoint, all learners should have opportunities to develop towards their full potential. From an economic or policy perspective, it is important that the most able are enabled to meet their potential, as that potential can be understood as a key societal resource (Subotnik et al. 2011). That is, many of the creative scientists and other significant contributors to a society are likely to have been gifted learners who were supported to develop their potential. So from these perspectives it is important that gifted learners are suitably challenged in their education. The present chapter however puts a particular focus on the learner experience, and considers how chemistry teaching can provide an intellectually *satisfying* experience for the most able learners.

Educational experiences of gifted learners

Given the diversity of educational provision across different national contexts, it is not appropriate to generalise about the nature of gifted learners' experiences in school, or even in a single school subject such as chemistry. However, there has long been a concern that when educational provision does not sufficiently take into account the needs of gifted learners there is a danger of them achieving much less than their potential.

In particular, learning activities that do not offer a gifted learner sufficient challenge can damage the students' motivation to study, and lead to boredom (Phillips and Lindsay 2006; Gallagher et al. 1997) and even frustration (Keating and Stanley 1972) and disengagement (Kanevsky and Keighley 2003) with school classes. Gifted learners in regular classes may face emotional problems "because of a mismatch with educational environments that are not responsive to the pace and level of gifted students' learning and thinking" (Reis and Renzulli 2004: 119). Most of us, gifted or otherwise, have sat through occasional presentations in an academic or professional context where we felt we were learning nothing, that the material was being over-simplified, that the style of presentation was condescending, and most of all that we were wasting valuable time. Some gifted learners in some classrooms may experience most instruction to be of that type.

Kanevsky and Keighley (2003) consider that learning can act as an antidote to the emotion of boredom in gifted learners. In other words, when we feel we are genuinely learning something, and recognise that we need to commit our concentration to do so, we are engaged and consider we are involved in purposeful and worthwhile activity.

What is giftedness?

Giftedness, and high ability, are understood differently in different national educational contexts (Cropley and Dehn 1996). So some work on giftedness is focused only on those who have demonstrated extremely high attainment, whilst elsewhere (in the English national context, considered below, for example) it simply means the top 5-10% of students (however judged) in any ability group (Taber 2012). There are different approaches to how giftedness is best understood and identified (Taber 2007c; Sternberg and Davidson 1986), for example about the extent to which it is determined by genetic factors, or can be nurtured through educational experiences. There are questions over whether giftedness describes a person, or needs to be understood contextually, i.e. that a person is only considered gifted in the context of certain activities that are evaluated in terms of particular norms and expectations (Sternberg 1993).

These are important issues, but detailed consideration of them is outside the scope of the present chapter. So for the purposes of the present account, giftedness will be defined in a pragmatic way that relates to the concerns of teachers and others charged with established curriculum or educational provision.

The premises of the present chapter are that:

1. In any teaching group, learners are likely to vary across a range of characteristics, including:

a) The extent of their existing knowledge of the material to be learnt;

b) Their prior learning of the prerequisite knowledge of what is to be learnt;

c) The cognitive and metacognitive attributes available to support new learning;

d) The predisposition to engage fully in learning;

2. This variation may not be uniform across a teaching subject (such as chemistry): for example, some students will more readily learn new conceptual material; some will enjoy practical work more than others; some with have particular strengths (or limitations) in applying mathematics in the subject; students may have uneven prior knowledge (stronger in some topics than others within a subject), with differences among a teaching group, etc.

3. Effective teaching will be pitched at a level that challenges learners whilst supporting achievement (see Chapter 3).

From these starting points we can recognise that in *any* class, undertaking *any* particular activity or studying *any* particular topic, a teacher will be undertaking ‘mixed ability’ teaching, and that the same teacher presentations and learning activities are unlikely to be *perceived* as of similar levels of difficulty by all those in a group. A pragmatic notion of who should be considered as gifted in any class would be the students who would not be suitably challenged by teaching that is pitched for the 'average' (median) student, and so would not benefit from such teaching in terms of achieving substantive learning.

This is of course a relative or contextual definition in the sense that in the same class it may lead, for example, to different learners being seen as gifted in tomorrow's melting point determination than in today's lesson on the characteristics of the transition metals. The core issue here, how to differentiate teaching to meet the needs of all students, is just as relevant to those who will have special needs by being at either end of the distribution, as it is clearly important that teaching should be matched to the needs of *all* learners in a class. The focus of the present chapter is on the gifted (where the teacher needs to increase the level of challenge): but that is not intended to suggest that the needs of the lowest achievers (where the teacher needs to increase the level of support or 'scaffolding') are not also important.

Responding to the needs of the gifted

There are various general approaches that can be used to address the needs of gifted learners, but all have limitations (Stepanek 1999; Rogers 2007). A well-established approach in some educational/institutional systems is setting or streaming. Streaming involves identifying students in different general ability bands, and organising classes accordingly. The top stream will be taught all or some of the different subjects in the curriculum as a class, whilst perhaps being in mixed-ability groups for some other subjects, or for pastoral sessions. Setting is subject-specific, with students grouped according to perceived ability in a particular subject.

There is an ongoing, and sometimes vigorous debate in educational circles (e.g., Boaler et al. 2000) about whether such approaches are (a) effective (overall, or for particular ability groups); and (b) fair or desirable on other grounds. This is not the place to engage in such issues in any detail, however one particular concern is that once students are identified as being in a particular band or set it may become difficult for them to be promoted into a 'higher' group as over time the additional, or distinct, work completed by the top band or sets will make transfer into those groups difficult - even for a student who is achieving at a very high level in another class that is completing less, or less demanding, work.

This is an important consideration because it is easier to identify current levels of attainment than potential for future achievement, and so a student working below potential may lose the option to engage more fully once they are assigned to a set or stream where the work does not challenge them. Moreover, intellectual development is not an even process, and does not occur at the same rate in all learners. An apparently average student may suddenly start to show higher levels of ability: especially so for adolescents who are undergoing major hormone-moderated changes (Ramsden et al. 2011).

These arguments aside, as pointed out above, a subject like chemistry involves a wide range of intellectual and other skills, and even subject-specific setting has to be based on typical levels of performance (or a prioritisation of some skills/abilities being seen as more significant than others) when some students show very uneven profiles across a subject. Even a skill such as problem-solving in science may depend upon a range of cognitive skills/variables (Stamovlasis and Tsaparlis 2002). It is also possible that as a subject changes over time (and chemistry certainly becomes more abstract and conceptually sophisticated through secondary and college education) it may start to better suit different students.

There is also the difficult issue of meeting the needs of the so-called twice-exceptional learners (Winstanley 2007; Sumida 2010) – students who may show exceptional potential in some regards, whilst also having learning difficulties, or even difficulties in such basic skills as producing speedy and accurate handwriting (Montgomery 2003). So, for example, students who are highly able and conceptually very 'sharp', yet have specific learning difficulties that compromise their writing abilities may struggle to produce acceptable written work, whilst shining in classroom discussion. Most school chemistry teachers will have come across students who fit this description – students who seem engaged and full of ideas, and who ask perceptive questions, but who are unable to produce written work that reflects this. (Such students are less common in college level chemistry classes – simply because of the usual ways we formally assess student achievement and filter those offered admission to further and higher education.)

These arguments suggest that streaming or setting may not be an ideal solution, and of course in some educational contexts (e.g., schools in very rural settings; classes in many school 'sixth-forms', for example) there is only one class taking a subject at any level, so such an option is not available. It is also clear that setting will only reduce (and not eliminate) the range of levels of attainment of the students in the class. When considering 'top sets' (or streams) the issue can be more extreme because of the nature of distributions: in many educational contexts a top set will include students of modest ability but high motivation and engagement; alongside the students of very high, and sometimes extremely high, achievement in the subject, who are found on the tail of the distribution.

In some national contexts it is not unusual to promote particularly advanced students to a cohort that is essentially comprised of an older age group: but this may have complications, both in terms of social cohesion, and what happens when the student reaches the 'end' of the system early (for example completing school before a legal school-leaving age). Another strategy is to offer something additional (enrichment, such as the in the project discussed below) to supplement the core curriculum. If this is done outside of normal timetabled sessions, it may well have some benefits, but again there are potential problems. One is of equity – should the most able be offered *more* (rather than different) education and access to learning resources than other learners – who arguably need access to educational resources at least as much? It may also be the case that the additional enrichment activities can be seen by gifted learners as challenging and enjoyable: highlighting just how pedestrian the compulsory core classes seem (certainly an issue suggested in the project discussed below). They may wonder why they have to give up some of their own time to experience chemistry teaching that excites and challenges them. Enrichment activities should not therefore be seen as compensating for undemanding learning experiences in regular chemistry classes. That is not an argument for avoiding suitable enrichment activities - such as chemistry 'Olympiads' - for those students who are suitable and keen to be involved: however such optional extras do not negate the need for *all* learners to be suitably challenged in their standard curriculum sessions.

Optimal levels of challenge when teaching gifted learners

A key feature of effective teaching is tuning the level of demand of tasks to match the learners (see Chapter 3). It has been suggested that student learning experience can be characterised in terms of how task demand matches student skill level (Nakamura 1988). When a task makes high demands that are matched by high levels of skill, students can potentially engage productively, and experience what has been termed 'flow' (Csikszentmihalyi 1997) – a high level of engagement in an activity. When students feel they are being successful in responding to what they recognise as challenges in their learning they are more likely to experience learning as a positive - rewarding, worthwhile - activity that makes them feel good about themselves (see Figure 1). Similarly, there is potential for learners who regularly experience failure in the face of such perceived challenges to doubt their ability and find learning a negative experience. This is a general argument that applies to all learners, whether gifted in chemistry, more typical, or struggling in the subject. The particular issue with gifted learners is that work which offers optimal challenge to many of their peers offers little to stretch their thinking and tempt them out of their comfort zone - their 'zone of actual development' (Vygotsky 1978) - where drill may improve accuracy and speed, but does little to develop their thinking or skills.

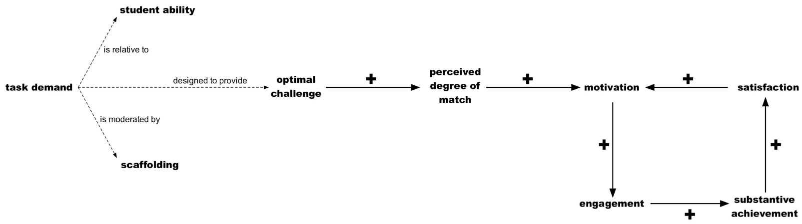

Figure 1: Optimising the level of task challenge can engage learners as well as supporting learning (see Chapter 3)

Higher levels of intellectual development

To consider how the teacher should design learning activities to offer optimal challenge for the most able learners it is useful to consider some ideas about the nature of intellectual development. Bloom's taxonomies (Bloom 1968; Krathwohl et al. 1968) can offer some guidance here, but especially when considered in relation to the work of Perry (1970) on the intellectual and moral development of college students.

Bloom's (1968) taxonomy of educational objectives in the cognitive domain is often used as a tool to consider the demand of learning activities (Anderson and Krathwohl 2001), and teachers are aware of the importance of setting work requiring 'higher-order' cognitive skills, such as analysis, synthesis and evaluation – especially when working with more advanced learners (Taber 2007c). The parallel taxonomy of educational objectives in the affective domain (Krathwohl et al. 1968) is less commonly referred to. The five major categories in the taxonomy are 'Receiving', 'Responding', 'Valuing', 'Organisation' and 'Characterization by a value or value context', each of which is divided into subcategories.

The highest level of the typology was labelled as 'Characterization by a value or value complex'. Characterisation here refers to how *the individual* can be characterised, because they have an internalised set of values that consistently informs their actions. This was divided into two sub-levels. The first is called 'Generalized set' which was said to provide "an internal consistency to the system of attitudes and values at any particular moment" providing a 'predisposition' to behave in particular ways (Krathwohl et al. 1968: 48). Bloom and colleagues considered this to provide a "basic orientation which enables the individual to reduce and order the complex world about him [sic], and to act consistently and effectively in it" (p. 48). The focus on complexity relates to an ability to make judgements in consideration of "situations, issues, purposes, and consequences" when it was not sufficient or appropriate to follow simple rules. Finally, the highest sublevel, or 'Characterization' concerns developing a consistent philosophy of life – a worldview that would encompass all domains within its range of application.

The development of a system of personal values

Arguably, Bloom's scheme for the affective domain is more difficult to operationalise in teaching than the taxonomy in the cognitive domain. However, it should be noted that the high level cognitive skill of 'evaluation' involves making judgements against some set of values or other, and such judgements will be more consistent where the individual has developed their own coherent set of values (i.e. the highest level of educational objectives in the affective domain), suggesting strong links between these two domains.

Following Piaget (1970/1972), cognitive development is often seen to lead to formal operations that are commonly attained during adolescence. However, a number of observers have argued that formal operations is not the end point of cognitive development, which needs to proceed to allow people to cope with the complexity of real-life scenarios where problems are often undetermined by available data, and where it is not possible to adjudicate between competing perspectives simply on logical grounds alone (Arlin 1975; Kramer 1983).

Whilst chemistry teaching has traditionally concerned itself largely with setting learners well-defined tasks, school and college science teaching increasingly includes consideration of socio-scientific issues which require more than simple logical application of concepts (Sheardy 2010; Sadler 2011). Arguably such activities offer particular potential to challenge gifted learners (Levinson 2007), who may spontaneously raise questions about such issues (Tirri et al. 2012).

Of relevance here is the work of Perry (1970), who explored intellectual and ethical development of students attending the prestigious undergraduate colleges of Harvard and Radcliffe. Perry developed a scheme to describe the stages through which learners passed, something akin to the Piagetian stages of cognitive development (Piaget 1970/1972). Perry was not the only person who explored aspects of moral development, and indeed Lawrence Kohlberg's (Kohlberg and Hersh 1977) scheme is probably more widely known. However, Perry's scheme did not seek to separate development of intellect from development of a personal value system. Moreover, some of Perry's key findings can be considered to be of particular relevance to science/chemistry education (Finster 1989, 1991). Perry's scheme, unlike the better known work of Piaget, did not exclude individuals from sometimes taking retrograde steps in relation to the hierarchy of levels or stages, and this reflects longitudinal research into the development of moral motivation which suggests a *general* trend towards greater degrees of moral motivation but with some *individuals* actually presenting downward shifts between measurement points (Nunner-Winkler 2007).

In particular, Perry found that adolescents and young adults seems to commonly pass through an intellectual journey away from a sort of absolutism, through a relativist phase towards a more sophisticated stage when value judgements can be made in nuanced ways. Perry's original work is quite detailed, offering nine stages, but for present purposes this simple three-stage simplification reflects this key issue. In caricature, then, Perry found that on starting college new students often expected their teachers to be a source of absolute knowledge and to refer them towards authorities that were considered to be correct. Instead, their teachers often directed them to diverse and apparently conflicting sources that offered opposing views (especially in the humanities and social sciences). The initial response to this was a shift from seeing knowledge in terms of truth to being a matter of opinion: i.e. different people have different opinions, and in education we learn about these different opinions, and perhaps we choose the opinion we wish to hold whilst recognising it is just that – an opinion. In this 'relativist' stage there can be no arbiter of truth or right, because it all comes down to different people holding different opinions – and everyone is *entitled* to an opinion.

Students could (sometimes slowly) move beyond this naive relativism to come to understand that even if we can no longer aspire to simple absolute knowledge, we can still form judgments that are principled and argued from a coherent position. So the final stages of this process, which Perry suggested even very able students might not complete during their undergraduate years, links to the highest level of the taxonomy of educational objectives in the affective domain, with its focus on personal values that the individual has characterised and organised into a coherent system.

Intellectual challenges in learning science

Notions that science unproblematically uncovers how the world is, leading to scientific truths that can be considered absolute knowledge, are now generally seen as naïve. Kuhn's (1996) highly influential model of how science has progressed highlights the role of such extra-logical factors as culture, advocacy, tradition, social organisation - and for some opened up the question of to what extent science is itself just a culturally relative form of knowledge - an issue that has become a major focus of attention in the philosophy of science (Laudan 1990; Rorty 1991). Kuhn himself did not consider science to be culturally relative in an extreme sense (that the true nature of the natural world depends upon where and when you want to know), but rather acknowledged the genuine issue of whether humans could make truly objective judgements that rose above their culture (Kuhn 1973/1977). Arguably, even if human intellect allows us to recognise the nature of our own conceptual frameworks, and the possibility of entertaining alternative ways of thinking (Popper 1994), the essence of being human is such that we can never completely step outside the culture in which we have been socialized (Geertz 1973/2000), so as to make fully objective judgements.

Such issues are not just of academic interest to educators, when the question of how scientists come to know is a core part of science education (Hodson 2009; Matthews 1994). A post-positivist view of science (Taber 2009b) sees it as a complex activity where judgements made cannot be based purely on logical application of formal operational thought.

The first of Perry's three general stages will be familiar to many chemistry teachers. Students accept what they are taught in science as absolute truth: i.e. this is what scientists have found out - what they have 'proved' by doing experiments. Perhaps that does not matter as long as what they are learning is that sodium is a metal, that the formula of sulphuric acid is H_2SO_4, and that in solution chlorine will displace iodine from its compounds.

However, the science that gets attention in society - and increasingly in science classes (Sadler 2011) - is often not the material that has long become part of canonical scientific knowledge, but rather the more controversial topics where either (i) scientific debate continues, or (ii) socio-cultural considerations have to be considered when deciding *how (or whether) to apply* the science. The science behind nuclear power stations is generally non-contentious, but how to weigh up the risks and benefits is less clear-cut. There is a widespread consensus that the climate is changing – but scientists do not all seem to agree on how quickly, how much is due to human activity, and how serious the consequences will be. Evolution by natural selection is the foundation of modern biology – yet there are many aspects of evolutionary theory where vigorous debate continues (something seized upon by those who reject evolution and wish to characterise natural selection as 'just' a theory).

Perry's work warns us that once students accept that absolute knowledge is just an ideal, and that education does not provide ready access to 'truths', the natural next step is to consider all areas where there is any kind of dispute as simply matters of opinion or little more than personal taste. Different scientists have different opinions on climate change, and nuclear power, and evolution: and they are all entitled to their opinions – just as the student or member of the public is entitled to an opinion.

That is not the kind of understanding of the nature of science that can productively inform future citizens in making science-related decisions (Sheardy 2010). Rather, learners must both appreciate how scientific knowledge can become robust and trustworthy (without being beyond further question), and so how our understanding of some scientific issues is still far from that stage; and how sometimes decisions about the applications of scientific knowledge can only be made by drawing upon values that are external to science itself (Sadler 2011).

Science can tell us the potential risks of building a nuclear power station – but it cannot tell us what level of risk *should* be considered acceptable. Similarly, science can offer us an extensive evidence-base for accepting natural selection, but it cannot tell us whether such acceptance is worth the risk of alienating friends and family when such ideas are considered to challenge the shared commitments making up a worldview for our community (Long 2011). This example reminds us that although from a personal constructivist perspective (see Chapter 3) we might consider when evidence should logically lead us to change our mind (Posner et al. 1982), this has to be understood in the wider context in which learning occurs: the drive to a more integrated, efficient, explanatory framework with wider application is not the *only* motivating factor in learning (Pintrich et al. 1993).

Inherent challenges in learning chemistry

Where in science education more generally we might recognise the need to apply values external to science in considering the social implications of science, the nature of chemistry is arguably such that the issues raised by Perry's work impinge significantly upon the learning of the science itself. Chemists and chemistry teachers often like to characterise the subject as a 'practical' or empirical subject, and indeed it is: but it is *also a theoretical subject*, and in particular one that is understood and taught with a wide range of models.

For one thing, although chemistry underpins materials science, chemistry itself is largely developed by the rather severe abstraction of being about substances. Very few everyday materials are pure samples of substances, and only a limited number of the millions of substances known to (and indeed often created by) chemists are familiar to most young people from their everyday experience outside the laboratory. Moreover, learning about even a tiny fraction of the vast number of substances that *are* known is only made manageable by a range of categories and typologies used to organise chemical knowledge. Some of these categories and classes may be considered quite close to natural classes – the elements for example. But others are more arbitrary or less distinct. Notions of which elements are metals and which are nonmetals admits matters of degree. Categories such as acid and oxidising agent are, to a large extent, classes of convenience, as evidenced by the way chemists have been prepared to redefine membership based on new theoretical approaches (and the availability of new reagents, such as superacids). This is inherent in the abstract and complex nature of chemistry as a subject to be taught and learnt.

The various descriptions of substance properties and behaviours observed in the laboratory that make up the 'natural history' of chemistry at the macroscopic-theoretical-descriptive level are to a large extent underpinned in modern chemistry by explanatory models of the structure of matter at a scale far too small for direct perception (Johnstone 1982). So students are taught about molecules and ions, about bonds, and partial charges, about orbitals and electron clouds, about shifts in electron density and the expansion of octets, and resonance structures and hyperconjugation. Not all of this material is taught at once, and some is considered more advanced, but there is a brave new world of submicroscopic particles with their properties and behaviours to be imagined and understood, and then to be used as theoretical tools in building explanations about the formal descriptions (changes of state, oxidations, precipitations etc) that are already one step removed from the flashes and bangs and colour changes and smells which are the actual phenomena directly available to learners (Taber 2013).

Aspects of this account are well recognised. Johnstone (1982, 1991) long ago raised the issue of how new learners can suffer from information overload in being asked to deal with the macroscopic and submicroscopic levels, and the various forms of symbolic representations used to think and talk about them. Moreover, work in the Piagetian tradition highlighted how the abstract theoretical nature of much in the secondary school curriculum did not seem to be aligned with the levels of cognitive development of many learners of secondary school age (Shayer and Adey 1981).

However, Perry's work suggests there is another issue, related to the *multiplicity* of much of what is set out as target knowledge to be learnt in chemistry. This has been described as 'model confusion' (Carr 1984), but it has not had the attention it perhaps deserves as a major issue in teaching chemistry. Carr referred for example to the issue that there are several models, and so definitions, of acids, that appear in school and college curricula. In part this is a historical issue – as chemists make new discoveries, and propose new ideas, which can be tested empirically, they refine their theories (Lakatos 1970): yet in education such historical models are often presented ahistorically, and indeed what gets presented is sometimes a hybrid curricular model that is not true to any of the historical scientific models (Justi and Gilbert 2000).

However, this is not the whole story, for in chemistry we often retain and continue to apply models that are less sophisticated even when newer models (so to speak) become available, because the simpler/older models are still considered to have a valid range of application and to be useful tools in our theoretical toolkit, fit for some purposes (Taber 1995; Sánchez Gómez and Martín 2003). We still use Brønsted-Lowry and Lewis definitions of acids, depending upon context. We model molecules as perfectly elastic spheres for some purposes, and yet as fuzzy irregular complex field patterns capable of superposition, for other purposes. We might describe the bond in water as covalent one day, and yet polar another. We still explain some things in terms of a model of the atom as having concentric shells of electrons, whilst for other purposes we consider such a notion inadequate.

This is both an opportunity and a challenge (Taber 2010a). The challenge is that students struggle to make sense of how a science that is meant to offer truth contradicts itself from day to day. For example, a student I interviewed over an extended period (Taber 2000, 2001, 2003) suggested that the concepts taught in college chemistry seemed so different from school chemistry that having studied the subject at school interfered with studying the subject at the next level:

> "If I hadn't have done chemistry G.C.S.E. [i.e. at secondary school level], in some aspects, some aspects of chemistry G.C.S.E., I would have found this [college level chemistry course] like easier to understand maybe, because like what they taught us at G.C.S.E. and what they teach us now like contradicts, as it were, and like it's harder for you to understand, 'cause … you have to learn this for this exam, and then you learn it and then you remember it, and then when I do this course, or when you teach me, or [another lecturer] teaches me, I always think of that thing that I learnt for G.C.S.E. and it sort of like clashes, therefore like it's harder to remember…when they tell you the exact opposite, well not the exact opposite, but not, not very close to the truth, then it can't really be developed because you have to think in a different way"

Students despair of having learnt one model, only then to be told it is not really like that, and they should learn this other model. Of course it is not really exactly like this model either as they *are models*, and that is the point that often does not get communicated: for we are teaching models, not absolute accounts of nature. The opportunity here is two-fold. If we make more of an effort to teach chemistry as often about building, applying and critiquing models (Taber 2010b) then chemistry offers an excellent basis for getting across something of the nature of science as both provisional, partial, open to reinterpretation, but still able to offer useful and sometimes robust knowledge. Moreover, we can ask students to engage with precisely the kinds of complex situations that Perry found students struggle to make sense of. If young people need time and contexts to shift from absolutism, past relativism to a more mature position of commitment based on a system of underlying values, then here is an opportunity to engage with and practice such ways of thinking - chemistry offers a suitable theatre for trying out these ways of thinking when what is at stake offers limited risk to self-esteem, or self image, or community identity, than some other contexts.

The importance of metacognition in experiencing learning

It seems then that there are strong links between the cognitive and affective domains. Another area or domain of importance is metacognition, which relates to the ability of a person to be aware of, monitor and control their own cognitive functioning (Whitebread and Pino-Pasternak 2010). Metacognitive development is related to the ability to become a 'self-regulated' learner, something that facilitates a commonly recognised educational aim of developing 'independent' learners (Meyer et al. 2008). White and Mitchell (1994) argued that a focus on developing learners' metacognition could contribute to both supporting desired conceptual change, and improve learners attitudes to science learning. Research supports links between cognitive, metacognitive and affective factors in learning. For example, Aydin, Uzuntiryaki and Demirdöğen (Aydin et al. 2010) used structural equation monitoring to explore a model relating self-efficacy, anxiety, task value, cognitive strategies and metacognitive self-regulation. Among their sample of Turkish students who were studying or had studied some chemistry at university level, they found that "as students realise the value of the academic task and get intrinsically motivated, they are more likely to utilise higher order strategies leading to meaningful learning" (pp.63-64).

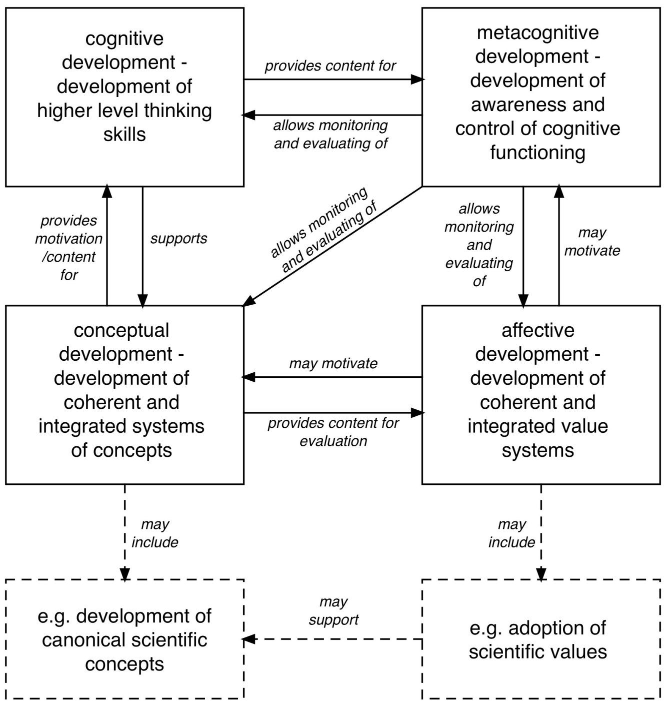

Figure 2: The development of a system of values (in the affective domain) may motivate conceptual and metacognitive development

One approach to conceptualising the links between the metacognitive and other domains is represented in Figure 2. This suggests that metacognitive development potentially links with cognitive development (which provides the basic cognitive skills to support metacognitive faculties, and which can potentially be monitored metacognitively), conceptual development (as understanding of concepts can be monitored and evaluated, i.e. metacognitively), and affective development (as the development, application and systematicity/coherence of the individual's values can be monitored and evaluated).

Metacognition may for example be important in allowing learners to 'stand back' from their ideas and beliefs, and so for example appreciate the limitations of their alternative conceptions. The highest level of affective development (Krathwohl et al. 1968) involves acquiring a coherent set of values that can be applied systematically in life. Educational institutions would normally seek to guide learners on the values that should be adopted (e.g. fairness, compassion, etc.,) and this might be considered to be more the remit of moral education or best facilitated by studying the humanities. However, science education certainly offers target values that it hopes learners will adopt into their personal value system: for example, values relating to the importance of evidence, objectivity, seeking consistency, and being critical. Arguably such 'scientific' values are not always those that should take precedence in all contexts (e.g. there are occasions when it is more important to offer emotional support to a friend in distress than to seek to offer a critical objective analysis of their situation), but at the highest levels of the taxonomy of educational objectives in the affective domain the individual has developed a system of values that allows judgements to be made about which particular values take priority in particular contexts. A strongly developed system of values, including acceptance of the importance of scientific values in enquiring into the natural world, and a high level of metacognitive monitoring and control, may be especially important when a learner is faced with science teaching inconsistent with their, and their peers', current conceptions in a topic (see the discussion in Chapter 3), and can potentially support the teacher's aim of bringing about desired conceptual change.

Developing metacognitive skills (just as with other areas of learning) depends upon learners bring offered suitable challenges in their learning, and so requires support from teachers (Postholm 2010). Learners must be given opportunities to exercise substantive choices in their learning, and then to monitor the effects of their decisions, if they are to practice and enhance their metacognitive skills and become self-regulated learners. Building some elements of choice into classroom activities offers opportunities for learners to make decisions, and reflect upon the outcomes of those decisions, and can be introduced with minimal risk to other learning outcomes and modest teacher effort. For example, in teaching high achieving secondary age students about the nature of scientific explanations, alternative choices of context were provided for some activities (Taber 2007a). Simply offering small choices in this way helped give learners a sense that they had some control and responsibility of learning activities. Clearly, teachers do not have the spare capacity to regularly build alternatives into all their lessons but this case study suggested that providing a choice of alternative examples to work on enhanced the learning experience for a 'top set' of 13-14 year old students.

It was suggested above that learners identified as gifted may show uneven profiles of developments, but in general it is likely that gifted learners have developed their metacognitive faculties further than most of their peers (Shore and Dover 2004), and so are not only better positioned to respond to challenges to take more responsibility for their own learning but are arguably not being supported to develop their self-regulatory abilities *unless* challenged in this way, working in their zone of proximal (metacognitive) development. Some highly gifted learners may well have accepted that most classes they attend are not challenging to them, and may have already developed high levels of ability as autodidacts – seeking out their own learning challenges outside of the formal curriculum. One strategy that may be useful when teaching such students is to involve them in peer tutoring, as long as this is done in a way that allows the gifted learner to benefit as well as the peer being tutored. Teachers can draw on their own experience here and appreciate how the process of preparing to teach others demands high levels of metacognitive skills to identify and address shortcomings in one's own subject knowledge, as well pedagogic skills in making material accessible to others. In other words, asking the gifted learner to take on peer tutoring may be an ideal learning opportunity for *the tutor* as long as they are supported to understand and take on a pedagogic role (Taber 2009a). Teachers sometimes ask how they are meant to teach the highly gifted learner whose own learning of the subject has outreached that of the teacher. The answer will sometimes be to teach that learner in an area where the teacher does have greater expertise – as an educator. As teachers will appreciate, a well-prepared peer tutor can find the role highly engaging and satisfying – as well as suitably challenging.

Putting the principles into practice

This chapter has introduced a number of themes to consider in relation to supporting the learning of gifted learners. The remainder of the chapter discusses an example of an enrichment project ('ASCEND') which looked to supplement secondary science experiences for a group of students identified by their schools as likely to benefit from additional challenges related to science learning.

The ASCEND project

The ASCEND (*Able Scientists Collectively Experiencing New Demands*) project was an after-school enrichment programme for 14-15 year old students in Cambridge, England. State comprehensive schools nominated students they considered could benefit from experiencing challenging science activities. The programme involved seven sessions, each based around a different theme (Taber 2007b).

In designing the programme a number of principles were followed. Most of the activities were designed as small-group work, requiring group discussion, so that progress in tasks would require the students to explore and share their thinking. There was a deliberate attempt not to micro-supervise activities, such that once a session was set up, the groups were largely left to organise their own work. The programme was staffed by graduate students available for consultation, but asked to only intervene when invited by a group to contribute.

This was in part an attempt to encourage the students to take more responsibility for planning and monitoring their work, because it was considered gifted learners should either have advanced metacognitive skills, or at least have the potential to develop these skills; and the use of group work allowed the possibility of peers modelling the processes of monitoring and regulating learning activities within the groups. However, it was also in keeping with the intention to offer these adolescents, attending in their own free time, a taste of an adult learning experience. So the students were denoted as 'delegates' from their schools, and the sessions began with a conference-like registration with refreshments.

A main theme for much of the programme of activities was that of the nature of science. This was selected because of two sets of considerations. For one thing, the aim was to offer enrichment, rather than just teach material that would be met later in school (which might undermine later school learning), and yet to offer something clearly relevant to school science. The English national curriculum had an increasing emphasis on teaching about the nature of science (QCA 2007) but it was recognised that this aspect was challenging for teachers (QCA n.d.), and there was limited clarity of how this aspect of the curriculum should be taught.

The main reason for focusing on activities related to the nature of science was the potential to address a post-positivist view of science, where knowledge is never definitive and evidence is always open to other interpretations. Arguably this theme provides the ideal context to support development through the stages of intellectual and ethical development identified by Perry (1970). Science can be seen as being based upon the application of a well established set of values (such as always considering evidence; looking for the consistency between different concepts and theories; seeking objectivity; etc) to reach conclusions which can be seen as robust and trustworthy, even whilst accepting that one remains open to revisiting those conclusions in the face of new evidence. Science done well might be considered the personification of Perry's fully developed intellect on a collaborative scale.

A chemistry-based activity

ASCEND was a science enrichment programme, which included activities related to various science themes. One of the activities was related specifically to chemistry learning. The 'nature of science' theme for the session was the nature of scientific models. There were two similarly structured activities to be completed, each asking students to offer explanations based around one or both of a pair of models.

The first activity related to two models of the nature of matter at the submicroscopic level. A core issue in teaching chemistry is that phenomena that can be directly observed (dissolving, burning) are commonly conceptualised at two very distinct levels (Johnstone 1982): by a formal description and categorisation at the macroscopic level, and through explanation of observed behaviour based upon theoretical models of the structure of matter at a submicroscopic scale (Taber 2013).

Early in secondary education, students are normally presented with a basic version of kinetic theory, which models matter as composed of myriad particles that are much like tiny billiard balls that engage in perfectly elastic collisions. Arguably this is a model deriving from physics, and it can explain states of matter and phase changes – at least when the notion of the particles having some kind of 'holding power' for each other is included in the model (Johnson 2012). Although there is a lot that *can* be explained with this model, the notion of matter comprising of particles that bounce off each other without being changed by the interactions does *not* provide a strong basis for explaining chemical change.

In the ASCEND activities the delegates were provided with two paragraphs describing different models of the structure of matter. One model was the basic kinetic theory model of hard spheres that undergo perfectly elastic collisions. The other model referred specifically to molecules with electron clouds that could overlap, and interactions between the charges in different molecules. The delegates were also given a list of phenomena (e.g., an ice cube melting; starch being converted to glucose when mixed with saliva), and their task was to decide in their small groups whether each of the phenomena could be explained by one or other, or both, of the two different models.

The underpinning thinking here is that in upper secondary science learners are presented with models of the structure of matter suitable for thinking about chemical processes which are inconsistent with the basic particle model they have previously learnt to explain the nature of solids, liquid and gases. Engaging with this apparent contradiction would seem to require quite mature thinking in terms of Perry's scheme of development. Students who are concerned with developing a coherent understanding of the nature of matter have to either challenge the teaching they experience, or engage with the nature of models in science and science learning.

The second activity was similar in structure – two inconsistent models at the submicroscopic level and a list of phenomena to be explained – but concerning two different models of bonding in sodium chloride. One of these models was based in curriculum science, that is a model based upon the bonding as an electrical attraction between charged ions. The other model presented was based upon a common alternative conceptual framework of ionic bonding elicited from learners, which sees sodium chloride as forming molecule-like entities due to a fictitious electron transfer from a sodium atom to a chlorine atom that somehow comprises the bond (Taber et al. 2012; Taber 1994). The phenomena to be explained included two simple practical activities: observing decrepitation on heating NaCl crystals, and precipitation of silver chloride when silver nitrate solution is added to sodium chloride solution, as well as a range of statements about properties of sodium chloride.

From a curriculum science perspective, this task might seem easier than the first, as one model is clearly superior in explaining most of the phenomena: however, it is known that many students find the 'molecular' model of NaCl very convincing. From our observations of the students undertaking the two tasks, these learners experienced the activity as genuinely challenging and certainly did not find either task to be obvious or trivial.

Student responses to ASCEND

At the end of the programme of seven after-school sessions, the delegates were asked to offer feedback on their experience of being involved in ASCEND (Taber and Riga 2006). One of the questions asked was: *What did you enjoy most about being involved in this project?* As this was an open-ended question, students were free to suggest whatever they wished, and there was a range of responses. However, one feature suggested by a number of students was that they had most enjoyed the group-work ("working in groups to work out things"), whilst a number of others noted the subject matter being distinct to their school science lessons. However by far the most popular type of answer was classified as being about 'exploring ideas' (see Figure 3).

So students highlighted:

- Exploring new ideas and a new way of thinking. We were not just told facts but asked to think and question our knowledge
- Thinking about more complex ideas in the theory of science
- Thinking about more complex things that I haven't thought about before
- Getting the opportunity to tackle interesting and stimulating problems
- Being involved in interesting discussions
- Discussing and listening to ideas and theories
- In-depth discussions, understanding complicated things
- I got to come up with theories and present my point of view
- It stimulated me to think about science from different angles. Made me think about simple things on a deeper level than I've been taught. Made me realise how little of the simple things I remember
- Chance to think independently
- Discussing my ideas and working things out
- Discussing different ideas that we had and finding things that made *other* things make sense

It should not be surprising that being asked to engage in in-depth exploration of complex questions that facilitates "understanding complicated things" should be linked with enjoyment, for as Trout suggests, "there is a special kind of intellectual satisfaction — an affective component—that occasions the acceptance of an explanation, a sense that we have achieved understanding of the phenomena" (Trout 2002, p.213).

Another question asked learners what they had found challenging about the sessions, and responses included "reasoning my ideas, not just taking what I had been taught on face value"; "thinking about the connections between various things"; "thinking for myself, thinking beyond the box"; "sometimes we have to decide something that is not very clear" and "not being given the answers immediately when asked". When asked what they felt made the ASCEND activities distinct from school science, the delegates gave a range of suggestions but referred to the work being "much more intense and in more detail" and involving "more complex discussions".

Delegates referred to how the activities had made them "much more independent" as "they made us do the work rather than being told it". One student noted that "this is more like self-learning while in school most stuff is taught by teachers", and another responded that "we were given a lot more space to think for ourselves and allowed to develop ideas further" compared with school science. One of the delegates suggested that unlike in school the ASCEND sessions had not involved work being "dumbed down for others".

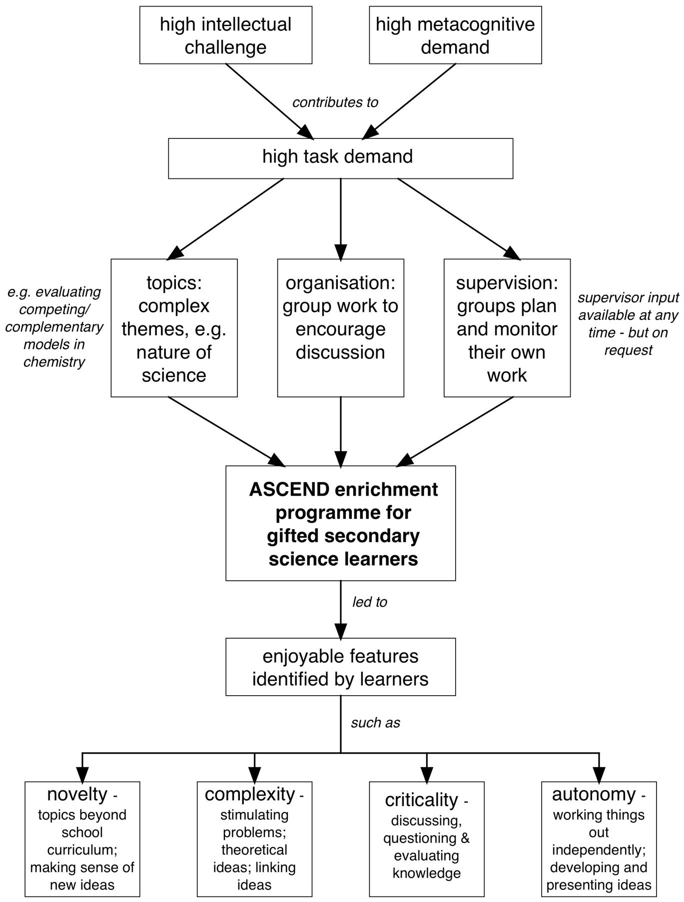

Figure 3: The design of the ASCEND project offered intellectual demands matched to gifted learners, which allowed them to enjoy a higher level of intellectual engagement

Implications to be drawn from the ASCEND project

ASCEND was one project, carried out in one educational context, and care should be taken in generalising from one example. Two major limitations of the programme were that the schools selected those they considered gifted in science based on their own criteria and the ability range of delegates was broad (our perceptions was the cohort included some highly able learners, but also some capable and enthusiastic students who probably would not have been considered gifted in most national contexts), and that most activities had not been piloted to any great extent in advance, so there had been no chance to fine tune the level of demand of the activities to the need of the target group (gifted 14-15 year-olds learning science in the English curriculum context).

Despite some caveats, ASCEND demonstrated that it was possible to design science activities based around 'nature of science' themes, that gave students a feel for science as a challenging intellectual activity, that engaged learners over extended periods of time (e.g. an hour for a complex activity, cf. school lessons usually divided into short structured tasks), working with limited input from teachers and requiring learners to take some responsibility for monitoring and evaluating their own progress on tasks.

In the case of the chemistry-specific activity, one of the potentially challenging and de-motivating aspects of learning chemistry – being taught apparently inconsistent accounts of chemical concepts – was addressed directly, by being explicit about the nature and role of models being used in chemistry, and asking learners to (i) consider apparently contrary accounts as models that have particular ranges of application (as they are understood in chemistry itself) and (ii) evaluate their utility in that context.

Our evaluation based upon the feedback of the learners who attended ASCEND was that the activities were experienced as quite different to school fare, and that accordingly the work was challenging: seen as complex, lacking obvious 'right' answers, and requiring extended engagement with ideas. However, these features of the programme that provided a high level of intellectual challenge also seem linked to the features that the students told us they most enjoyed: being given complex issues to consider, and allowed to develop their ideas and arguments without the frequent interruptions and input from teachers that characterised their experience of school science lessons.

That is certainly not to suggest that the science teachers who worked with these learners in school were misjudging the amount of input needed by *many* of the students in their classes: quite likely other students in the same classes were better suited by work which was more tightly structured and sequenced into more readily achievable sub-tasks, and benefitted from regular teacher input in the form of reminders, hints, checking on progress and on thinking to date (cf. Chapter 3). The difficulty in class teaching is offering the level of structure and support - the scaffolding that allows successful completion of task that is needed by some students - without trivialising the demands of activities for the more gifted students. The challenge for the teacher is to differentiate the level of support so that the challenge of activities matches the needs of different students in the same class.

However, in principle, differentiation by support is certainly one strategy that teachers can use: where what is essentially the same task is given to all of a class, but there are different expectations in terms of the amount of support provided to different groups of learners within the class. In principle this could be combined with the point made earlier about the potential of offering choices for motivating learners. Students could be offered versions of tasks with different levels of support built-in, although that strategy does depend upon student having already developed sufficient metacognitive skills to understand the purpose of the strategy and to evaluate their own learning well enough to make effective choices.

The more gifted learners can only experience 'flow' in their learning when they are given the opportunity to engage in sufficiently demanding activities to experience a challenge, knowing that they have been given genuine responsibility for planning and organising their learning, and sufficient time to explore the complexity of the task and make real progress before they are asked to account for their work. The highly scaffolded tasks and constant checking and feedback by teachers that is necessary for some learners can actually undermine the deep engagement of the most able in a class. Yet, as was illustrated in ASCEND, when gifted students are suitably challenged and also given genuine scope to respond to that challenge, they not only enthusiastically engage in exploring concepts and theories, but they also report enjoying the experience.

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