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SCIENTIFIC THINKING IN GIFTED CHILDREN

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Abstract

The intellectually gifted are different in their learning. They not only have exceptional thinking and learning abilities but also use them more effectively, and can more readily adopt scientific thinking. In a Follow-up study Freeman found that youngsters of high intellectual ability reported exceptionally effective intellectual strategies. They also knew both about how to motivate themselves to study and their personal learning style, though these could be inhibited by emotional disturbance. Evidence from international studies, along with the lessons from these highly-able learners, provides insights into scientific learning strategies for all children.

If, as the evidence indicates, the intellectually gifted think and learn differently from others, then it is important to teach them appropriately. Scientific thinking is not confined to scientists. Even for small children, scientific thinking means using a critical analysis of ideas and trying out hypotheses against data to see how they fit into the known world. But at school, and particularly in higher education, most of us are taught to think in such a hyper-critical way that it tends to reduce the richness of ideas to just the skeleton of their construction both in creative production and in receiving ideas from other sources.

The problem is how to reach the right balance in scientific thinking, using not only critical faculties but also creative ones which connect with other forms of knowledge and creative ideas. Without creativity in scientific thought there is no revolutionary scientific advance, which according to Thomas Kuhn, the philosopher and the inventor of the paradigm shift, occurs when a new paradigm emerges and becomes accepted by the scientific community, which must, of course, be open to it.

Internationally, giftedness is most frequently determined by a score on an IQ test which is above a chosen cut-off point, usually at around the top 2- 5%. Children's educational environment contributes to the IQ score and the way intelligence is used. For example, a very close positive relationship was found when children's IQ scores were compared with their home educational provision (Freeman, 2001). The higher the children's (Stamford-Binet) IQ scores, especially over IQ130, the better the quality of their educational support, measured in terms of reported verbal interactions and activities with parents, number of books and musical instruments in the home etc. Because IQ tests are decidedly influenced by what the child has learned, they are to some extent measures of current achievement based on age-norms; that is, how well the children have learned to manipulate their knowledge and know-how within the terms of the test. The vocabulary aspect, for example, is dependent on having heard those words. But IQ tests can neither identify the processes of learning and thinking nor predict creativity.

Gifted children are defined here in two ways (Freeman, 1998). Firstly, as those who either demonstrate exceptionally high-level performance, whether across a range of endeavours or in a limited field. Secondly, as those who's potential for excellence has not yet been recognised by either tests or experts. Yet excellence does not emerge without appropriate help. To reach an exceptionally high standard in any area very able children need the means to learn, which includes material to work with and focused challenging tuition – and the encouragement to follow their stars.

Barriers to scientific thinking

Barrier one – uncontrolled emotion: Scientific thinking depends on strong cognitive processes, so that relatively more imaginative and constructive options are used in decision-making than emotional reactions, though those are also part of the decision-making. For example, in a dispute one would not just think 'I'm for it' or 'I'm against it', but come up with options like these which employ both sympathy and reason.

- I understand, but stop arguing until people cool down
- Compromise: start with a clean slate and a new policy
- Ask a trusted friend or colleague to referee
- Insist on the point at hand, but make a concession on something else

Barrier two - common sense Not only can emotion get in the way of scientific enquiry, but so does 'common sense' But what one person sees as 'common sense' another can see as biased and stupid. For example, whereas in one family success is seen as due to hard work, in another it may be seen as all down to luck. In an English experiment to test the understanding of flotation, pressure, motion and shadows, 24 children aged 9-14 were interviewed then asked to experiment to see whether their original beliefs were correct (Howe & Tolmie, 1999). Very few understood that to find out which of the variables were influencing the results it was necessary to manipulate that variable, and that variable only. So many ideas in the form of extraneous variables were introduced that the children had great difficulty with the experimental processes of predicting, observing and drawing conclusions.

The promotion of scientific thinking

Self regulation

The equation appears to be relatively straightforward: the more able an individual the more self-regulation in learning will be needed for high achievement; the less able an individual, the more teacher regulation is needed (Span, 1995). There appears to be a qualitative difference in the way the intellectually highly able think, compared with more average-ability or older pupils, for whom external regulation by the teacher often compensates for lack of internal regulation. To be at their most effective in their self-regulation, all children can be helped to identify their own ways of learning – metacognition - which will include strategies of planning, monitoring, evaluation, and choice of what to learn. Emotional awareness is also part of metacognition, so children should be helped to be aware of their feelings around the area to be learned, such as curiosity, persistence, and confidence.

High achievers have been found to use self-regulatory learning strategies more often and more effectively than lower achievers, and are better able to transfer them to novel tasks, to such an extent that measures of autonomous learning could even indicate talent. Overviewing research on the thinking processes of highly able children, Shore and Kanevsky (1993) put the teacher's problem succinctly: 'If they [the gifted] merely think more quickly, then we need only teach more quickly. If they merely make fewer errors, then we can shorten the practice'. But of course, this is not entirely the case; adjustments have to be made in methods of learning and teaching, to take account of individual thinking differences.

Yet in order to learn by themselves, the gifted do need some guidance from their teachers. Conversely, teachers who offer too much direction can diminish their gifted pupils' learning autonomy. Although 'spoon-feeding' can produce extremely high examination results, these are not always followed by equally impressive life successes. Too much dependence on the teacher risks loss of autonomy and motivation to discover.

When teachers help pupils to reflect on their own learning and thinking activities, they increase their pupils' self-regulation. For a young child, it may be just the simple question 'what have you learned today?' which helps them to recognise what they are doing. Given that a fundamental goal of education is to transfer the control of learning from teachers to pupils, improving pupils' learning to learn techniques should be a major outcome of the school experience, especially for the highly competent. There are quite a number of new methods which can help, such as child-initiated learning, ability-peer tutoring, guided dialogue, etc. Such practices have been found to be particularly useful for bright children from deprived areas.

Methods to promote self-regulation in learning (Nisbet, 1990)

- *Talking aloud*. The teacher talks aloud while working through a problem so that the pupil can see the working.
- *Cognitive apprenticeship*. In this the teacher demonstrates the processes that experts use to handle complex tasks, guiding the pupil via experiences.
- *Discussion*. This must involve analysis of the processes of argument.
- *Cooperative learning*. The pupils explain their reasoning to each other. Cooperative teaching-learning interactions in the classroom are ideal for helping pupils take the leap to higher levels of understanding.
- *Socratic questioning*. In this, the teacher uses careful questioning to force pupils to explain their thought processes and explain their arguments. The questioning is not used to teach new knowledge, but to help pupils to know and use what they already have.

Meta activities

The degree to which high-level scientific thinking can be strengthened and mobilised depends on developing the meta-activities needed for autonomy in learning. This not only involves the metacognitive overview and direction of one's own thought processes, but also a mixture of attitudes, such as curiosity, persistence, and confidence, as well as the use of strategies, such as planning, monitoring, and evaluation.

Applied research into how children learn science brought Adey (1991) to the conclusion that "the children's ability to think about the nature of their own thinking was a critical contributor to their success" (p.28). In CASE (Cognitive Acceleration though Science Education) work, "students are encouraged to take time to reflect on how they solved a problem, what they found difficult about it, what sort of reasoning they used, how they sought help and what sort of help they needed" (p. 6).

But scientific progress is not all theoretical, knowledge is vital to outstanding performance: individuals who know a great deal about a specific domain will achieve at a higher level than those who do not (Elshout, 1995). Research with creative scientists by Simonton (1988) brought him to the conclusion that above a certain high level, personal characteristics such as independence seemed to contribute *more* to reaching the highest levels of expertise than intellectual skills, due to the great demands of effort and time needed for learning and practice. Creativity in all forms can be seen as expertise combined with a high level of motivation (Weisberg, 1993).

So, learning is not just a matter of cognitive processing; it is affected by emotions of both the individual and significant others. Positive emotions facilitate the creative aspects of learning and negative emotions inhibit it. Fear, for example, can limit the development of curiosity, which is a strong force in scientific advance, because it motivates problem-solving behaviour. In Boekaerts' (1991) review of emotion in the learning of very high IQ and highly achieving children, she found emotional forces in harness. The children were not only curious, but often had a strong desire to control their environment, improve their learning efficiency, and increase their own learning resources.

Novices and experts

The difference between a novice and an expert is that the expert has a much broader knowledge base on which to use the same level of intelligence and creativity. For scientific thinking, the novice has to accumulate not only more information, but also the increasingly complex procedures to apply it to a greater variety of problems. Any expert action, such as high-level examination achievement, requires both knowledge and the skills to use it. In well-practised everyday activities like making a phone call or driving a car, everyone makes use of such expert actions. It is even possible to develop general adaptable expert strategies for problem-solving. Professional administrators have a selection ready to apply in very different fields of activity and situations. This is why a competent manager can move with good effect from, say, a factory producing glassware to a business buying and selling cloth.

One can think of children as novices and adults as experts, and gifted children may become experts well ahead of their years. This may mean an advanced ability to see relationships between objects and to apply them in new situations. A gifted child may even jump whole stages in an argument or logical progression, though may be unable to describe how he or she reached those conclusions. This can be disconcerting to adults. A child may also see ambiguities in questions which others do not see, needing time to pause and consider before answering and maybe appearing to be slow in responses.

However, it is usually agreed that even though a child may give adult-expert type performances, such as Mozart and Mendelssohn did in their early musical compositions, those works were in fact the products of infant prodigies and do not compare in depth either to their own adult works, or the work of other composers in their adult years (Radford, 1990).

Advanced thinking in children can be seen in terms of problem-solving skills (Chi *et al*, 1988). The level that can be reached depends both on knowledge and the quality and efficiency of its mental organisation - vital in high-level scientific thinking. Even young gifted children show a distinctly more mature, expert-type competence in information-processing than their non-gifted age peers. Thinking techniques used by the gifted have been found to have a degree of sophistication normally used by older children of average IQ.

Ferranti & Butterfield (1989) found a clear IQ correlation with the levels of sophistication of the children's thinking approaches.

Differences in problem-solving strategies between high and average school performers were investigated by Shore, *et al,* (1992), who audio-taped and analysed the young pupils' thinking-aloud comments. The researchers found that the performance of the more successful learners was closer to that of experts, in that they made more reference to prior knowledge, rather then only to information presented in the problems (Luthar *et al,* 1992). However, others have concluded that the learning procedures of the highly able are distinct in style, rather than simply being more mature (Kanevsky, 1992).

There is a growing body of evidence that both metacognition and motivation are shaped by culture (Collier, 1994). For example, Schneider (2000) found that German children were more likely to use memory strategies and recall significantly more material than Americans. These characteristics were traced to differences in home and classroom. German parents reported more direct instruction of strategies were more likely to check their children's homework, and possessed more games in which strategic thinking was required. The trend for teachers was the same; they were more likely to direct memory strategies.

FREEMAN'S FOLLOW-UP OF GIFTED AND NON-GIFTED YOUTH

The uniqueness of this 27-year follow-up study has been in the in-depth, counselling-style interviews, with gifted and average ability young people, their teachers and parents, about the fabric of their lives, each one in their own home across Britain (Freeman, 2001). 210 children entered the study in 1974 aged 5-14 years-old. Hundreds of hours of follow-up interviews were audio-recorded and keyed in to a computer to be analysed. Part of the research was concerned with their thinking and study habits, illustrated briefly here.

It was clear that when a child's educational environment was inadequate for learning and mental exercise, the development of metacognition was impeded. So, children of high potential living in culturally poor circumstances which detracted from their energy and positive attitudes to learning, needed much more teacher assistance. Those who were intellectually gifted and achieving at a high level often had an advanced degree of awareness of their mental processes, so they could function nearer to their best for longer than the others in the sample. They told it in their own words, as one gifted mathematics student at university said:

> "The secret of my learning is that I've got to understand what I'm doing. For me, there are two approaches to work. If it's a subject that bores me, or a problem I find difficult to understand, I know I have to plough through it, referring to notes and back, just learning by heart. But if it's something I enjoy, like maths, I just sit back, look for the important points, and I can do it."

How the gifted learn

To different degrees, about a dozen gifted youngsters in the sample had allowed their study habits to become really rigid, and relied heavily on their exceptional memories in a relatively superficial and unthinking way though rote-learning, memorising pages of information. Such habits are not only inefficient in the long term but very boring, and so detract from the pleasure of learning. Their attraction is that it appears to require less effort from both learner and teacher. It also offers the learner an immature, spurious emotional security, in that he or she does not have to make their own learning decisions, but only reproduces what an authority such as a teacher or text-book writer has said. In the panic before big exams, even the most sophisticated thinkers in this study sometimes abandoned their valuable, higher-level strategies for a frenzied, indiscriminate search though their notes.

Even when he was 10, I had observed that Neville, who had a top-of-the-scale IQ, also had an anxious personality and natural reserve, which seemed to have been reinforced by unrelieved school pressure to absorb information. He was aware that he used the false security of rigid, learning strategies as a shield to hide from his emotional self. No-one had ever helped him develop a feeling of competence in his own thinking so that he could use his extremely high potential in a flexible and productive way. As a science specialist, his school had obliged him to drop all the arts subjects, and he had developed little insight into or love of the more creative aspects of life. At university, Neville was becoming desperate about what he felt was missing from his life, so much so that he was considering dropping-out before his finals (he didn’t). Nor had his study methods improved, his poor (but examination effective) learning habits had become ingrained. He looked at the ground when told me despondently:

> “I don't read textbooks: I'm not very good with them. My notes are so vast, 50 pages of dense writing. I go through them again and again, just writing down occasional sentences. I learn all those, and then go through problem sheets and exam papers.”

Lack of discipline

Although Samantha had achieved superb school-leaving grades, her poor metacognition, her lack of awareness of how best to use her powerful mind, showed up when she had to survive on her own at university.

> “People say I'm weird because I will think of something which will remind me of something else, then my mind will go racing along the new train of thought. I'll arrive at an observation which has got no relevance to anything that anyone else can see. It's a handicap when I'm trying to learn, because, say I'm looking something up in an index, I'll be triggered into finding something else to look up, but then I won't get back to the original thing for hours. I still have to rely on my memory.
>
> Until I got to university I’d never actually had to work - I did my homework on the bus or while eating my tea. It was never difficult. When I started my degree course, I tried to do the same with the first maths problem sheet we were given. I soon realised that this was ‘hard’! And most of the others on the course had been used to finding this stuff hard, and settled down to work at it. I’d never had to learn how to work - and being away from home at the first time, at the age of 17, is not the best time to have to do that! So I never really put in the necessary effort, right from the start. And that’s why I failed.”

Overdoing it

Alternatively, the intellectually gifted are sometimes faced with the temptation of frenetic mental activity, which may not appear to be to any productive purpose. It seems to happen when the emotional part of a person either becomes disregarded or actually crippled, as though it were irrelevant to the individual's thinking and creativity, almost as though someone has become just a brain physically supported by the rest of the body. Such a person can enter a maze of ideas, developing theories and sub-theories which have no useful function other than intellectual exercise. William Sidis, the American genius who supposedly had one of the highest IQs ever measured, found himself trapped by such mental convolutions. His upbringing had led him to believe that he was only valued for his intellect, compounded by the devastation of his peace of mind though his media fame for being brilliant. His relatively little productive work has not withstood the test of time (Wallace, 1986).

Stephen Harris, a supremely gifted 14 year-old, showed evidence of too much dependence on his cognitive skills. He was the child of warring divorced parents, somewhat emotionally neglected and lonely. He told me:

> “I learned to programme when I was eight. Now, I'm working out a formula to translate into computer language. It's quite a simple programme, finding elements in Pascal's triangle. But the thing that made it a lot more complicated, was that I wanted to do it for very large numbers, so it required a different method of storage from the ones the computer actually provides for you. At the moment, I'm working on a version of Manic Minor, a computer game on a large scale with 50 different screens. I invented a card game once called Seven Card Wiggle and typed the rules for that, which I don't think I'll ever finish because there are about seven thousand.”

By his thirties, Stephen had taken a job much below his abilities, and though it was somewhat boring, it brought him a steady salary so that he could return home at the end of the day in a peaceful state. He knew quite well that he had no wish to return to the emotional turmoil of his childhood, and if the price to be paid was a dull life, then that was what he had chosen.

Similar evidence of emotional insecurity and dependence on purely cognitive skills can be seen in many high-level school-achievers as they go through life. Rather than daring to create ideas, they seem almost desperate to show how much they know by answering other people's questions correctly and being informative, as though life was one long educational grilling on which they were to be judged. This situation was described in a follow-up of 1964-1968 Presidential Scholars in America (Kaufman, 1992). Kaufman found that although the ex-scholars continued to do well, they knew they often relied on school-type learning, not only to provide themselves with an identity but also a feeling of worth. But then, at any age, being a ‘know-all’ is not perhaps the best way of attracting friends.

Good strategies

The most frequent strategy used by the successful young people in Freeman’s study was to look for the principles in their work first, and then fill in the details appropriately. To do that calls for the confidence to take an authoritative overview of both the subject under consideration and of one's own mental approach. Jacob, a gifted flexible learner and a confident scientific thinker, studying medicine, said:

> “I'm a great believer in trying to find a rule that makes things work. I can very often remember the principles first time through. I certainly avoid learning things by rote.”

Multi-attention

The ability to be focussed has its advantages, in that greater progress can often be made in the desired direction. But working in several areas at once is also useful in both intellectual and practical ways. Mary, with her top-of the scale IQ, was at university studying Computer Systems Engineering. She explained:

> "I often do two things at once. Right now I'm building a synthesiser, so I've got piles of components and bits of things to stick to this piece of board. Unfortunately, as I haven't got all them all it's a bit difficult trying to imagine where they're going. I've brought it home to do, so I do it while I watch television. I like to have something on in the background, because it's a boring job; the first component in is much like the eightieth component in."

Speed of thinking

A high proportion of these gifted young people could think very rapidly. Mary continued:

> "At school I was in a small class so I went at my own speed. I would say to my teacher, 'I think I know this well enough now', and we would move on. But at university it's mixed ability, everybody in one class. There are 25 of us on our course, and we're spread out across the whole ability range. Those who want to work quickly can get on and then take more free time than others. But I'd really prefer to be in a group where everybody wants to work quickly.
>
> I like working quickly. You don't sit next to Mary unless you want the answer before you've started the problem! I sit there, and the question will be written on the board, and before the lecturer's finished the question, I've started writing. And while everybody else is writing down the first formula, still wondering what to do, I'll say, 'Finished!' But that speed only works for logic and maths because it's numbers and figures and symbols. Something I could do symbolically in a couple of minutes might take me upwards of half an hour to explain to somebody else. Anything where I've got to express my own ideas and explain why something happens, or write an essay, takes a lot longer, because you've really got to stop and think.
>
> I find it very hard to stop to think in the middle of a flow. I'd much rather get it down, then go back and check through every step. In an exam, I'll whiz through the paper, spending about two-thirds of the time writing, and the other third going through, checking my answers and often changing things. It's a case of, does it feel right and does it make sense?"

The high-achievers in this sample often had a good grasp of their own metacognition - knowing how they learned and thought, and with the ability to work in ways which suited them. They were often able to describe their systems explicitly, and say how it could affect their results. In that way they could harness the mental power they were born with in hard work that was well aimed and coordinated, although very few had been taught how to do it. They were also much more keenly aware of different possible approaches to the work than the relatively less successful students, who had to use more energy to cope in a more rigid way with less success in their learning.

Mary the computer student explained:

> "Everyone knows which is the best way for themselves to work. Children have got to choose their own way, otherwise they're not going to do their best, and it may be difficult for them to express themselves in a way which doesn't fit their style. I would have liked the teachers to know what we thought. It would have been nice for us to have been able to say, 'Look, I don't like the way it's done. Is there nothing we can do to change it?'"

Concentration

While some of the most gifted said their normal attention span was only a few minutes at a time with constant breaks, others claimed many hours of unbroken concentration. Others described how they could adapt to whatever the circumstances called for, altering the length and depth of concentration appropriately.

It can vary, as a gifted boy said:

> "I usually take breaks about every ten minutes. Once though, I worked from four o'clock when I got home, till half-past one in the morning, and then had my break for tea. I concentrated totally. It was just something that had to be done."

Some took this to extremes, such Jacob, the top-of-the IQ scale medical student:

> "I've got exams in three or four weeks, and I'm being quite honest when I say that I haven't opened a book all year. I like to feel the pressure, to build up some anxiety, so I know that if I don't start now, I'm definitely going to fail. It's the challenge of doing that. I'm fully dedicated to working at this point, and only at this point. For my first year exams, I only started revising two days before. My method is to cram for couple of weeks, doing 24 hours a day, and not sleep for a few nights. I'm a totally different person when it gets to that stage. Everything seems to go in at that point, so I must be able to absorb the stuff."

Examples of educational schemes for encouraging high-level scientific thinking

It is clear from the evidence that excellence in any sphere does not emerge without appropriate help. If the recognition of high-level potential is restricted to school and test achievements, much will be missed. To reach an exceptionally high standard in any area, potentially gifted children need the means to learn; this includes the material to work with and focused, challenging tuition, sometimes including tutoring or mentoring that is not provided in normal schools. It is suggested that given the opportunity and with some adult guidance, children of high potential and motivation should be able to choose to work in any area at a more advanced or deeper level.

Every school should have a clear policy for the encouragement of high-level performance in both pupils and teachers (see Freeman, 1995). Such a statement would also provide an indication of how the school deals with the different educational requirements of all its children. Any policy must also involve the commitment of the head-teacher and a whole-school approach.

Rather than continuing the search for elusive definitions, it would be more productive to look at the dynamic interaction between individuals, and their opportunities for learning throughout life. Without that dynamic element, we return to the old ideas of fixed abilities, most notably of intelligence. What is needed to enhance every child's potential is often already available, at least in the developed world.

Cognitive Acceleration through Science Education (CASE)

Cognitive Acceleration through Science Education is a British system used in several countries, which has sound experimental evidence to back its aim of improving scientific thinking (Adey, 1999). Part of its design for increasing scientific thinking in school-children, is to speed up their "'natural' development process through different stages of thinking ability, towards the type of abstract, logical and multivariate thinking which Piaget describes as formal operations. Formal operational thinking is characterised by the ability to hold a number of variables in mind at once – for example, to be able to weigh up two sides of an argument, to consider even-handedly the advantages and disadvantages of a particular course of action, or to be able to see both the separate and combined effects of a number of input variables (for example – sunlight - carbon dioxide - water) on an outcome (the production of glucose)." (p.5)

In spite of being based on Piaget's theory of stages, the CASE intervention procedure rejects the simple idea of matching learning material to the stages because that keeps cognitive demands at the same level as the current level of the learner's thinking. Instead, it uses Vygotsky's concept of Zone of Proximal Develoment - the difference between what a child can do unaided and what a child can do with the help of an adult, (as does Feuerstein's programme of Instrumental Enrichment). The teacher structures the lessons for higher-level thinking, but cannot independently put capability into a child's head. The child must do this alone, which can take time and patience.

CASE distinguishes between staightforward instruction - aimed at content objective - and intervention in the cognitive development process - aimed at raising levels of scientific thinking within the curriculum. It challenges learners to transcend their present level of thinking and speed up their rate of intellectual development.

Selection procedures which choose children by their current achievements, rather than what they might be capable of doing, such as in the vast majority of standardised tests, will inevitably miss children who are not functioning at their best.

A self-selection scheme for learning science - Migal

Opportunities for potential ecologists are provided by Migal at The Technological Centre for the Galilee, Israel. For about 20 years, the Centre has invited teenage boys and girls from local comprehensive schools to work on their own projects under supervision. They are not pre-selected in any way. The Centre has the specific aim of developing scientific thinking, using projects such as the effects of magnesium on plants, or cultivating wild mushrooms, or the effects of hormones on fish reproduction. In the laboratory, youngsters design and conduct work on original problems for which there are no existing answers, nor (often) methods, then continue to work with the data back at school. The teenager has to prepare and write a research proposal, which is discussed with the laboratory supervisor, and submitted to the Ministry of Education for approval; then, he or she can begin, either alone or in a group. Each participant has to be able to work on a computer, and eventually will provide a bound dissertation. The Centre displays the youngsters' work, which is sometimes of Master's degree standard. This shows what can happen when motivation is allied with opportunity, and the potential to take advantage of it. The cost is low and largely supported by the state, and the results are extraordinarily high.

The Sports Approach to promoting gifted learning and thinking

Excellence in some abilities is more acceptable than others in all cultures. In almost all parts of the world, local education authorities encourage enthusiastic, talented footballers to benefit from extra tuition outside school hours. They are provided with equipment (possibly including clothing), transport is arranged for them to meet and play with others at the same level as themselves, and it is all paid for by the local authorities.

There is some provision around for other subjects, notably music, and there are mathematics contests and extra-curricular activities, such as art classes in museums. Too often, school laboratories remain closed out of school hours. It is neither difficult nor expensive to find out what interests and motivates pupils via questionnaires, interest tests, or simply by asking them. The facilities are already largely in place to provide excellent support for gifts other than football.

Freeman (1998) has proposed that, given the opportunity, and with some guidance, the gifted (and motivated) should be able to select for themselves work at any subject at a more advanced and broader level. She terms this the 'Sports Approach'. The model works in the same way as school attitudes to sport. Just as youngsters who are talented and motivated can select themselves for extra tuition and practice in a particular sport, they could opt also for biology. This would mean that facilities must be available to all, as sport is, rather than only to those pre-selected by tests, experts, or money

This is neither an expensive route, nor does it risk emotional distress to the children by removing them from the company of their friends. It makes use of research-based understanding of the very able, notably the benefit of focusing on a defined area of the pupil's interest, as well as providing each individual with what they need to learn and make progress.

However, to practice the Sports Approach, most teachers would need more training in differentiated teaching methods and techniques for bringing out high-level potential. But most importantly there would have to be some unification of policy within a school or authority. The recognition of talent in this way would also include recognition of the learning plan to which the pupils had access. This could be done by a simple rating-scale; children who were excelling within their context would be seen to be doing so, and not penalised because they had poorer provision than others. By such means, the proportion of those we now consider to be gifted could be considerably increased, to the greater benefit of all concerned. There are, however, certain guidelines to be aware of in this approach.

Identification and development of gifts through provision:

- Development should be process-based and continuous.
- Identification should be by multiple criteria, including targets for learning and outcome.
- Indicators should be validated for each course of action and provision.
- The pupil's abilities should be presented as a profile, rather than a single figure.
- Increasingly sharper criteria should be employed at subsequent higher-level learning stages.
- Recognition should be given to attitudes possibly affected by outside influences, such as culture and gender.
- The pupils must be involved in educational decision-making, especially in areas of their own interest.

Internet help for scientific thinking

There are many sources of rich encouragement and provision for inspiring potential scientists to be found on the World Wide Web. For example -

An initiative based at Sheffield Hallam University, the *Pupil Researcher Initiative* or *PRI* (http://www.shu.ac.uk/schools/sci/pri/welcome.htm/) sponsors science fairs, and presents pupils with challenging, relevant investigative tasks. The activities presented in the *PRI* units of work should help teachers to prevent boredom amongst their more gifted pupil scientists.

The Eco-Schools project (http://www.abdn.setpoint.org.uk/setpoint/aberdeen/section/eco-schools/), the *Crest Awards* (http://www.nybep.demon.co.uk/STEM/CREST/CREST.HTM), and school industry links encouraged by local SATROs (Science and Technology Regional Organisation) encourage pupils to undertake extended, appropriate interesting projects of their own choosing. The *Crest Awards* also include an element of competition.

The British Association for the Advancement of Science (http://www.nybep.demon.co.uk/STEM/BAYS/BAYS.HTM) supports teachers wishing to run science clubs through the provision of special experiment packs. They also sponsor special events during science weeks, and their popular BAYSDAYS in national museums. Within these schemes, pupils can choose to pursue activities with a distinctive biological flavour.

The Internet gives pupils and their teacher's access to working scientists through web sites (e.g. The Woods Hole Oceanographic Institute, on http://www.whoi.edu/science/B/dept/Biology_Staff.html).

Organisations such as the Association for Science Education also provide more direct access to scientists via the Internet during SET science weeks.

The Science museum inspired STEM project (http://www.nmsi.ac.uk/stem2/oyster.pl?stem/stemintro), is another useful source of challenging materials.

Science across the World project (http://www.ase.org.uk/sworld.html) presents pupils with the chance to participate in international data collection as individuals or as groups. The open-ended nature of the units of work facilitates data analysis at the highest level, and the project encourages links between like-minded pupils across the World. It thus encourages both child-initiated learning, and ability-peer tutoring.

REFERENCES

Adey, P. (1991), 'Pulling yourself up by your own thinking', *European Journal for High Ability*, *2*, 28-34.

Adey, P. (1999). *The Science of Thinking and Science for Thinking: a Description of Cognitive Acceleration through Science Education*. Geneva: International Bureau of Education. www.ibe.unesco.org

Boekaerts, M. (1991). 'The affective learning process and giftedness', *European Journal for High Ability*, *2*, 146-160.

Chi, M.T. H., Glaser, R. & Farr, M.J. (1988). *The Nature of Expertise*. Hillsdale, NJ: Lawrence Erlbaum.

Collier, G. (1994). *Social Origins of Mental Ability* New York: John Wiley.

Elshout, J. (1995) Talent: the ability to become an expert, in J. Freeman, P. Span, & H. Wagner (Eds.) *Actualizing Talent: a Lifelong Challenge* (pp. 87-96) London: Cassell.

Ferrenti, R.P. and Butterfield, R.C. (1989). 'Intelligence as a correlate of children's problem solving', *American Journal of Mental Retardation*, *93*, 424-433.

Freeman, J. (1998). *The Education of the Very Able: Current International Research*. London: The Stationery Office.

Freeman, J. (2001) *Gifted Children Grown Up*. London: David Fulton Publishers.

Howe, C. & Tolmie, A. (1999), 'Experimental appraisal of experimental beliefs in science: Constraints on performance in the 9-14 age group', *British Journal of Educational Psychology, 69,* 243-274.

Kanevsky, L. (1992), 'Gifted children and the learning process: insights on both from the research', in F. Mönks and W. Peters (Eds.) *Talent for the Future*. Assen: Van Gorcum.

Kaufman, F.A. (1992), 'What educators can learn from gifted adults', in F.J. Mönks & W. Peters (Eds.), *Talent for the Future*, Maastricht: Van Gorcum.

Luthar, S.S., Zigler, E. & Goldstein, D. (1992), 'Psychosocial adjustment among intellectually gifted adolescents: the role of cognitive-developmental and experiential factors', *J. Child Psychol Psychiat, 33*, 361-373.

Nisbet, J. (1990). 'Teaching thinking: an introduction to the research literature'. SCER *Spotlights*, 26.

Radford, J. (1990). *Child Prodigies and Exceptional Early Achievers*. London: Harvester Wheatsheaf.

Schneider, W. (2000), Giftedness, expertise, and (exceptional) performance: a developmental perspective, in K.A. Heller, F.J. Mönks, R. Sternberg & R. Subotnik (Eds.), *International Handbook of Research and Development of Giftedness and Talent* (pp. 165-177) Oxford, UK: Pergamon Press.

Shore, B. M. & Kanevsky, L. S. (1993), Thinking processes: being and becoming gifted, in Heller, K. A., Mönks, F. J. &. Passow, H. A. (Eds.) *International Handbook of Research and Development of Giftedness and Talent* (pp. 133-147) Oxford, UK: Pergamon Press.

Shore, B.M. & Kanevsky, L.S. (1993), 'Thinking processes: being and becoming gifted', in Heller, K.A., Monks, F.J. &. Passow, H.A. (Eds.) (1993) *International Handbook of Research and Development of Giftedness and Talent*. Oxford: Pergamon Press.

Shore, B.M., Coleman, E.B. & Moss, E. (1992), 'Cognitive psychology and the use of protocols in the understanding of giftedness and high level thinking', in F. Mönks and W. Peters (Eds.) *Talent for the Future*. Assen: Van Gorcum.

Simonton, D.K. (1988). *Scientific Genius. A Psychology of Science*. Cambridge: Cambridge University Press.

Span, P. (1995). Self-regulated learning by talented children, in J. Freeman, P. Span, & H. Wagner (Eds.) *Actualizing Talent: a Lifelong Challenge* (72-86) London: Cassell.

Wallace, A. (1986). *The Prodigy. A Biography of William James Sidis, the World's Greatest Child Prodigy*, London: Macmillan.

Weisberg, R. (1992). *Creativity, Genius and Other Myths*. New York: Freeman.