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Taber, K. S., & Corrie, V. (2007). Developing the thinking of gifted students through science. In K. S. Taber (Ed.), *Science Education for Gifted Learners* (pp. 71-84). London: Routledge.

## **6. Developing the thinking of gifted students through science**

*Keith S. Taber & Vivien Corrie*

This Chapter considers how science education can contribute to the development of thinking skills, with particular attention to the needs of the highest achievers. We will consider what is meant by the term 'thinking skills' when used in educational contexts, and will briefly consider a number of commonly used models for planning teaching designed to develop student thinking.

### **Developing thinking as an imperative for the school curriculum**

It is easy to think of curriculum in terms of timetabled subjects, so that the school curriculum consists of science alongside mathematics, history and so forth. The science curriculum may then be primarily conceptualised in terms of the science topics to be 'covered': energy, electrical circuits, acids, green plants etc. Whilst it is important for teachers to be able to think about their teaching in this way, it is also very important for all teachers to keep in mind the wider aims of education. The curriculum is, after all, intended to be a programme to achieve more general educational aims. Any rationale for the importance of science in the school curriculum-based primarily upon the need for students to learn about oxidation or photosynthesis or gravitational fields is likely to look

quite unconvincing to many educational stakeholders – to many tax-payers, to many parents, to many school children themselves.

The rationale for schooling, as a means to collectively educate young people, is based on an assumption that schools can effectively help develop the whole person – at least in those ways that society feels are important. Whilst acquiring specific knowledge and understanding *is* important, the perceived importance of any specific knowledge for its own sake is likely to change over time. This has always been the case, but is even more pertinent at a time when scientific knowledge is accrued at a vast rate, and school children are used to readily accessing (if not always appreciating) information via the internet.

Since the nineteenth century education has been expected to support the individual's intellectual, aesthetic, moral/ethical and physical development (Hirst & Peters, 1970). Science can certainly contribute in all these areas (see Chapter 10). However, it is in terms of intellectual development that science is expected to play a major role. Science is well placed to do this, but - as Howard Gardner (1993) points out in the context of developing his notion of multiple intelligences – it is just one of a wide range of 'academic' school subjects that can all be seen to primarily develop this aspect of the person.

Although the principle of developing the whole person, and related notions of the 'liberal studies' curriculum - 'concerned with the comprehensive development of the mind' (Hirst, 1972, p.408) - have a strong tradition in educational thinking, science education has passed through phases where this imperative has become obscured by other foci. School science is not a given delivered by fiat from on high, and nor is it simply 'science' taught in schools. Rather the school science curriculum is the outcome of political processes (Kind & Taber, 2005) – political in the sense of being shaped by various interest groups who have the power to have influence in the matter (e.g. see Chapter 5). School science in the UK has passed through phases when inquiry was a key concern (e.g. at the time when Nuffield curriculum projects were having a strong influence), and in the 1980s when process skills were a prime concern - something

reflected in the work of the government's Assessment of Performance Unit at that time (APU 1988a, b, 1989). Since the introduction of the National Curriculum (NC) in England, it is probably fair to say that the main focus of science teaching has switched back to teaching and learning of specific (and specified) science content. Although more recent changes are to be welcomed (QCA, 2005), both scientific enquiry and the nature of science have been in practice downplayed since the introduction of the NC in view of the way most teachers interpreted the assessment arrangements and set their teaching priorities accordingly (Kind & Taber, 2005). In the US in recent years, there has been a move towards the establishment of national standards for science education (NAS, 1996), which have, bearing in mind the federal nature of the US, approached the status of a NC. However, in the US, inquiry seems to have a much higher profile, presumably due to the way the standards have been developed and presented.

Inquiry, when done well (see Chapter 13), is certainly an excellent context for developing thinking skills. Teaching science subject content can also be an excellent context for developing thinking skills *when* there is a focus on looking at how ideas relate to, and develop in response to, evidence. Teaching for rote-learning of science facts and for reproducing set answers in science examinations is much less likely to provide a useful context. It was never the intention of government agencies or examination boards to allow school science teaching to evolve towards being concerned primarily with 'transmission' of knowledge and rote learning, but that seems to have been one unintended consequence of the NC. It is certainly the case that the UK government has recently recognised the need for emphasising the teaching of thinking skills through the curriculum (e.g. McGuinness, 1999; DfES, 2005).

### **Approaches to thinking skills**

There are a number of ways of conceptualising student thinking that can be helpful in teaching. Here we briefly consider three perspectives that can usefully inform thinking. These include the developmental perspective, the curriculum demand perspective and the

metacognitive perspective. These are not mutually exclusive perspectives, but rather focus on different aspects of thinking.

*The developmental perspective.*

The developmental perspective considers that cognitive abilities increase with age. The growing brain is considered to have the potential to develop ‘higher’ cognitive abilities over time. The extent to which this maturation process is dependent upon external factors has long been a matter of debate. Jean Piaget researched and wrote about this topic for many years and became very influential in educational circles in many countries. His work explored what he considered a natural unfolding of cognitive abilities. The environment played an important role, but largely through the individual’s deliberate actions, interacting with aspects of the environment. Piaget’s contemporary, Lev Vygostsky, focused on the role of others, peers and more advanced thinkers, in providing interactions that could scaffold development, enabling learners to acquire and develop cognitive tools (see also Chapters 4 & 8). A main outcome of Piaget’s work was a theory of the stages through which human thinking tended to develop (Piaget, 1972). Early stages took place pre-school and during the primary ages, but a particular distinction of interest to science teachers was that between ‘concrete’ and ‘formal’ operational thinking (see Box 6.1). Much of the thinking that teachers might consider as ‘scientific’ is at a level of abstraction that requires formal operations in Piaget’s scheme.

concrete operations - actions on what can be directly experienced	formal operations - working with concepts that are abstractions/generalisations
pouring this water into another beaker	water as an example of substance, which is a fluid and so can be poured
observing the motion of this ball	the ball as a moving object, and so having associated kinetic energy
this plant died when we did not water it	water being essential for the life processes of plants
there is a full moon tonight	the phases of the moon as a periodic change in appearance due to the shifting relative positions of the observer, moon and sun

**Box 6.1: concrete and formal operations**

For example, conservation of mass, conservation of energy, electricity, particle theory and the carbon cycle are just a few of the ideas and topic areas that demand abstract thought and are taught at lower secondary level. Teachers use a variety of techniques to help make the unfamiliar (abstract) familiar through concrete examples, demonstrations and activities.

As one example, the type of understanding of electric circuits we might hope for in secondary school requires an appreciation not only of the concept of electrical current, but also potential difference ('voltage') and resistance. These ideas (especially voltage) are abstract and for most students a deep understanding is unrealistic. When lower secondary students are taught about circuits, the teacher needs to provide a range of models (see Chapter 7), analogies (see Chapter 2) and metaphors for students to think with as they explore the practical effects of making changes to circuits (Taber, de Trafford & Quail, 2006). In introducing the notion of electric current to a class, the students might act out a role-play of how electrons move through a circuit and then use this 'concrete' experience to model the effects on brightness of bulbs in series and parallel circuits. We might expect the most able students to go on to critique the various models and so show an understanding of the more abstract ideas.

Another example would be introducing particle theory, which is known to be extremely challenging to most learners: so computer simulations may be used to demonstrate (for example) factors affecting the rates of reaction in a way that less able students can access and explain because the abstract is made visual. Gifted science learners may well demonstrate they are able to visualise and mentally simulate such processes and so predict outcomes (cf. Georgiou, 2005) without needing to be shown the computer simulation.

Piaget's scheme assigned nominal ages for the main transitions between different stages of cognitive development, based on the typical results found in his and his collaborators research. In Piaget's original thinking there was a strict hierarchy in the stages, so that

every individual passes through the same stages in the same order, albeit the actual ages at which stages were attained would vary between learners.

Clearly from a Piagetian perspective, a learner who had advanced to higher stages of cognitive development than her classmates would be capable of more abstract thinking, and might well be seen as gifted in this sense. The sciences offer a great many highly abstract ideas that many students find difficult, but may well offer a level of intellectual challenge that the most able would find engaging (see Box 6.2 for just a few examples).

Particle theory – appreciating how the properties of macroscopic matter may be explained in terms of the nature and configuration of particles (for an example, see episode 4 in Chapter 8);  
Energy as an abstract accounting system;  
Plant nutrition – the relationship between photosynthesis and respiration;  
Chemical equations – deducing feasible chemical equations from common types of reaction and balancing equations;  
Deriving units – such as showing that a Newton is a kilogramme metre per squared second, or that power has the same fundamental units whether (work done  $\times$  time taken) or (p.d.  $\times$  current);  
Calculating specific heat capacities, from experiments where the thermal capacity of the calorimeter has to be factored in;  
Evolution – appreciating the main principles of natural selection;  
Periodicity – how and why properties of the elements vary as they do;  
Structure of DNA, and the implications for cell division;  
Mapping proton number versus nucleon number for radioactive decay series

**Box 6.2: A few of the abstract ideas in school science**

There are clearly *many* more potential examples: often the very topics that are considered ‘too difficult’ for most students, and may be squeezed out of courses or over-simplified by using selective examples, that can be rote-learnt for examinations.

Piaget’s original work has been the subject of a great deal of scrutiny and criticism. His stage theory considers the core of intelligence as some form of central processing capacity that is accessed regardless of the context being ‘thought about’. In its purest form this suggests that individuals should demonstrate the same level of thinking across the board – and should not be found to exhibit higher-level thinking in some contexts compared with others. However, in practice, this variation was apparent – learners seemed to be able to think more abstractly in some contexts than others. Piaget

introduced the notion of 'd calage' (or lag, e.g. Sutherland, 1992). The modified theory suggests that learners attain a level of cognitive ability, that they can *potentially* apply in all areas, but where in practice they need to be familiar enough with material to demonstrate their abilities. (By extension, opportunities for immersion in a field are needed to develop sufficient familiarity to develop an 'intuitive' understanding: cf. Chapter 2). This is quite reasonable, that thinking at a high level requires both cognitive ability, *and* conceptual understanding, but can also be seen as something of weakening of Piaget's original ideas. (It makes the theory 'less falsifiable' if any differences in an individuals' measured cognitive level can potentially always be explained away.)

Piaget's ideas were the basis of a very influential study in science education, where Michael Shayer and Philip Adey (1981) argued that the demands of much of the secondary science curriculum were pitched at a level of cognitive development that surveys (measuring Piagetian levels) suggested many of the intended learners would not have attained.

Shayer and Adey later applied Piagetian ideas to develop materials for 'cognitive acceleration'. The CASE (Cognitive Acceleration through Science Education) project was designed for lower secondary students (e.g. 11-14 year olds), and provides experiences intended to facilitate the progression to the more advanced 'formal operations' (Adey, 1999).

### *Cognitive Acceleration through Science Education*

There is little doubt that science requires the types of formal operations Piaget believed were only reached during adolescence: abstraction, classification, generalisation, the ability to work with various symbol systems and formalisms, are a key part of science, and of secondary and college science lessons.

To the extent that some secondary students are not using formal operations, or not consistently using formal operations, they will clearly be at a disadvantage in science lessons. A programme that provides lower secondary level learners with experiences that scaffold the development of such thinking earlier than they might otherwise be attained

would clearly be to the benefit of those students, and their teachers. CASE is such a programme, which aims to use the context of science-based activities to help students make advances in Piagetian levels. It is claimed (based on research carried out by the CASE team) that when CASE is adopted and executed correctly during the lower secondary years (11-14) it leads to better examination performance – not limited to science - at age 16 (Adey & Shayer, 1994). The evidence for these gains has been convincing enough for many schools to adopt the programme – including the purchase of materials, buying the specific staff training, and finding a lesson per week on the timetable.

The CASE programme is based on ‘five pillars’, derived from well-supported principles, and would seem to offer a sound rationale regardless of how convinced one might be about the validity of Piagetian levels (see Table 6.1). However, it is accepted by the CASE team that the programme may not be useful for the entire cohort. Those students who are still some way from developing formal operations may never experience sufficient cognitive conflict to facilitate the changes in thinking required.

**Table 6.1: The CASE process (\* after Adey, 1999)**

Of more significance for our present concerns: if – on a Piagetian model – gifted students are those who have attained formal operations early, then there is likely to be little in the programme for them. These students will progress through the activities quickly and effectively (already being able to operate effectively with ratio, proportions etc.), but without being challenged to change their thinking in any significant ways. Perhaps for the gifted learner, CASE could offer cognitive stagnation rather than cognitive acceleration.

### **Formal operations and beyond**

This does not mean that the developmental perspective offers nothing for teachers of gifted students, but rather that the popular Piagetian stage theory may not be the most useful approach. A number of commentators have observed that formal operations are most useful in contexts where there are clear patterns to abstract; where rules and



schemes can be unambiguously applied; where evidence converges to clear conclusions. In these situations tidy logical thought is appropriate and readily applied. School science is often presented through curriculum models that are over-simplifications, and through practical work engineered to offer clear conclusions (Kind & Taber, 2005).

However, ‘real life’ is seldom like this. To the extent that school may make science appear this way to learners, school science provides a less-than-authentic image of the way evidence is often collected and interpreted in scientific research, or debated among scientists (see Gilbert & Newberry’s characterization of the nature of science in Chapter 2). In real research the evidence is often partial, imprecise, unclear and even contradictory. Scientists have to be able to make decisions in the light of such situations – perhaps using a more ‘fuzzy’ form of logic. Similarly, when we explore socio-cultural issues in the classroom (see Chapter 10), we need to help learners appreciate that even when inherent scientific values suggest our knowledge base is robust and reliable, we then have to re-consider the relevance and significance of scientific evidence in a wider context, using a distinct set of values external to science.

For this reason it has been suggested that there must be a ‘fifth stage’ of cognitive development beyond the four main Piagetian stages (Arlin, 1975). So-called post-formal operations (Kramer, 1983) concerns making rational and pragmatic decisions when simple logical thought does not allow any firm conclusions to be drawn.

One theory that may be useful here is that of Perry (Fenster, 1989; Moseley, et al., 2004) who developed a model of stages of intellectual development more suitable for college level students. In (over-)simplified terms, Perry considered how learners progress from assuming there are absolute right and wrong answers, to accepting that we may not *yet* know the answers, to recognising that different opinions may be justifiable, to eventually appreciating the nature of commitments as current positions. For teachers of gifted learners, cognitive acceleration may well imply helping students move *beyond* formal operational thinking. This requires setting tasks that are open-ended enough not to have clear ‘right’ answers.

An example of such an activity we have used with KS4 students involves using data from Antarctic ice cores to find out if there is a relationship between temperature variation and atmospheric carbon dioxide over 400 000 years. Students have to make a number of decisions about what data they will select which requires them thinking about the true meaning of 'reliability' (since the experiment cannot be replicated in the way that they have experienced in their own experimental work). They are required to plan ahead in terms of the data they will want to plot, making decisions about what data to 'collect'. This piece of work provides students with challenge because there is no 'perfect' way of sampling the results. They learn that scientists may need to compromise when collecting data and take a pragmatic approach when a vast quantity of potential data is available. Superficially, the data that students collect shows a relationship between the variables: however, it is not an absolute match when they start looking at it in more detail. This provides able students with a genuine challenge when writing their conclusion. This piece of assessed work is particularly interesting given the implications of their conclusion on government energy policies.

Indeed, 'STS' (Science-Technology-Society) or 'controversial' issues offer considerable scope for providing open-ended challenges. For example, in a debate on the use of 'GM' (genetically modified) material in foodstuffs students must attempt to weigh up the costs and benefits on both environmental and socioeconomic issues, many of which are still unknown. Students are asked at the beginning of the lesson to place themselves on a continuum line between agreeing and disagreeing that there should be research into developing genetically modified food. After a lesson in which students explore the issues, they are asked to review their position on the continuum line. However, this task can be made more challenging when they are asked to take a position from within a role (such as a research scientist; a politician; an agriculture development agency for an African country) such that they have to make a judgement from a given perspective, considering the complexities of the issue.

There are suitable materials available to support teachers in setting up this type of STS debate. For example the SATIS (Science and Technology in Society) materials, although pre-National Curriculum are still used in many schools - and are being recommended for

teaching about 'How science works' in the revised curriculum leading to school-leaving examinations in 2008 (QCA, 2005, p20). In one activity, the Limestone Quarry Inquiry in which students role-play a public inquiry into the extension of a quarry in the Peak District. Placing the most able students in the role of 'Inspectors' gives them an opportunity to listen to the conflicting arguments and make a pragmatic decision as to whether to support the appeal or reject it. The ASE's (Association for Science Education, <http://www.ase.org.uk>) 'UpD8' ('update') materials offer mini-projects on contemporary issues. This type of activity can be made personally relevant. So students are asked to research and find evidence to address the question 'are mobile phones dangerous to human health?' (see also Chapter 9), and then they are asked to apply it to their own decision making – i.e. 'will I continue to use my mobile phone?'. The recent English curriculum changes implemented for 14 years olds from Autumn 2006 (QCA, 2005) allow examination courses, such 'Twenty-first Century Science' that offer many opportunities for engaging in activities that encourage such 'post formal thinking'.

*Bloom's taxonomy – a tool for planning teaching.*

Bloom and colleagues produced taxonomies of educational objectives in the cognitive and affective domains. The former was adopted by many teachers and others working in education, and reference to Bloom's taxonomy usually signifies the taxonomy of educational objectives in the cognitive domain (Bloom, 1964).

Bloom proposed six levels of demand associated with tasks that learners might be set, and a revised version has been developed (Anderson and Krathwohl, 2001) distinguishing the nature of the knowledge being processed, and the type of thinking required. In the Revised taxonomy, the main classes of the cognitive processes dimension are:

1. Remember: Recognizing, Recalling
2. Understand: Interpreting, exemplifying, classifying, summarizing, inferring, comparing, explaining
3. Apply: Executing, implementing

4. Analyze: Differentiating, organizing, attributing
5. Evaluate: checking, critiquing
6. Create: generating, planning, producing

The knowledge dimension was divided into four main types of knowledge: factual, conceptual, procedural and metacognitive. The separation out of two distinct dimensions allows the taxonomy to be presented in the form of a table (with each cell representing a type of operation upon a type of knowledge) that may be used as a tool for planning teaching and assessment. If learning activities (or assessment items) are categorised in the table, it provides an immediate visual impression of the kinds of demands being made of learners.

A key to challenging learners is to ensure that learning activities include the higher levels of cognitive processing. For gifted learners in particular, it is important that the profile of activities is rich in analysing, evaluating and creating. An effective way of ensuring that the most able students are consistently challenged in their thinking, particularly when differentiating in a 'mixed ability' context, is to write lesson/topic objectives using the taxonomy, and ensuring there is a spread of objectives across different levels.

For example, when Y7 students (11-12 year-olds) study adaptation of animals and plants, students are asked to design a hypothetical animal or plant that would be adapted for a specific environment (such as deep in the ocean, where it is very cold and dark). This allows students to be creative whilst working with the key science ideas. In a Year 8 lesson (for 12-13 year olds) when students are studying the changes in length of day during changing seasons, the most able students are given data from the southern hemisphere, but without telling them where it is from.

General points that can be applied within the science curriculum include always asking the most able to critique methods in practical work, and suggest modifications, and - wherever possible - asking them to produce their own models (see Chapter 7) and analogies (see Chapter 14) for concepts being studied.

### **Metacognition and independence in learning**

One of the key changes in the revision of Bloom's original taxonomy is the inclusion in the knowledge dimension of consideration of metacognition 'knowledge about cognition in general as well as awareness of and knowledge about one's own cognition' (Krathwohl, 2002). Metacognitive knowledge is the knowledge an individual has about their own learning and thinking processes.

Traditionally school learning was planned and managed by teachers, with students expected to follow directions: being told what to study, when to study, how to study. However, such an approach had a number of obvious disadvantages. For one thing, when the locus of control over learning is retained by the teacher, the process breaks down as soon as the student needs to make decisions in the absence of the teacher. It has long been clear to teachers both that students need study skills to (for example) revise effectively for examinations, and that part of the school teacher's role is to equip students to be effective learners once they leave school. In terms of the wider aims of education, which it was suggested above should provide the rationale for including material in the curriculum, it is clearly important that students are supported in developing into self-regulated learners.

Acquiring 'study skills' (Bulman, 1985) is now a well-established feature of tutorial or personal development programmes in many schools. This may include knowledge about the best ways to schedule review sessions informed by memory studies. Often students are taught about such notions as learning styles. This may be limited to rather simplistic approaches such as designating students as 'visual', 'auditory' or 'kinaesthetic' learners based on commercially available questionnaires. Such 'VAK' schemes are poorly supported in terms of research evidence (Coffield, Moseley, Hall & Ecclestone, 2004) perhaps explaining why they are often inappropriately linked by proponents to Gardner's well-developed theory of multiple intelligence. However, even such a highly flawed approach focuses both teachers and students on (a) the importance of individual differences among learners and (b) the availability of different 'channels' for receiving teaching.

Again modelling may be a very important activity in this regard. The process of building physical models (e.g. with different coloured plastic modelling materials) not only allows students to demonstrate high levels of creativity, but also facilitates learning through visual and tactile/kinaesthetic modes. Such opportunities may be especially useful when students have limited language comprehension or level of literacy - but can also be valuable for gifted learners who suffer specific learning difficulties such as dyslexia (see Chapter 3). These learners may have particular difficulty producing written texts which can demonstrate their level of understanding. Sometimes offering such tasks as elective alternatives to written work for all students can also provide students with a choice of learning activity.

Another key concern is the ‘myth of class teaching’. It is possible for a skilled tutor to closely monitor the thinking of an individual pupil and carefully make effective pedagogic decisions to steer learning. However, it is obvious to anyone familiar with the reality of class teaching that it is clearly unrealistic to expect a teacher to effectively monitor and manage the learning of perhaps thirty or more individual learners concurrently without help ‘from the inside’. Classroom teaching is more effective when aims are shared with individual learners, and they take some role and responsibility in monitoring their own learning, and even making decisions.

This thinking is strongly represented in the assessment for learning movement (Harlen, 2006). So, for example, students are given feedback on their work with the stress on what they have achieved and what they need to do to improve, rather than how well they have done in terms of some grade or score. With students who are already attaining high standards, it is important to acknowledge that, but still offer comments that encourage them to achieve more:

‘Dan, your written work is of a very high standard, I would like you to share your ideas verbally in class. Articulating your ideas will help to develop your thinking.’

‘Peter, you showed me that you understood the ideas of conservation of mass fully by what you said in class, you now need to develop your written explanations so they give full answers to the question. You need to include more scientific terms.’

In particular, the most able students can be set targets to challenge their thinking:

‘Sarah, in the box below, I want you to think of a question about this topic for which nobody knows the answer.’

Having students involved in assessing their own work can help them appreciate both requirements and their own levels of attainment. For example, 11-14 year old students may be asked to write a scientific explanation (some examples of the questions used are: what happens to the mass of iron when it rusts?; what happens to sugar when it dissolves?; how are identical twins formed?; what would happen if you dropped a feather and hammer at the same time on the moon?). The students are then given a contextualised mark scheme and asked to assign a level to *their own* piece of work, before then peer-assessing *another students’* work and suggesting one way in which the peer could achieve the next level. Students are given the opportunity to re-write the explanation before handing it in for the teacher to assess.

In the context of the English NC, the prescribed NC ‘levels’ may be used as indicators of attainment and progression. The levels ‘mountain’ (Newberry, Gilbert & Hardcastle, 2005 – see also Chapters 7 and 15) provides a guide for developing specific mark schemes that can be used in this way. For example, in ‘levelling’ an explanation of the measured change of mass when iron rusts the following criteria may be used to award levels:

- Level 3: the mass of the iron goes up
- Level 4: the iron reacts with oxygen which makes the mass go up
- Level 5: the iron reacts with oxygen to form iron oxide. Explain in terms of the *concept* of conservation of mass – particles having mass, oxygen being added

- Level 6: use the word equation to represent the reaction. Explain in terms the mass of reactants = the mass of products. Use the theory of conservation of mass in the explanation *OR* use a model/analogy to explain the increase in mass
- Level 7: Use the chemical equation and chemical formula to explain the increase in mass quantitatively.

Such an approach can mean that the teacher spends more time explaining ideas to students and focusing minds on the nature of what is considered ‘good’ work, and less time in ‘marking’ piles of student work. The most able students soon learn to access the marking criteria and effectively apply criteria for evaluating (a high level cognitive skill) their own and other student’s work.

It is also important to point out, that student involvement in the monitoring and management of learning, and particularly in being empowered to make choices (see Chapter 12), can engage them in learning and improve their attitudes to classes (see Chapter 4). There is also a particular link here with those learners that we may consider gifted. The ultimate self-regulated learner is the autodidact: the self-taught learner (such as the Nobel laureate cited by Gilbert & Newberry in Chapter 2). Autodidacts are the small proportion of learners who seem able to master complex material without the formal structure provided by teachers and instruction. The self-taught, whether in mathematics, piano, or anything else, are generally considered to be of exceptional ability.

It is quite likely that many gifted students have highly developed metacognitive skills that enable them to plan, organise, monitor, and evaluate their own learning to a higher level than most peers. To some extent teachers may be tempted to differentiate ‘by support’ by spending time with struggling students, and allowing the gifted to use their strengths to find their own way through work. This may *sometimes* be appropriate - as long as the gifted students are given work of a suitable level of demand.

However, we suggest here that just as more dependent students need to be supported to become independent learners, the gifted also need to be helped to develop their existing



levels of metacognition. Gifted students should not only be set work that requires them to use higher level thinking skills, but also given work that makes increasing demands of their abilities to regulate their own learning.

This may mean, for example, that gifted learners are sometimes set work with a much more open brief, and having longer time-scales than other students. Another potentially very powerful approach is through peer tutoring. Many teachers and student teachers come to the view that that they only really came to understand key features of their subject, and especially aspects of the structure of disciplinary knowledge, once they were charged with teaching others (Taber, 2001). From this perspective peer tutoring can be a valuable experience for gifted learners. This does not mean just using gifted learners who finish early to explain the work for slower peers, but building up their responsibilities for analysing and organising the material in order to teach it to their classmates.

## **Conclusions**

This Chapter has offered perspectives on thinking skills that teachers may find useful in planning science teaching for their most gifted students. To the extent that the gifted in secondary schools may often be those who attained formal operations early, and so indeed may be those most ready to meet the challenge of tasks requiring and facilitating ‘post-formal’ operations, it is important to plan work that helps their ability to deal with complex, ambiguous, poorly-defined and nuanced situations.

A tool such as the taxonomy table, developed from Bloom’s model of levels of cognitive demand, can help teachers check that they are including sufficient higher level thinking in lessons for all students, and can provide a tool to help differentiate for the most able who need a profile of work skewed towards evaluative and creative activities.

Finally, planning teaching to develop metacognition is important for all students, but is especially crucial for gifted learners who may already be highly self-regulated, and so have the potential to become effective autodidacts and so effective learners when they move on to less structured learning situations after school. It is the most independent

learners who are likely to have the type of idiosyncratic intellectual life that may be both personally satisfying and potentially able to lead to original contributions to society. Science education has to contribute to the development of the whole person, to help all learners reach their potential. In the case of the intellectually gifted, science needs to stimulate new ways of thinking, and new levels of awareness and control over that thinking. This is a major challenge for the teacher, but we hope that the perspectives illustrated in this Chapter will help inform effective planning and stimulating science teaching.