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Watching the plants grow

Understanding giftedness in science

Abstract:

This chapter considers what might be meant by suggesting that someone, and, in particular, a school-age learner, is gifted in science, and offers some suggestions for how such a student can best be supported by teachers and parents. Observing, and noticing, are therefore important, although not enough by themselves to make a future scientist. The scientific mind does not just make and classify observations, but seeks to explain them. So gifted young scientists show a critical faculty not to simply accept the word of an authority, but to want to think things through and be persuaded for themselves. Giftedness is clearly associated with high intelligence, which is often measured by IQ tests. However, there have been various attempts to offer broader and more inclusive understandings of intelligence, and, given the range of characteristics useful to achievement in science, the gifted scientist is not simply someone with a very high Intelligence Quotient.

This chapter considers what might be meant by suggesting that someone, and, in particular, a school-age learner, is gifted in science, and offers some suggestions for how such a student can best be supported by teachers and parents. The term 'gifted' can have some unfortunate associations (for example that some people have been blessed in some particular way, and so, by implication, others have not), but as it is widely used it will, with qualification, be adopted here. The qualification is that the term gifted will be understood and used in a particular way.

Giftedness and high ability in science

The notion of giftedness informing this chapter might be described as 'contextual' and, when used in relation to educational provision, 'pragmatic'. It is *contextual* in the sense that it is not considered that there are some people who simply 'are' *gifted*, or indeed 'are' (absolutely and for all time) *gifted in science*, but rather that a judgement of giftedness relates to a person relative to a particular learning context (or a particular area of practice, such as working in a particular scientific field at some particular stage of its development). If Isaac Newton or Marie Curie could somehow be transferred into a contemporary university science department today then they would be unlikely to be able to perform as productive scientists, let alone be perceived as scientific geniuses. Perhaps such a time-travel scenario is unfair to them, as they would likely still have the *potential* to be great scientists, but unable to show this potential as they would not have been inducted into the current ideas and practices of science. Yet, as Thomas Gray (1751) long ago recognised, history has ignored countless people with the *potential* for greatness but born into circumstances where their potential was never nurtured and fulfilled to enable notable achievement.

So judgements of giftedness are made within particular contexts, and this links to the *pragmatic* notion of a learner being seen as gifted within a specific educational context. In some teaching contexts there are students that have existing levels of knowledge, understanding, and skills, such that curriculum and teaching suitable for their classmates would not be appropriate for them (Taber, 2007b). Suitable and appropriate are here related to the idea of educative provision capable of supporting a learner's substantive development. There are times in an educational programme where it may be useful to have students practise existing skills and apply previously mastered knowledge in order to reinforce learning, and perhaps increase accuracy and speed of recall. We might associate terms such as 'exercises' and 'drill' with such activities. However, an educational programme that only (or mainly) provided these types of experiences would offer little basis for learning new skills, developing new insights, and opening up new areas of knowledge. Educative experiences are those that support these types of qualitatively novel - for that learner - developments.

A well-designed curriculum or programme of study should be educative in this sense. However, it is possible for a student to be placed in a programme which is a poor fit, such that it is experienced mainly as review and drill, rather than offering anything substantially new. (It is also possible for some students to be in inappropriate programmes because they have insufficient skills and background knowledge to effectively engage with teaching and access learning. That is an equally serious concern, but not the focus here.)

School classes are by their nature made up a range of students with different current levels of attainment, and of readiness and potential for making further progress, and therefore teachers are faced with planning teaching that can concurrently be educative for students with quite different characteristics. In practice, it may often be the case that classes, and indeed prescribed curriculum, may be designed with a notional 'typical' learner in a particular grade level in mind, in which case it is quite possible that there may be some students in the class not readily challenged. Whilst these learners can certainly complete work effectively and successfully (at least if they can be motivated to engage with it), they benefit very little from activities that are genuinely educative for many of their classmates.

It is these students that are considered here to be usefully identified as gifted: those that will not be challenged and developed by curriculum, teaching, and learning activities, considered suitable for their peers. Such a judgement is contextual in a number of ways. For example, development of intellectual skills is not uniform, and a seven year old who would be considered gifted in their year group might later (through no blame on the child) have ceased to count as gifted by 14 years of age. Equally, the opposite might be true. People have different strengths. Learners who are bored and find no stimulation or challenge in mathematics classes that stretch most of their classmates might attend literature classes, with the same group of peers, and be fully engaged in work that is pitched at a level that is educative for them (again, or vice versa).

Perhaps there are some children who we should just consider 'gifted' as they are exceptional all-rounders - but we also find children and young adults who are clearly gifted in some curriculum contexts but not others. It has also been widely reported that some learners are twice (or more) exceptional in the sense of having some particular learning difficulties that slow their progress in some aspects of school, whilst showing exceptional abilities in particular areas (Sumida, 2010; Winstanley, 2007). An example might be a student who due to specific learning difficulties struggles to produce high quality written work, but when engaged in oral discussion is able to demonstrate highly complex and sophisticated thinking and argumentation skills not reflected in their writing. Clearly it would also be possible for the true potential of gifted learners with, say, short-sightedness or hearing impairment not to be apparent unless those conditions were diagnosed and addressed to allow the learners to properly access teaching.

It should also be pointed out that, as with most human characteristics, giftedness is not binary (gifted/not gifted) but can be seen to lie on a continuum - or more correctly, given that it is multifaceted, to occupy a point in an imaginary multidimensional space. Given this contextual and pragmatic perspective, references to learners who are 'gifted in science' have to be understood here to mean those judged to need particular provision in the sciences, or some aspects of science, at this particular time, given the curricular programme they would normally be expected to follow.

The reference to some aspects of science is important as it is possible to be considered gifted in physics but not biology, or even to show exceptional insight in, say, understanding chemical reaction mechanisms and suggesting synthetic routes, whilst not standing out from the class when carrying out calculations in physical chemistry. Ideally we would want *all students* in *all classes* to at *all times* be tasked with work that is sufficiently challenging to potentially catalyse their development, whilst simultaneously being sufficiently supported to engage productively and so to make clear progress in their learning (Taber & Riga, 2016). Such an ideal may not be feasible when teachers are working with large classes and have limited time for preparing or sourcing classroom resources, or if they are expected to teach through an impoverished pedagogy (if teacher led exposition to the whole class is not complemented and co-ordinated with dialogic class discussion, enquiry activities, group-work, etc.), but it is a worthy aspiration, even when an unrealistic expectation.

Giftedness is clearly associated with high intelligence, which is often measured by IQ tests. However, there have been various attempts to offer broader and more inclusive understandings of intelligence (Gardner, 1993; Sternberg, 2009), and, given the range of characteristics useful to achievement in science, the gifted scientist is not simply someone with a very high IQ (Gilbert & Newberry, 2007).

What makes for a gifted scientist?

Given a contextual notion of giftedness, what makes for giftedness in science needs to be understood in the context of the nature of science. Clearly being a successful student in science will involve developing a good deal of scientific knowledge, being able to understand and apply abstract ideas (such as laws, principles, models, and theories), and effective deductive thinking to draw logical conclusions. The latter is itself a contextual matter as although deductive logical has an algorithmic nature - in principle it could be programmed into a machine - the appropriate conclusions that can be drawn from a particular data set always depends upon the theoretical framework being employed. That is, data only become evidence within a particular theoretical perspective.

So, students that are successful in science and can proceed to scientific careers will tend to have at least these qualities in common. However, scientists who become recognised as leaders among their peers (in their professional context) tend to notice things that others do not consider as significant, and imagine possibilities that their peers have not considered (Kuhn, 1970). They tend to be especially inquisitive, and to not be satisfied with standard and accepted answers.

Examples might include the likes of Darwin who built a new central perspective for the science of biology based on his own extensive field observations, and reports he collected of observations from anatomists, farmers, pigeon fanciers and others; and Einstein who based some of his most influential work on the outcomes of imagining what it would be like to travel on a beam of light. Nobel laureate physicist Richard Feynman highlighted the inquisitive nature of successful scientists, as people who are not satisfied with surface explanations and who engage with problems as puzzles to be solved - such as his role in identifying the cause of the NASA Challenger Space Shuttle failure. When working as a young scientist on the Manhattan Project (that developed the first US atomic weapons), Feynman treated the locks on the cabinets where secret documents were stored as puzzles to be solved. In 1959 Feynman gave a talk that in retrospect can be seen as manifesto for a new area of science developing machines on a scale comparable to molecules. He imagined the possibility of what we now call nanoscience or nanotechnology.

Those who make the greatest breakthroughs are often those who are prepared to entertain alternatives to what might be considered as accepted truths: what if the universe is not centred on the earth; what if the continents are not fixed features of the earth's surface; what if all life on earth is related by descent from on common ancestor? For example, Einstein disregarded the common-sense notion that the measured speed of light would depend on one's own speed (as in everyday experience: when a car travelling at 55 km/h overtakes a lorry travelling at 50 km/h it is moving at a speed of 5 km/h relative to the lorry), and explored the consequences of assuming the seemingly illogical premise that the seed of the light is the same for all observers regardless of how fast they are moving. This led to the general theory of relativity, which has since been extensively tested and found to fit observations,

Spotting gifted science students

These considerations suggest two complementary ways to identify those we might consider gifted in science among children and young adults - in terms of the ease of meeting curriculum goals, or in terms of potentially indicative characteristics. A teacher should be concerned about any student who seems to succeed in class activities without needing to stretch themselves intellectually. School is not meant to be like adult work in one important sense. In an employed position we generally (if not always) want workers to be working within their comfort level where they can succeed in assigned tasks. We do not want to be operated upon by the surgeon who has never undertaken this new procedure before - even if the experience will be educative for the doctor. We are unlikely to want to buy a recording of the concerto being played by an artist who is currently struggling to add it to her repertoire, even if it reflects an important phase in her artistic development.

Most parents would be concerned to be told that because of unexpected staffing changes in the school, their child will now be taught history by a mathematics teacher who has not taught history before but who has some capacity in her timetable to take on an additional class: even if they knew she was a good maths teacher, had always liked history, and was really committed to doing a good job. Yet a learner's job in school is just like this, to work at something they are not currently competent in, and develop new skills or areas of expertise. We want the teacher to have expertise in the curriculum being taught, but if a student already has that expertise then the demands need to be raised. So, teachers should always be seeking to ensure all students are being suitably challenged to move beyond their current levels.

It may not always be easy for parents to apply the same criteria. A child who is consistently achieving very high grades in school, and does not seem to need to make great effort to do so, may be insufficiently challenged: but the parents will not have a full picture of the context of performance and the level at which assessment is being pitched. Moreover, in many education systems, study in the lower grades is less clearly discriminated across subject boundaries, and there may be few obvious indicators to parents of how challenging different curriculum areas are found to be. Some gifted children, if by no means all, may be perfectionists, and so may report subjective evaluations of needing to work harder in a subject (or even of 'failing'), despite objectively performing at exceptional levels. The most able often have greater metacognitive awareness and can be better at recognising their limitations that many of their peers. There are, however, some other potential indicators that may prove useful to parents, as well as teachers, looking to identify those potentially gifted in science.

Scientific interests

Whilst interest does not necessarily indicate ability - it is quite possible for someone to be fascinated with an academic area without becoming accomplished in it - some gifted learners may demonstrate intense, perhaps almost obsessive, interests in specific areas of science. Science is not an activity which at its heart is about compiling facts (even if the layperson may sometimes think otherwise), but it does depend on data as the basis for building scientific knowledge.

So, it is not unusual for young people to take an interest in, say, dinosaurs, but a gifted youngster may start to develop an encyclopaedic knowledge of where fossils of particular species have been found, what those species ate, when they are believed to have lived, and so forth. This is just one example, and the focus could be volcanoes, or galaxies, or trees, or spiders, or minerals, or computer chips, etcetera. The point of relevance is that the knowledge built up is extensive, and systematic, and not just a scattering of isolated facts. Systematic here means in the sense of relating specific examples to formal typologies and schemes of classification, which involves abstraction and often links to theoretical considerations.

The particular interest may be quite specialised but may be strong enough to encourage consideration of a career in the relevant science, and to motivate wider studies that will facilitate this. Systematicity is a characteristic of scientific activity, and might be seen as one quality needed for a 'scientific mind': so a precocious tendency to organise and categorise and systematise (whether in a traditional hobby such as stamp or coin collecting, or by sorting the loose buttons in a sewing box) at an early age may indicate an aptitude for science.

Observational skills

Classifying requires observation skills, and these also link to habits of mind. Children generally have similar perceptual abilities, but they do not all notice the same things. To, with William Blake (1863), "see a world in a grain of sand" one has to first notice the grain and imagine that it is worth close inspection. A typical garden may be visited by a range of bee species of quite different size and appearance, but this needs to be noticed (unless it has been pointed out), which only happens if attention is paid. When the bath is emptied, the water flows down the plug hole - but how does this happen? Someone who had never paid attention might suspect a continuous body of water in the bath and pipe that slowly drops in level. Does a child like to wait and watch as the water exits the bath and see how (usually!) a vortex forms and changes shape and apparent speed as the system evolves?

What if is a child is asked to describe moss? Do they offer more than it is a green material sometimes found on rocks and wood? Do they describe the texture, and comment on variations. Have they used a magnifying glass, or even a microscope, to resolve the single mass into discrete plants. Do they see 'moss' as a unitary notion, or have they (as with bees) recognised this as a category that encompasses subdivisions? Have they noticed that sometimes, but not always, the mosses have stalks rising above the main body of the plants?

Such observations can certainly be considered protoscientific. In some areas of science, expertise allows the scientist to make observations that the lay person is not equipped to make. For example, although some fossils may be obvious in their natural context (albeit our observations are flavoured by the theoretical perspective we adopt - at one time many people dismissed fossils as simply decorative patterns found in rocks), the professional palaeontologist or anthropologist may be able to identify small fossil fragments, on a beach for example, which are not readily discriminated from the background material by the untrained observer.

Awe and wonder

The reader may suspect that the previous sentence betrays a fallacy in the suggestion that gifted young scientists can sometimes be identified by the habits of observation: after all observation can be trained. Learning to see cell organelles down a microscope, for example, is not simply a matter of being observant: it is a process of coming to interpret observations in relation to canonical scientific knowledge. The student learns to see the nucleus, the chloroplast, the mitochondria, and so forth.

This is true - we can learn to make observations if we are prepared to put in the time and attention required. The sports fan who regularly watches televised football matches learns to see patterns in play, and to spot rule infringements, and tactical shifts. Likely, some people have greater propensity than others to learn to observe these things, but what is required is the motivation to engage in close observation, regular feedback (from expert commentary, and the decisions made by match officials), and the commitment of a good many hours of engagement in the activity!

Motivation to engage in close and extended observations is therefore an issue here. Some children take time to look closely at the moss, or to wait watching till the bath empties, and many do not. Scientists often have a sense of awe and wonder about the natural world when many (if certainly not all) other adults may take natural phenomena for granted. Young children tend to have this sense of awe and wonder, but (for whatever reason) differ in the extent to which they retain this as they grow. The five-year old that spends an hour staring at how the cloud formations slowly shift in the sky may be considered quaint, but if a 15 year-old does the same they they risk being judged as retarded or lazy: after all, once you've seen a few clouds and learnt that they move across the sky and change shape over time, what else is there to see?

Yet the scientist often retains that childlike sense of wonder in nature, and does not take natural phenomena for granted but retains a strong aesthetic pleasure in the night sky, or the reflections on a lake, or the apparently metallic lustre of a beetle's cuticle. The child examining yet another acorn or yet another oak leaf may be genuinely enjoying the beauty of these apparently simple, but actually highly complex, structures, with their commonality of form (every oak leaf is the same…) but unique individualities (…whilst every oak leaf is different). One characteristic that marks effective scientists is the tenacity to commit to and stick with a project and see it through: single mindedness and patience, and confidence that perseverance can be rewarded, can be useful habits of mind for the future scientist.

Inquiring minds

Observing, and noticing, are therefore important, although not enough by themselves to make a future scientist. The scientific mind does not just make and classify observations, but seeks to explain them. Why does the moss tend to grow here, and not there? Why does its extent change over the year? Why does it only sometimes produce those stalks with their capsules at the top - and is there a pattern to when this happens (when it gets warmer; or after heavy rain?)

Again, children often ask many questions when young - perhaps to the point where parents get frustrated, and may often not know the answers. Most parents would struggle to offer valid answers to the multitude of potential questions curious children can ask: Why is the sky blue? Why does water make you wet? Why do we have to eat? Why can't you see the stars in the daytime if the sun only blocks a tiny part of the sky? Why do onions smell?

Perhaps especially relevant are those questions that are based on some form of comparison between parallel observations: Why do dogs bark, but cats do not? Why do some trees grow taller than others? Why can't we breathe underwater, if fish can? Why does the grass grow back after it has dried out, but many other plants die off? If babies can live healthily on milk, why do I need a varied diet?… These questions may indicate the development of the basis for that most important scientific technique: control of variables.

Scientists do not only ask questions, but they the critique answers recieved and then seek deeper levels of understanding. Some children may be happy enough to be told that cats do not bark because they meow instead, but others may see that response as little more than deflecting the question. Explanations that are little more than tautology (gem stones have regular shapes because they are crystals) or based on classification (a kangaroo has a pouch because it is a marsupial) may offer only momentary satisfaction. In science the most satisfactory answers are those that fit within an existing conceptual framework, and ideally can be subsumed under widely applicable principles and theories (such as conservation of energy and momentum, natural selection, and the molecular theory of matter). This may be reflected in the gifted young scientist with her tendency to systematise.

As has been clear since at least the time of Aristotle there can be different kinds of explanations, and for the inquisitive mind a satisfactory explanation may be multi-levelled. That some trees shed their leaves, and others do not, could be explained by suggesting there are two classes of tree: deciduous and evergreen - but that will not satisfy the inquisitive mind that wants to follow-up the original question with a "but why?" Older people often need to wear glasses because people tend to get more long-sighted as they age: "but why?" (And, indeed, "how?") Toilet cleaner is often blue because it contains copper salts which are often blue: "but why" are copper salts often blue. Just as parents may be tempted to respond to the question of why it is time for bed, with a "because I say so", they may sometimes have little to offer the inquisitive child's questions ("why does Mars have two moons and Earth only one?") beyond "that's just the way it is".

Science itself seek to ultimately understand just the way things are, and often proceeds, like the inquisitive child, in steps such that each explanation can in turn be seen as an explicandum to be explained by a more nuanced or subtle answer. When adolescent students were questioned by an interviewer taking on the role of the inquisitive child (by asking series of questions, such that the student's explanation for a phenomenon was itself subjected to a "but why…" type follow-up question) it seemed that learners differ considerably in terms of how quickly they reach a "that's just the way the world is" position (Watts & Taber, 1996). The 'natural attitude' (Schutz & Luckmann, 1973), that people come to accept many of the regularities in the world as given and not needing further explanation, is probably a necessary coping strategy - but the scientific attitude avoids too readily accepting that something is "just natural" and the gifted young scientist is likely to always be seeking to understand (rather than just know), and is seldom satisfied for long with the first level of explanation encountered.

Testing truths

So gifted young scientists show a critical faculty not to simply accept the word of an authority, but to want to think things through and be persuaded for themselves. They are likely to try planting seeds from imported fruits that they have been told "will not grow here" to see for themselves. They are less likely to take on board dubious common notions with currency among their peers: for example, noticing that sometimes they can see the moon in the daytime sky, so it is not only a nighttime object. They may even want to test out for themselves what seem perfectly sensible notions: *we all know* that plants grow too slowly for us to directly observe the growth (thus the attraction of those films made with time-lapse techniques which accelerate such processes). If they read, or hear reported, that the direction in which the circulation occurs when the bath drains is different in the Northern and Southern hemispheres, they may question this idea by imagining adjacent baths emptying with their plugs either side of the equator, and asking themselves "how could such a small different in position matter - is there a possible mechanism?" This thought experiment requires running a mental simulation, informed by their intuitions about how things work - a technique sometimes employed by professional scientists.

In general terms, 'the enquiring mind' may be understood as one that asks questions, but *in science* enquiry goes beyond asking to seek to find out by empirical investigation - such as perhaps seeking to make a sequence of observations over successive bathing episodes to test whether what they see is consistent with the (actually false) claim that the rotation is always in the same sense North (or South) of the equator. Indeed, the precocious young scientist may well accelerate the programme of research by spending a few hours repeatedly filling and emptying the bath to collect data.

The laboratory of the imagination

Carrying out experiments to test ideas is only possible when someone can imagine possibilities to test. One would need to imagine the two baths at the equator before it would be possible to set up a real test. All scientific discoveries occur twice: first, they are discovered as a possibility in the mind of a scientist, and then in the conclusions drawn from the result of experiments set up to test that possibility (Taber, 2011). If being discovered only as a possibility seems a weak kind of 'discovery', then we might instead say that scientific discoveries are *invented* prior to discovery. Genes, germs, molecules, double bonds, neutrons, Neptune, and so forth were all first invented as ideas (discovered in the mind) before they were found in nature. Of course, science is an iterative process, so observations invite explanations…that invite testing, and so further observations…. Once the idea of germs has been invented, and experimental work has confirmed that the germs idea seems a good explanation for some diseases, then we might consider that perviously available data can now considered evidence of germs: but that is a reconstruction.

It is now thought that Galileo Galilei observed and recorded the position of Neptune - but it was more than two centuries later that Neptune (having been imagined as an additional planet, and predicted, and looked for) was discovered. Indeed, many scientific discoveries are smeared out over time. Humphry Davy discovered potassium, but it only became potassium after he had conceptualised and tested out his initial discovery of what appeared a previously unknown metallic substance. Moreover, it only became potassium *as characterised today* after many decades of further measurements, some of which relied on ideas and instruments (e.g., X-rays, radioactive decay) that had not been 'invented' in Davy's lifetime (Taber, In Press).

Some of the great discoveries of science have arguably only completed the first stage - discoveries in imagination still being tested empirically. Evidence for the Higg's boson (sometimes called the 'God particle') has now been obtained, but it is very indirect evidence of data from one set of instruments (albeit at CERN, the extensive European centre for nuclear research) interpreted in term of complex models and assumptions,. Gravitational waves seem to have now been detected, but about a century after Einstein imagined the possibility. Darwin discovered (the idea) of the common ancestor of all life on earth; but like the Big Bang, and superstrings (and the extra dimensions of reality assumed to be associated with them), and the dark energy and WIMPS (weakly interacting massive particles) said to make up much of the mass of the universe, and many other conjectured scientific objects and events the accretion of convincing evidence for the referent is an ongoing process.

The history of science is indeed littered with imagined discoveries of conjectured entities that are now no longer widely considered to really exist: phlogiston, N-rays, caloric, polywater, cold fusion. In many spheres of human activity such episodes might be considered errors and failures, but in science the testing of such ideas, and finding them an inadequate match to our observations of the world, is considered an essential component in making progress (Popper, 1989). Even if it seems idealistic to expect scientists to always be pleased when their pet ideas seem to have been discredited, the scientific attitude is to value the resulting advance in knowledge above any personal disappointment.

It is well recognised that science relies upon deductive logical, and scientists must be rational thinkers: but it is just as true that science relies on imagination, and productive scientists must be creative thinkers. The gifted young scientist needs to adopt high levels of abstraction and systems-thinking. Imagination is one of the most important faculties for the young scientist, and the child gifted in science is likely to have a very active imagination. We should encourage gifted young scientists to generate alternative conceptualisations for testing, rather than prematurely closing down judgement and committing to an enticing idea that may later have to be modified or discarded.

Watching paint dry - or plants grow

There is an idiom that "it was like watching paint dry". The implication intended is that some activities are as boring as watching paint dry: something that is a slow process with nothing to see. The gifted young scientist might well take that as a challenge. Paint drying involves a transition between two very different states, but a gradual transition - and presents a challenge for understanding, and indeed setting up conditions for productive observation. This is certainly a suitable focus for scientific enquiry.

Everyone knows that plants grow, but, as suggested above, also that this is a slow process that cannot be directly observed. Everyone knows this - apart, that is, from a gifted youngster who has invested substantial periods of time observing how the tendrils of a climbing plant, such as a passionfruit vine, behave when the breeze brings them into contact with something offering potential support. Observation is said to be theory-laden (Basu, 2003), which does not necessarily mean that we only ever see what we expect to see, but certainly does mean we often miss what we cannot imagine to be the case. The careful observer will report having directly observed the tendrils both visibly lengthen and coil during one episode of direct observation: something that is invisible to the casual observer without the curiosity to wonder how the plant manages to climb, the imagination to consider possibilities, and the patience to seek out the conditions expected to be productive for observation (where a tendril is periodically making contact with or rubbing against a suitable supporting structure) and spend time waiting to see what will happen. This is patience that is supported not only by the epistemic hunger to acquire an understanding, but also the desire to see for oneself.

Implications for teachers

Teachers are professionals who should be entrusted to make decisions about the education of young minds in their care. Yet, the scope teachers actually have to design and implement curriculum varies considerably, and with an increasing 'accountability' culture in many educational contexts, and the importance placed on formal 'high stakes' tests that often have highly specified learning objectives, many teachers may be offered limited scope to shift from prescribed schemes-of-work.

One approach to working with gifted learners is to advance them by moving them ahead of their age group. This is sometimes successful, but is not always appropriate. For one thing, this requires a consistent approach - there is little point accelerating gifted students in this way only for them to later reach a point where acceleration to the next stage is not possible and they need to repeat a year. This is also a solution that assumes giftedness is a global evaluation: timetables seldom allow easy acceleration some but not other subjects, and progress in intellectual development may not be matched by emotional maturity or physical development. Such approaches may be questioned on social grounds as developing peer relationships (which may be disrupted by advancement, and may be harder to initiate with older peers) are as important to personal growth as classroom learning.

An alternative approach to meeting the needs of gifted students not challenged by the curriculum is to offer suitable extra-curricular activities. These can include 'Olympiad' type competitions (Oliver, 2017; Petersen, Blankenburg, & Höffler, 2018) or special programmes put on by University outreach initiatives (Horner et al., 2018) or enrichment programmes especially designed for gifted science learners (Taber, 2007a). These types of provisions can be very valuable, as gifted learners often find them enjoyable, and appreciate they are doing something special - and indeed they may report that they appreciate being challenged to think at a deeper level (Taber & Riga, 2006). However, unless care is taken (Kulbago, Mulvey, & Alamri, 2016), Olympiad type events, based on *competition* between teams or individuals, could give a particular impression of science that may be considered unbalanced - for example from feminist critiques (Bentley & Watts, 1987). Activities that require students to visit universities or special study centres may have particular impact, but may raise questions about access unless efforts are made to encourage gifted learners from all backgrounds, and provide funding (for travel and so forth) for those who do not come from families readily able to make such investments in extra-curricular activities. Indeed, gifted learners in some groups, such as indigenous learners in some national contexts, may need particular targeting or support to allow them to access gifted programmes (Franco, Verjovsky, Cisneros, & Torre, 2017; Rosin, Cutler, & Carson, 2017).

The terms 'extra-curricular' and 'enrichment' reflect the main reason why this approach to meeting the needs of gifted learners should not be a primary strategy. If gifted learners are only challenged in science by attending extra activities, then this equates to spending their time in science lessons as 'treading water', constantly waiting for the rest of the class to catch-up. It is clearly not right that we make students attend standard classes which are not matched to their needs, and then suggests that if they actually want educative experiences they need to *also* commit additional time to something extra. *Extra*-curricular provision should offer enrichment beyond, and in addition to, a suitably challenging core curriculum, and suitable opportunities should be available to all those keen on science, not just the gifted.

The teacher with some gifted young scientists among a more diverse class therefore needs to consider other options, and this will mean some level of individualisation in learning. One approach might be a form of compacting (Renzulli, Smith, & Reis, 1982), where in each topic those considered gifted in that context (perhaps identified by topic-specific pre-tests) spend part of their time working with the rest of the class, but some time on different work. Perhaps the teacher provides expositions of new ideas and content for all, and whilst most of the class undertake learning activities to review and reinforce what has been presented, the more gifted learners are set more challenging activities such as exploring nuances of theory and more complex applications.

The principle here, as outlined earlier, is that all students should be sufficiently challenged and suitably supported. Many students find new abstract ideas met in science as alien and counter-intuitive, and need to be given opportunities to work with those ideas in relatively straightforward ways as they become familiar and slowly mastered. Gifted learners tend to make the abstractions more easily, and sometimes actually find they match their own intuitive notions or possibilities they have already imagined, so they do not need as much time in the familiarisation stage, and they are ready to test, develop, and apply, the ideas in contexts not suitable for most of their peers.

It seems that perhaps whilst most of the class are working on basic activities to consolidate teaching, gifted learners could be undertaking project work, enquiry activities, problem-solving, discussion work, developing an artefact (such as a model), and so forth. Yet, there is a danger here. Educational research shows the value of dialogue, argument, enquiry, etc. in learning, and such activities can be very engaging. It would clearly not be appropriate if a group of gifted learners were undertaking such activities whilst most of the class were doing book-based exercises that might appear inherently (and, to students, obviously) less exciting. Providing educative provision for gifted learners should not appear to be rewarding the clever children with more interesting work. So similar pedagogy should be used for all the students, but honed to meet the needs of different groups. One principle that has been suggested, based on the educational ideas of Vygotsky (1978), is that teachers might plan learning activities with the most gifted learners in mind initially, and then consider the types of supports and additional resources and bridging activities that would make the work accessible and manageable for other learners in the class (Taber & Riga, 2016).

Another potentially valuable strategy is to enrol gifted learners in supporting the learning of others in the class, by giving them roles in micro-teaching episodes, peer tuition and the development of new learning resources. This must not be (or be seen to be) on the basis of "you have finished the work, so you can help someone else". Rather, whilst supporting other learners is a valuable side-effect, the logic here is to provide gifted learners with a meaningful activity that has a clearly useful purpose, but which enables them to explore and apply their new learning in more challenging ways (Taber, 2015). It is widely recognised that using knowledge to teach others requires in-depth examination of that knowledge, and how it is connected, and how it might be understood: and so is potentially educative for the teacher. Gifted students must appreciate they are undertaking work that is valuable for them as well as others, and the teacher needs to be sensitive to learners' preferences - some gifted children will revel in explaining things to others; some may not be comfortable in face-to-face teaching roles, but may be happy building a teaching model or designing a poster. An alternative, more subtle, approach that can sometimes be employed is to design group-work (e.g., different groups in the class design posters summarising different themes in a topic) where the gifted learners can provide intellectual leadership without being highlighted as having a particular role in the activity.

Implications for parents

Parents may have limited input into the formal teaching their child experiences, but are much less constrained than teachers in developing the 'curriculum' of out-of-school activities. In some national contexts it is usual for concerned parents (or at least those with the resources) to seek to supplement formal schooling with evening or Saturday schools and private tutors to reinforce and drill school learning. This is probably not healthy for children in general, and certainly is likely to be resented by gifted students who may already find school lessons too pedestrian. In some other cultures there is (again, usually in those groups with the resources to afford to do so) a very well-meaning attempt to provide a rich learning environment for children by signing them up for a wide range of intellectual, artistic and sporting activities to fill-up their free time. This may not be an ideal approach to helping children develop either.

That is certainly not to criticise parents who wish to offer their children the opportunity to try out Kayaking, pony riding, judo, dance, additional languages, piano, and the rest. The gifted young scientist may well benefit greatly from visiting museums, science centres, zoos, botanic gardens, observatories and attending science and technology clubs, and so forth. However, there are two important provisos. Gifted learners often tend to develop particular interests, and may focus on them in depth (where many of their peers may soon become bored, and flit from one activity or hobby to another). It is useful if parents can *introduce* young children to a wide range of clubs and activities and give them a taste of what is on offer. However, children will only benefit from activities they are motivated to commit to, and it is counter-productive to push them to continue with activities they are not enjoying. Gifted students may be better supported by enabling them to spend extensive time in a small number of actives where they genuinely become immersed, than pushing them to spend time in activities where they are not keen to engage. Boredom is perhaps a particular turn-off for gifted people, and - especially as children approach adolescence - nothing is as boring as being somewhere you would rather not be, doing something that does not interest you, because someone else thinks it is good for you.

The second point is also related to the distain for being bored, in that gifted learners are unlikely to be bored when left to their own devices. Imagination is core to scientific work, and the gifted child is usually very good at developing imaginative play. Scientific successes often depend on periods of intense practical activity, interleaved with periods of mulling things over - whilst walking, or swimming, or taking a bath - and distraction and focus elsewhere. It is important that children, and, arguably, especially gifted children, have some regular free time that is not organised for them by adults or older siblings. This allows them to identify and develop interests, and to follow them up in depth. It gives time for wondering (and wandering) - and so for the kinds of aesthetic experiences described above: really spending time looking at the shape and structure of a tree, watching how the cloud formations slowly shift, staring at the evening sky to see how more and more stars slowly become visible as it gets darker. The noticing, can lead to simple enquiry activities such as following the ants back to find the nest, tracing the course of a stream…

Parents can support their gifted child by being tolerant and supportive of their interests. Although sometimes this may mean encouraging a child to develop alternative activities which use resources more carefully: it is not environmentally-friendly to keep filling a bath with clean water, just to empty it again - so how can we model this system less wastefully? Ideally, a parent may not want hundreds of decaying leaves brought into the house or a telescope left set up by the lounge window, but it may be possible to negotiate compromises between the child's tendency to see the home environmental as part of the 'laboratory of the world' and a desire for more domestic normality. Perhaps a box room or shed can be used for on-going investigations that would be compromised by tidying away. Perhaps there is a small area of garden that can be given over to activities that may be more productive in germinating ideas than edible or pretty plants. Perhaps the most important thing a parent can do is maintain the balance of showing a genuine interest in the gifted child's activities and ideas, without seeking to take over leadership of them. The parent may sometimes have a better idea of what is likely to produce results than the child, and should certainly offer guidance if consulted, but the gifted youngster will likely both appreciate, and benefit more from, being left to dwell on challenges, and recognise and appreciate their own failures (which often motivate thinking again, and trying something else), than being offered the shortcuts of received wisdom.

In conclusion

In science itself, eventual success derives from habits of being amazed; wondering; questioning; periods of deep reflection; imagining and even day-dreaming; repeated testing; close and prolonged observation; coming, sometimes slowly, to recognise that an idea is wrong; accepting the implications of empirical evidence over pet hunches and assumptions; and seeing failure as the successful elimination of one alternative, and so as an impetus for going again. The gifted young scientist will benefit from educative activities, whether at school or at home, that encourage the development of such habits.

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