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ASKING GIFTED SICENCE LEARNERS TO BE CREATIVE

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'Chemical reactions are like hell because...': Asking gifted science learners to be creative in a curriculum context that encourages convergent thinking¹

INTRODUCTION

The focus of this chapter is an activity, a science analogy game, introduced as part of a science enrichment programme for 14-15 year old gifted students attending English state schools. The 'game' was designed to be fun, but had a serous rationale. The activity was intended to encourage students to think divergently around school science concepts, and thus to be creative in a science learning context. Creativity is an essential part of the scientific process, and is an important area for development for all learners; but is arguably of particular relevance in identifying and developing those learners who may be labeled as gifted (Kim, 2008; Sternberg, 2010). Yet, arguably, since a mandatory National Curriculum was introduced in England over twenty years ago, English school science provides very limited opportunities for students to demonstrate their creativity, or indeed to even appreciate that science is a creative endeavour (Osborne & Collins, 2001).

The chapter will offer the reader some background regarding the English curriculum context, and the national 'gifted and talented' policy issued to guide schools in working with their most able learners. This provided the context in which the ASCEND ('Able Scientists Collectively Experiencing New Demands') project was conceived as an after-school enrichment programme intended to challenge secondary age students. ASCEND was designed around a number of principles relating to a focus on the nature of science, learning through collaborative group work, and encouraging a metacognitive approach to science learning. The rationale and structure of the ASCEND programme will be outlined, before the analogy game, and student responses to the activity, are considered in more detail.

Terms such as 'gifted', 'high achiever', 'high ability' do not have an agreed meaning internationally, and are not always used consistently even with the English context that is the setting for this chapter (Taber, 2007c). In the present chapter, I will tend to refer to gifted science learners, meaning those perceived by their schools as being of notable (but not necessarily exceptional) high ability in science, as this is how the term is generally used in the English system.

The intention behind the analogy game will be explored, and its basic structure explained. The use of the analogy game within the ASCEND programme will be illustrated through samples of student dialogue. Publication of the ASCEND teaching materials (Taber, 2007b) means that the analogy game is available for adoption, or adaption, by teachers. However, even more importantly, it offers an example of how creativity can be encouraged in the teaching of science at secondary (middle/high) school level.

CREATIVITY IN SCIENCE AND SCIENCE LEARNING

Creating new scientific knowledge

Science is a creative process. Scientific discovery relies upon the construction of new ideas, new mental models, new hypotheses, new explanations, new techniques, new instrumentation, new analytical tools, new theories, and so forth. This is widely recognised in the cases of major scientific breakthroughs, and great scientists are seen as creative geniuses alongside composers, novelists, creative artists and so forth (Csikszentmihalyi, 1997; Simonton, 2004). However, it is not just the Newtons, Darwins and Einsteins that are creative. The basic process of science relies upon the power of the human imagination to consider new possibilities that can be conceived, and - if judged promising - tested. The scientific research paper is often

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a rational reconstruction of the discovery process that focuses on the context of justification – the argument and evidence that supports a new knowledge claim (Medawar, 1963/1990). This might easily lead to the impression that it is the demonstration of a 'proof' of discovery that matters, not how the discovery came about. It is the logical rigour of the argument from observations and measurements to a theoretical claim that is privileged in the traditional scientific report.

This is fine as it goes, if we recognise that given the purpose of research reports, to make new knowledge claims, they necessarily focus on the justification of those claims. So a seed for Einstein's theory of special relativity may well have germinated from the paradox encountered when imagining how light should be understood to a traveler who moved at the same velocity as light (Gutting, 1972), but it is the calculations and their eventual relevance to real measurements that persuaded others that Einstein's revolutionary ideas should be taken seriously. It is irrelevant whether August Kekulé, as he claimed (Rothenberg, 1995), really dreamt up the ring structure of benzene, as long as the evidence supported his proposed structured. It matters not if Barbara McClintock could only explain how she came up with the idea of jumping genes in the vague terms of how her brain was able to 'integrate' her observations (Keller, 1983): what matters is whether she offered persuasive evidence that genes do sometimes self-transpose within a genome. Whilst the scientific community was (for some time) unconvinced by her arguments, she could be considered something of an eccentric crank; but once her arguments from research evidence were considered convincing, she was promoted to the status of visionary and Nobel laureate.

Perhaps part of this attitude links to the notion of science as an objective activity: where in principle scientific observers are interchangeable without changing the outcomes of scientific investigations. What one scientist claims is worth little until other researchers can reproduce the original results. The claimed discovery of cold fusion, with its immense potential to overcome a world 'energy crisis' generally ceased to be considered a major scientific breakthrough as it become clear that it could not be replicated reliably in other laboratories.

Unfortunately, just as history is said to be written by the winners, science texts books generally tend to report only what is now generally accepted. Not only do school and college texts usually focus on the 'winners', but they often offer reconstructions of scientists' work that are tided up on the basis of hindsight (Niaz & Rodriguez, 2000). So what is presented is often what we now consider to be the case, based on the decades of careful work that followed (what in retrospect is considered to be) a major breakthrough. So all the uncertainty, controversy and the flaws of early results are ignored in the process of offering students a concise and simple account of what we *now* think, and why we *now* think it. This may be a sensible approach to pedagogy if what we wish to teach is the products of science (the laws, the theories, the models of consensus science): but it leaves a lot to be desired if we hope to teach students something of scientific processes (Lawson, 2010) – let alone suggests something of the thrill and drama of research.

'Admitting' the subjective into science

A problem with the creative step is its lack of objectivity. We cannot directly share our imaginings (which draw upon pre-conscious thinking that we cannot even access ourselves by introspection), and we cannot readily replicate the creative process. Major breakthroughs have relied on creative insight that derives from a nexus of the problem-context, the institutional and professional environment, and the cognitive resources of a unique individual thinker (Gardner, 1998; Sternberg, 1993). As Pasteur noted, chance favours the prepared mind, and the experience and learning of each scientist is unique, preparing them to notice specific things and understand them in particular ways. If Benjamin Franklin and Rosalind Franklin had been swapped at birth (using a suitable time machine of course), then it seems very likely that discoveries about both the nature of lightning and the structure of DNA would have been delayed. Interestingly, where most people find special relativity counter-intuitive when hey first meet it, Einstein's own path to the discovery was to follow-through on the consequences of his own intuition of the invariance of the speed of light. It has been argued that the personal, implicit knowledge of the individual scientists plays a key role in scientific work as the source of such intuitions, and that this necessarily amounts to an unaccountable subjective element in scientific discovery (Polanyi, 1962/1969).

Yet even though we do not fully understand the creative process, and even though it is subjective and unpredictable, every scientific discovery every made (whether of the revolutionary or more typical routine variety) has involved someone imagining a new possibility. The creative process is essential to science, and indeed creativity is the necessary complement to logic, for science to make progress. Kuhn referred to the way progress in science depends upon both tradition and innovation existing in an 'essential tension' (Kuhn, 1959/1977). It may be logical and rational thinking which is so often recognised as essential to science, but without creativity and imagination, logic would have no scientific work to do (Taber, 2011b).

It has long been suggested that school science attracts convergent, rather than divergent, thinkers (Hudson, 1967), but that does not reflect the nature of science itself. We do not need to admit creativity, with its subjective nature, into science, in the sense of letting it in; as it is already 'in' science: being an inherent and essential foundation for any kind of productive science to exist. However, when we teach science, we do need to admit creativity in the sense of acknowledging to our students that creativity plays a major role. We need to confess that science has a strong subjective component at the individual level, which provides the raw material that objectivity and logical argument need to work on. If nothing else, this should help our students realise that science is an ongoing and unfinished human adventure with plenty of scope for them to make unique individual contributions.

Creating new scientific learning

Now in a sense, what is true of science is true of science learning. The science student, at least at school level, is not expected to help develop new scientific knowledge claims, and rather is generally charged with recapitulating the scientific discoveries that others have already made: developing new personal understanding. However, learning is still about developing new knowledge (albeit personal knowledge), and this requires the ability to imagine possibilities not considered before. The constructivist perspective on learning suggests that each individual learner is set the task of reconstructing, from their own existing mental resources, the ideas valued in the wider community (Taber, 2011a). Yet, of course, if each learner has unique cognitive resources, and constructs their personal knowledge within a unique conceptual ecology, each reconstruction is actually not a replica of the science represented in the curriculum, but more a pastiche or homage.

Indeed, one of the criticisms addressed to learning theorists is to explain the so-called learning paradox (Scardamalia & Bereiter, 2006), that is, how any individual can construct new learning, given that they would not have had the understanding in place to know what they were constructing until they actually formed the new learning. I have never been convinced there is a problem here as the natural world is full of systems that build up iteratively, without following any 'deliberate' (i.e., consciously developed) plan: but even if learning something new is not a paradox, it is certainly a personal achievement.

Learners' potential for creativity in science is hardly in doubt, given the immense challenge faced by science teachers of children who commonly come to class already holding intuitive ideas at odds with science, and then proceed to interpret teaching in all sorts of imaginative, if non-canonical, ways (Duit, 2009). Unfortunately this creativity, often recognised in terms of misconceptions, alternative conceptions, learning difficulties etc, is commonly only seen as a barrier to learning the 'right' ideas (Larkin, 2012). Sometimes this may be a reasonable stance to take, but it has long been argued that learners' non-canonical thinking can often be more helpfully seen as the available resources for new learning (Smith, diSessa, & Roschelle, 1993). If the vast research effort exploring students' ideas in science has shown anything, it is that it is a mistake to assume that learners' alternative ideas about science topics all have the same nature, and play the same potential role in learning (Taber, 2009). Rather, students' ideas in science vary along a wide range of dimensions, including their openness to modification, and their potential as starting point for learning the scientifically accepted ideas.

Any one who spends time talking to children and young people about the scientific understanding will come across all sorts of creative suggestions. So, Bert, a Y10 (14-15 year old student) suggested to me that bonding was something that arose during the evolution of atoms. Amy, at the same age, suggested that differences in electrical conductivity depended on the density of particles in a material because the densest materials did not leave space for electron flow. A younger student, Jim in Y7, hypothesised that the air hole in the base of a Bunsen burner was there to let dirt out. (These and many other examples of student thinking about science topics can be found at https://camtools.cam.ac.uk/wiki/eclipse/ECLIPSE.html).

In each case, it would be easy to simply dismiss the idea as 'wrong' – but such ideas potentially offer the raw material for scientific testing (although Bert's idea might be rather difficult to test in practice). The philosopher of science, Karl Popper, suggested science proceeded through bold conjectures (Popper, 1989): 'bold' because there is little risk in hypothesising something that already seems very likely in terms of existing scientific theories: and so there little is likely to be learned by testing timid hypotheses. When *our students* make bold conjectures, it is too easy to simply see this as getting the science wrong, but we should perhaps do more to acknowledge and encourage their thinking when they actively engage with possible

reasons and mechanisms to explain their observations (Taber, 2007a). Creative scientists often have lots of bold ideas, only a few of which bear fruit. We therefore need to encourage science learners to see having ideas as intrinsically a good thing in science, even when those ideas are later found not to be right. Indeed, à la Popper, science is meant to proceed through bold conjectures, *and their refutations* - and the scientist is supposed to celebrate the process that being proved wrong represents. Whilst that prescription seems a little idealistic, it is certainly the case that successful scientists have to produce creative suggestions, and then accept that most will be pruned away in identifying the few that actually take forward our understanding of the world.

If we teach science in a way which implies students' creative ideas are unwelcome distractions or, worse, simply wrong, and so suggest to students that the job of learning science is to just receive the already demonstrated correct ideas, then we do little to either encourage the creative thinkers to become scientists, or to encourage future scientists to think creatively. The present chapter reports on a study from England, where the curriculum has been considered as too crowded with prescribed topics that teachers are required to 'cover' to offer scope for creative activities. Moreover, gifted education in English schools is generally conceptualised in simplistic terms (Taber, 2007c), and, for historical reasons, expertise in gifted science education is rather thinly spread in the state schools.

REPRODUCTION RATHER THAN CREATION: LEARNING SCIENCE IN ENGLISH SECONDARY SCHOOLS

England has a national Education system, with a good deal of local variation. The wider UK context is more complex, with Northern Ireland and especially Wales having much in common with England, but Scotland having quite a different school system. The project discussed here, ASCEND, took place in England, and discussion here is limited to that country. The vast majority of school-age students in England attend state maintained schools, that is schools funded from the public purse. All children of school-age are entitled to a place at a state school. Something like 7% of children are educated outside of the state system in independent, 'fee-paying', schools that are subject to some of the same regulations as state schools, but are exempt from others. So, for example, whilst anyone working as a teacher in any school in England has to be vetted to check whether they have a criminal record involving an offence which would deem them unsuitable to work with young people, independent schools are otherwise free to employ who they see fit as teachers, whereas state schools are required to employ qualified teachers who have completed a nationally recognised course of training. At the time of the ASCEND project, state schools were largely free to set their own curriculum (Since the project as carried out, the requirement to follow the National Curriculum has been relaxed for some, but not all, state schools).

Whilst the independent sector educates a minority of students nationally, it is worth reflecting that traditionally a disproportionate number of those who achieve high office in the UK are educated in the independent sector. For example, a very high proportion of cabinet ministers and senior civil servants, and high achievers in other public spheres, are privately educated. A simple interpretation might be that independent schools offer a 'better' education, but that of course is over-simplistic. Certainly some well-established private schools have excellent records of getting students into Oxbridge (i.e. Oxford and Cambridge) and other prestigious Universities, which is often a major step to later career success. But, of course, these top independent schools are highly selective. Students generally obtain places at independent schools because either their parents are paying a hefty fee, or because they have won competitive scholarships demonstrating they are very high achievers who will likely attain at high levels in public examinations. Arguably, disposable income to send your children to private school, and aspiring to have your children educated away from the proletariat, are both factors linked to the remnants of a class system that dominated social structures in Britain for many centuries.

Gifted education moving out of, and back into, educational fashion

This 'political' aside is necessary to understand the nature of the state school system in England, for it has two consequences. One of these related to 'creaming': that in many state schools a disproportionate number of the most able students who might have attended that school have moved out of the state system, leaving a somewhat skewed distribution of ability among the school's student population. In most cases this is not extreme, yet if the most able students (who by definition only make up a small proportion of the cohort)

benefit from time working with their similarly able peers, then even the loss of small numbers of such youngsters can significantly reduce the cadre of 'gifted' students in any year group in a state school.

The second issue concerns the acceptability of focusing attention and other resource on 'gifted' learners in state schools. In the 1960s, gifted education was a focus of some research attention (Fisher, 1969), and in the last decade or so, gifted education has become a policy issue that all state schools are required to respond to (DfES, 2002; The National Strategies, 2008). However, between these periods there was tendency for this issue to become unfashionable, and even to be seen as 'politically incorrect'.

The secondary school system established in England at the end of the 1939-1945 'World War' had set up discrete types of schools for students with different aptitudes, determined by an academic test taken by all students at eleven years of age. Passing that test meant admission to what was termed a grammar school, preparation for public examinations, and a good chance of progression to university education - and so to the professions and other well-paid 'white-collar' positions. For many years, failing a test taken on one day at primary school meant attending a secondary school where public examinations were not taken and there was no provision for study to university entrance level. Over time it became very clear not only that failing the 'eleven-plus' made it extremely unlikely a student could ever progress to higher education or the professions unless the family could afford private education; but also that testing pupils at age eleven meant sorting them by family background and associated social capital as much as in terms of true academic potential.

This led to a major shift, largely in the 1970s, in most parts of England, to 'comprehensive' secondary schools that accepted all local students regardless of primary school achievement (Crook, 2002). Moreover, given the dangers of early (or perhaps any) labeling of students by ability, there was a strong movement toward teaching largely in 'mixed-ability' classes, rather than streaming students within schools according to perceived ability. Awareness of the potential implications of premature labeling of students by ability, and the dangers of Hawthorne-type (Rosenthal & Jacobson, 1970) effects (with ability labels becoming self-fulfilling prophecies), made many working in the comprehensive school system wary of any kind of sorting of students by ability (White, 1987).

More recently the comprehensive system has suffered a great deal of tinkering by successive governments attempting to offer parental choice between schools, and significantly, setting in most school subjects has now become the norm, at least in the senior secondary years. Indeed the lead party in the current government have suggested that they wish to offer 'guidance' to the school inspectorate "to ensure that schools – particularly those not performing at high levels – set all academic subjects by ability" (Conservatives, not dated, p. 33). Just as any kind of ability labelling become suspect for some decades, the once ideologically correct notion of mixed-ability teaching has now come to be seen as something radical and almost subversive: too liberal; too progressive; too egalitarian; too relaxed. Such are the whims within an education system directed centrally by whichever ideologically motivated political party is in government.

There are clearly some important and complex issues here which cannot be treated in depth in the present chapter, but it was against the background of 'comprehensivisation' and the widespread adoption of (what was then considered) ideologically sound mixed-ability teaching that an interest in the learning of gifted students in state schools seems to have been widely seen as unsound (Boaler, Wiliam, & Brown, 2000). After all, it was sometimes suggested, all students have their gifts. And surely the most able learners already have advantages, so limited resources should be focused on those who will not succeed without extra support. No doubt, for some, there was also a sense that the 'gifts' of gifted students were often largely down to luck in their upbringing, and therefore there was a social imperative to attempt to make up for such inequity by offering some form of compensation for the less lucky.

This is not the place to consider the merits of these arguments in any depth, but there was clearly a rather major flaw in the social equity issue when the most able students in state schools were not getting special attention, but would have to later compete for university places and employment with students attending prestigious fee paying schools (with their smaller classes and myriad extra curricula opportunities), which were largely able to ensure their student body consisted only of those youngsters judged to be academically strong. An alternative egalitarian argument might be that education should offer all learners the best possibility of meeting their true potential, and gifted learners are unlikely to be supported by being assumed to have the same needs as all their classmates (Reis & Renzulli, 2010). There is of course also an economic argument for public investment in meeting the needs of gifted learners, if it considered that those gifted learners will potentially offer the greatest return on public spending on their education, because they may pay back to society in disproportionate ways through wealth creation and other significant contributions.

A national policy on 'gifted and talented'

By the time of the ASCEND project, there had been a significant shift in attitudes to the gifted. The government had introduced a 'gifted and talented' (G&T) policy, first in particular geographical areas (generally cities with relatively high levels of social deprivation), and then nationally. In the language of G&T, students could be gifted in one or more academic subjects, such as science, and/or talented in subjects such as the creative arts or sport. The G&T policy was both simplistic and simple. It was simple in that all state schools would be expected to show that they had a register of G&T students and could account for how they were providing suitable provision for their G&T cohort. The policy was simplistic in that it defined students as gifted if they were in the top 5-10% of students, according to whatever measures might be seen as appropriate. Given the near-dearth of decent research into gifted provision in England for many years, and the lack of capacity in gifted education within the state sector, a good deal of guidance was provided on how to identify gifted learners, but much of this was vague, general, aspirational, and untested (Taber, 2007c).

Moreover, having identified the gifted students, there was limited expertise among science teachers about what to do with them, apart from expect them to be performing especially well when studying the National Curriculum. Yet that National Curriculum was based on a 'one-size-fits-most' approach that assumed the same basic curriculum was appropriate for the majority of students, with just a small proportion of secondary students adding a bit more of the same (even more topics, rather than seeking more advanced understanding) and another small proportion taking a reduced spread of topics to either address limited attainment in the subject, or to make room for extra study elsewhere (DfEE/QCA, 1999).

The curriculum was a fairly comprehensive tour of most important areas of biology, chemistry, physics and some earth/space science. It offered a broad view of the scope of the sciences, but limited opportunities for studying any particular topics in depth - and virtually no opportunities for extended enquiry work within normal curriculum time, as commonly happens in some parts of the United States for example (Eilam, 2008). The National Curriculum was linked to an increasingly specified, high stakes, public examination system that encouraged teaching for the test, but had little scope for questions that might expect creativity from students - and so require markers to think beyond a highly structured mark scheme (Collins, Reiss, & Stobart, 2010). This pattern has also been noted in other National contexts, such as the US (Longo, 2010).

Whilst schemes had long existed to support teachers in helping students to undertake creative project work in science (Taber & Cole, 2010; West, 2007), the perceptions of the requirements of the curriculum, and its associated assessment regime, meant that these were often only adopted for occasional use, or as an extra-curricular option where teachers were especially keen to offer additional opportunities.

It was also increasingly recognised that although the national curriculum for science had been intended to help learners appreciate the nature of science, as well as learn about specific science topics, in practice students generally learnt very little about the processes of science beyond a formulaic and simplistic approach to fair testing (Taber, 2008). In a 'investigation' for their school science examination course work, a student learning science under the English National Curriculum might typically have decided to test whether the concentration or temperature of an acid influences the rate of its reaction with some magnesium ribbon – knowing full well that both factors should make a difference. Already knowing the answer hardly provides an authentic experience of enquiry, even if it helps students get good marks for their practical work. Attempts to modify curriculum and assessment to address this issue were recognised as making limited progress – partly because teachers generally felt they lacked subject knowledge in this area themselves, and because they felt unsupported by available school text books or suitable teaching resources. Inadvertently, a system seems to have developed which provides a science education where the conscientious and studious can do well, but where the creative gifted learner with a tendency to think divergently is likely to both struggle to perform to their potential, and indeed struggle to find the kind of challenge likely to engage their interest.

Meeting the needs of the most able in science

This set of circumstances left many science teachers in state schools concerned about what they should be doing to support their most able learners, beyond helping them obtain good grades in the formal examinations. This set of circumstances motivated a project (organised with Prof. John Gilbert, then at Reading University, and Prof. Mike Watts, then at Roehampton University, now at Brunel University) labelled as APECS (Able Pupils Experiencing Challenging Science), to explore these issues. With some

modest funding from the University of Cambridge Faculty of Education's Research Development Fund, a seminar series was established on *Meeting the Needs of the Most Able in Science*.

The seminars involved teachers as well as academics and students, and explored various aspects of teaching science to the most able pupils, with a particular focus on how such students could be challenged in the context of state schools charged with 'covering' the national curriculum requirements. This led to the publication of an edited volume, with contributions primarily based upon the ideas explored in the seminar series (Taber, 2007d). An opportunity to secure a small award to fund a project on 'teaching ideas and evidence in science' for the 11-14 year age group supported an initiative to help trainee teachers develop teaching about an aspect of the nature of science whilst on placements in schools, with a particular (but not exclusive) focus on the most able learners. This project was partially funded by a government agency, and partly by an educational charity, the Gatsby Science Enhancement Programme (SEP). SEP were open to considering other similar projects, and this coincided with the possibility of working with the state secondary schools in Cambridge (England), who had developed a confederation to share ideas and experience. This was the background for ASCEND.

ASCEND: A PARTNERSHIP PROJECT TO SUPPORT SCHOOLS IN PROVISION FOR THEIR GIFTED SCIENCE STUDENTS

ASCEND was conceived as a way to support the local schools in working together, by offering a programme of after-school extra-curricular science sessions in a University context for 14-15 year old students. The invitation to schools to join the project clearly indicated that this was seen as enrichment for gifted science learners, but it was left to each school to nominate the students considered most likely to benefit form attending. This was in keeping with national policy that required the schools to identify their own 'gifted' cohorts. The funding from SEP allowed us to put on the programme (employing graduate students to support the sessions), and to develop materials which could then be made available to the partner schools, as well as to any other schools it was possible to allow the students to work in the context of a relatively large group of like-minded individuals. The ASCEND cohort was about the size of a typical secondary school science class, whereas within each school the number of students considered 'gifted' in science in any year group was necessarily limited. The programme was designed to incorporate a number of features:

- Group work
- Metacognition
- The nature of science
- Conference format

Group work

Nearly all of the activities were designed to be carried-out in groups of about 4 students. We also encouraged the students to work in groups composed of students form more than one school, so they would meet and work with new potential friends. This approach was considered to give students opportunities both to explain their own ideas to an audience likely to be thinking at a similar level, and to have their ideas questioned and challenged in ways that were less likely to occur when students were normally working with less able peers.

Metacognition

We should expect gifted students to demonstrate high levels of metacognitive ability, although in this, as in other aspects of cognitive development, learners are only likely to reach their potential when given suitable opportunities to practice their skills. Given the nature of much school science in England (see above), and the normal pattern of lessons being broken into short, structured activities (something that tended to be seen as required by an inspection regime much concerned with lesson 'pace') it was anticipated that students would not be regularly asked to be independent (or even collaborative) learners in their normal science classes. This was confirmed in the feedback we received from the students attending the sessions (Taber & Riga, 2006).

Most ASCEND activities were designed to require groups to plan their actions, and to then regulate their work over a period of about an hour. Plenty of support was available if needed, but the 'staff' (graduate students who were either preparing for teaching or undertaking research degrees) were briefed to act primarily as observers, and to only intervene when asked, or if it was clear a group were making no progress. Again, the feedback we received from the students made it clear they were not used to being given this level of responsibility for learning in their science lessons and nor were they used to being allowed to develop and explore ideas for any extended period without regular scrutiny and guidance from teachers (Taber & Riga, 2006).

Most of the ASCEND activities were designed to have no single right answer, so students were expected to be able to evaluate their own progress and achievements. One of the activities asked the groups to work with a large amount of learning resource material to develop their own model/representation related to studying and learning. The time available did not allow a close study of all the source material, especially if all the students wished to read everything provided (rather than adopt a strategy to divide up the material).

Another activity asked students to determine which activates and occupations counted as scientific: the focus was on the use of criteria and argumentation, not on the actual decisions reached. Another activity offered three simplified models of the processes by which science makes progresses, and asked students to identify aspects of these 'philosophies' of science in brief vignettes of the work of well know scientists. Most of the examples did not clearly fit just one of the models. Another activity asked groups to act as an interdisciplinary team of scientists building up a synthetic model of plant nutrition drawing upon information for biology, chemistry and physics, and allows the groups freedom in how they chose to represent their model. The idea that gifted learners appreciated having some level of choice in learning activities had been something highlighted in the earlier APECS project (Taber, 2007a). These, and the other activities, are detailed in the book and teaching materials published by SEP (Taber, 2007b). It was hoped that this type of approach would offer students to demonstrate their creativity within the context of science learning.

The nature of science

The theme of the nature of science (NOS) was selected as a suitable theme for most of the activities (Taber & Riga, 2006). This was selected partly because it was known that this was generally a weak area in student learning in England (as suggested above), but also because it was felt to offer contexts for challenging tasks, suitable for gifted learners. So contexts such as the demarcation of science, the nature of scientific method, the nature of scientific laws, the criteria for a good scientific explanation, the nature of scientific models and so forth, all linked with the school science curriculum, whilst offering the opportunity to tackle tasks that would be considered too complex, too advanced, too abstract for use in classrooms with many students of 14-15.

It also allowed the selection of material that would not be met within the normal curriculum, whilst still being relevant to the objectives of secondary school science: so the possibility of introducing historical examples that would not normally be met, or taking challenging topics that did feature in the curriculum (chemical bonding, natural selection, photosynthesis), but asking students to discuss in depth abstract or complex features that would be only touched upon in school. That is, the sessions offered enrichment not in terms of these topics, but in terms of the abstract, theoretical treatment of the topics, and so the level of intellectual demand.

Conference format

A final feature of the programme was that I was keen for the students to be treated as adults. These 14-15 year olds were used to being considered as minors in school, but they were referred to as 'delegates' at ASCEND. Anyone who has taught students of this age knows most have considerable potential to behave as children or as adults depending upon the circumstances they find themselves in. The delegates arrived (often by bus, foot or on their bikes) to be met by a conference style registration, and to be given their delegate badge and conference pack (with materials they would need for that day's activities). They would then be able to claim refreshments from the Faculty cafeteria on showing their delegate badge. As most students were coming straight from school (and would arrive at different times depending on the school) this was a pragmatic approach, as well as a deliberate attempt to get the delegate to feel they were in an adult study environment.

THE ANALOGY GAME

The analogy game (Taber, 2007b) was designed to be played during the registration/refreshments period at the last session in the programme, before moving to the Science Education Centre for the main activity. It was meant to link to the NOS theme by indicating, in a fun way, that creativity was something to be valued in science, and to give delegates the opportunity to offer lateral, including humorous and perhaps even irreverent, thoughts relating to science concepts, in a context where this was seen as something positive. It also built upon the idea of analogy being important in science, that had been incorporated in an earlier ASCEND session.

Analogy, discovery and learning

Analogy is at the heart of major processes by which scientists develop new ideas, and by which learners acquire new understandings. In science, the importance of analogy in making discoveries has been recognised (Nersessian, 2008). If we notice that a system in which we are interested is somewhat like another system we already know about, then we can produce a mental mapping relating the two: drawing upon the known structure of the familiar to conjecture possible relationships about the system we are enquiring into.

In effect there is a multi-stage process here, the first part of which is to form a simile (to notice something is in a sense like something else). So, for example, Lise Meitner and her nephew Otto Robert Frisch, 're-cognised' the fission of a heavy nucleus as being like a water drop breaking into two smaller drops (Frisch, 1979). The nucleus was not a water drop, but that simile had potential for developing constructive hypotheses about nuclear fission. The simile of a nucleus being like a liquid particle in the way they could both divide into two smaller parts was a productive starting point for developing new ideas about the nucleus that could then be tested against empirical data (Meitner & Frisch, 1939).

In a similar way, teachers use such comparisons to help learners become familiar with the unfamiliar. A classic, if flawed, example is the teaching analogy of the atom being like a tiny solar system (Taber, 2001, In press). The logic is that the student may not know what an atom is like, but may be familiar with the general structure of the solar system. The analogy is in terms of structural similarities between the two systems: e.g. smaller bodies considered to orbit a large central mass (Nakiboglu & Taber, Accepted for publicaiton). The analogy goes beyond a simple similarity – but allows a mapping of structural features of the two systems (i.e. the relationships between parts of the systems). For example, if we know that a force is needed to keep the planets in orbit around a star, we might conjecture that similarly, a force might be needed to keep electrons in orbit about a nucleus, in the planetary model of the atom. Of course, we might then conjecture – as many students seem to - that gravity provides centripetal force in the atom, as it does in the solar system (Taber, In press). Analogy offers possibilities to consider: it does not assure us of drawing correct deductions. However, it can be fruitful in science: if we know that oscillations in a liquid drop can lead to the drop dividing, we may ask the question 'is it possible that some kind of similar oscillation process is going on in the nucleus that leads to it dividing?' (see Figure 1).



Figure 1: An example of the role of analogy as a creative process in science

In an earlier ASCEND session students had undertaken some simple laboratory work to explore the patterns of discharge of a capacitor, water level evening out between two connected burettes, and cooling of hot water. They were also given information about the pattern of radioactive decay, and about negative feedback in a system where the driver for change is itself reduced by the change it drives. (For example, the rate of cooling of hot water depends upon the temperature difference between the water and the surroundings. The greater the temperature difference, the faster the water cools – but as the water cools the temperature difference is reduced, which reduces the rate at which the water cools, etc.) That is, the ASCEND delegates were in effect introduced to a number of systems that exhibited exponential decay characteristics, and where the pattern of changes observed could be explained in analogous terms (Taber, 2011c). Having experienced how analogies between physical systems can be productive ways of thinking in science, the analogy game offered the students a chance to generate their own analogies.

Generating similes for scientific concepts

The analogy game is a card game in which each player is dealt cards, and seeks to win the game by laying down their cards first. There are two types of cards: science concept cards (with the name of a science concept that should be familiar from school science), and analog cards (which had the name of everyday objects, abstract ideas, or then current celebrities – as well as some 'wild' cards where students could offer their own analog term). Players took turns in playing, and on their turn were challenged to make an analogy between one of their concept cards and one of the analog cards. Players who could not make an analogy on their turn were able to swap some cards with the pack, but had to wait for the others to play before it was their turn again.

The materials used in the ASCEND session are included in the SEP publication (Taber, 2007b), but the activity could readily be modified (e.g. numbers of card originally dealt; precise terms used on the two decks of cards etc) to make it suitable for students following a different curriculum or of different ages. What was essential to the spirit of the game was that in laying down an analogy, the players had to have a reason as the other players could challenge a proposed analogy. Students were asked to explain "the [concept] is like the [analog] because...". So a student could not pair, say electricity with love without explaining their analogy: e.g. electricity is like love because both can give you a tingly feeling.

So the game incorporated a degree of peer review (something that might be considered an implicit NOS feature perhaps) in that it was for the player wishing to lay down cards to persuade their other players in their game to accept the analogy. Now, of course, this opens up possibilities for the game to be undermined in several ways. Friendship ties and perceived social status could influence how such justifications are achieved, and there is also scope for game strategies à la prisoner's dilemma. As the game was intended as a fun activity, with little at stake, these 'threats to validity' were not considered to be serious concerns. The two key features were that students were being asked to explicitly think analogically in a science education

context (providing a context for highlighting the importance of thinking creatively in the processes of science itself), and that they were being asked to justify their suggestions (potentially linking to the issue of what makes a good explanation, something that had been the focus of another earlier session in the ASCEND programme). In this simple fun activity, there was potential to reflect both the context of discovery (imagining a novel similarity) and the context of justification (explaining why a scientific idea is like an everyday idea or entity): in the same way that the creative and the logical are both essential in science itself.

Playing the analogy game

Digital voice recorders were used to record two of the groups playing the game (with the knowledge and permission of the players – we did not set up recorders where delegates had reservations). Modern digital voice recorders are very effective at recording sound, but when collecting group talk, especially in a public place like a cafeteria where there are various conversations underway, it is often not possible to obtain complete transcripts from recordings. That was the case here. However, the partial transcripts that it was possible to produce from the two groups certainly give a strong flavour of the activity, and a drawn upon in the account below.

IMAGINING AND JUSTIFYING SIMILARITY

Our experience of the ASCEND delegates plying the analogy game, supported by our transcriptions from the two recorded groups, suggested that most of these 'gifted' science students appreciated the rationale of the game quite quickly, and they were generally very willing to enter into the spirit of finding points of similarity between science concepts and everyday entities. Whether or not these students would have questioned the value or point of the activity had it been presented in the context of a formal science class, they seemed to take to the challenge in the context of the ASCEND enrichment programme. The similarities that were suggested, at least those we can identify from the clearly audible parts of our recordings, were quite diverse in nature – and often not well thought through. However, students were being asked to produce similarities spontaneously without preparation, and without guidance on what kind of similarity they might look for - in others words, in common with most of the ASCEND activities, there was considerably less imposed structure than they would expect in a science learning activity they were asked to undertake in their school science. The analogy game had been set up with necessary structure in terms of procedure (as there was not time for the students to devise and negotiate their own rules), but without the use of examples or indeed any formal teacher introduction.

To some extent this fitted the general approach of ASCEND to provide a learning experience that contrasted with the high level of scaffolding of tasks typical of school science, and rather to ask students to take more initiative. However, there was also the pragmatic consideration, that delegates were arriving unevenly, and the game was being played in the public context of a Faculty cafeteria – this prevented any formal or extended introduction to the activity. This setting for the activity was therefore not ideal, and likely impacted on the quality of the productions the delegates were able to offer.

Sharing the creative act

The first comparison offered in one of the recorded groups was that *cola is like a chemical reaction*. After this suggestion was offered by one of the girls, another player questioned whether saying 'cola is like a chemical reaction' was the same as 'a chemical reaction is like cola' (i.e. the task was to find analogies for the scientific concepts, not scientific analogies for the everyday items), but another player adjudicated that 'it's the same thing'. The justification for this first stab at a creative analogy was:

cola is like a chemical reaction because it's fizzy and it bubbles...and some people can drink absolutely loads of it and some people can have absolutely loads of it and other people can't and also ...um people...and people can never...people can never tell whether they've got diet coke or real coke and (unclear) in chemical reactions you've got...and in chemical reactions you can never quite tell what elements are there unless you're really, really good at it

There seem to be three phases to this proposed analogy. The first comparison (fizzing and bubbling) was a similarity, but was not developed. The delegate quickly moved on to a new suggestion related to how much cola a person can drink, but this did not seem to have been thought through (we might say the suggestion fizzled out), and she shifted to a third aspect of the justification. So a chemical reaction was like cola because people could not tell what type of cola they were drinking, and in a similar way one had to be very good at chemistry to know which elements were present during a chemical reaction.

The rest of her group seemed happy enough with this suggestion, and the group moved on. The next suggestion was that "the light is like money because you never know how much you've got till you're sitting...till you're sitting in the dark without it". The next suggestion, prefixed by the qualification "okay, this is slightly rubbish", was that "a molecule is like Africa because...Africa is one little thing in a mass of other countries and big things that makes up the world".

After a short pause one of the girls suggested that "DNA is like high-heels...um...every woman's got a pair and...okay...an ionic bond is like love because it's all about two things being joined". This was greeted with an exclamation of "that's good!" from one of the boys in the group, leading to the modest self-evaluation that "I got the cushy one, that was easy". The other players accepted the bond-love analogy for the bond, perhaps filling in the mapping (the elements as the pair of lovers) for themselves (see Figure 2), whereas the DNA-shoes suggestion did not seem to offer the player potential for moving beyond finding a similarity:





The very next suggestion offered a more explicit mapping: "the nucleus is...like the brain because the nucleus controls what the cell (does) and the brain controls what we (do)". This is a familiar teaching analogy, but was received as though novel to these students ("yes...sure!"). Later in the game, another analogy familiar to teachers was offered ("a cell is like a brick...they're used to build up the body"), but even if these examples might have been ones the delegates had met in their science lessons (perhaps recalled without being consciously aware of this), most of their suggestions seemed original.

The next comparison was that "reproduction is like Versace because...I presume Versace started as something very small...and has grown and multiplied, reproduced, big". One of the girls in the group then suggested that bicarbonate and alkali were analogous, based on bicarbonate being in the same way as an alkali. At this point, I intervened

Girl taking her turn: Bicarbonate...I think you put bicarbonate of soda on a wasp's sting so the wasp's sting must be acid.

Keith: But isn't that saying something is an alkali, not like an alkali?

Players: Mm.

Keith: What do you know about alkalis?

Girl taking her turn: They neutralise...

Keith: Okay, can you think of something else that neutralises something?

(No response.)

Keith: ...doesn't have to be a chemical substance...what might neutralise something?

Other girl: Aah...a peacemaker.

[Some chatter and laughter...]

Other girl: The United Nations are like an alkali...they neutralise...disagreement in the world...not always successfully.

Next girl taking her turn: Okay...an electric current is like a smile because from the right charge and through the right battery it ends up brightening up your day. [Then after group laughter]. Sorry that was very cheesy, I know!

This new suggestion was not spelt out in detail, but seemed to be appreciated by the others in the group, and seemed to play upon the literal and metaphorical meanings of 'brighten'. The group continued to play the game in this spirit. Some of their suggestions' continued to be underdeveloped: "velocity is like a courier...velocity is like speed with direction so it's like couriering the...whatever...in the direction of the speed"; an unclear suggestion along the lines that carbohydrates are like sandals because carbohydrates provide energy, and energy is needed to walk around in sandals; an apparent attempt to suggest waste is like bananas as many bananas are wasted in their countries of origin. However, other offerings were both structured as analogies, and creative:

- "condensing is like death...it's where you change from one state to another...from living to dead, from gas to liquid...I win...ha ha!"
- "acceleration is like...holidays...because acceleration is a change of speed...[and] holidays is a change of...place"

Prioritising justification

If anything, the group's progress was perhaps limited by their apparent reluctance to challenge each other to explain their proposed analogies. The situation was very different in a second group, where the players were much more argumentative, and seemed more competitive in playing the game. This is clear from the very beginning of the transcript where one student is arguing that he can justify his mooted analogy "because they're both written on little rectangles of paper". There then followed a debate about whether this was allowed within the rules of the game. I was asked to arbitrate and limited my input to pointing out that it could be a very boring game if it proceeded on the basis of accepting any two terms as analogous simply because they were both written on rectangular cards. The next suggestion was more in the spirit of the game, if not presented as a comparison: "I've got one – you need Energy to run a Control Centre". This suggestion was rightly challenged on the grounds that "you've got to say why [it's] like the Control Centre". An initial attempt at a response to this challenge was interrupted before it could be developed. After some squabbling over whether they were now experiencing some tit-for-tat challenges, the group went back to the instruction card and re-read (or perhaps, read) the rules. This led to a reformulation of the analogy as "Control Centres make things work and Energy makes things work". This was accepted by the other players.

The next suggestion was that 'electric current is a flow of electrons' The group considered whether to accept this suggestion, and one of the other players agreed, before another then challenged: "well, no, what's the analogy?" This led to a disagreement over whether *being the same* counted as *being alike*. It was eventually decided that identify did not count as similarity in the context of the game. The next mooted analogy was that 'Smith is like an atom because both are extremely common'. After this straightforward comparison, the next suggestion was somewhat more involved: that 'string is like acceleration [because] when things accelerate and you look at them through a camera they go like blurred and long and string is blurred and long'. Whilst somewhat convoluted (as with many of the suggestions this had the flavour of ideas being developed as spoken), this example revealed a creative link between two quite different ideas (acceleration and string).

The next comparison suggested is of particular interest given the competitive way the group had entered into the activity, a one player offered a suggestion that another member of the group developed.

Player 1: Here we go here we go ... a bible ... is like a molecule ... both contain (lots of) information

Player 2: How does a molecule contain information?

Player 1: Molecules contain loads of atoms...proven!

Player 2: I've got a good one I've got a good one...for that.

Player 1: Yeah, go on then.

Player 2: A molecule is a complex arrangement of atoms and a bible is a complex arrangement of stories...and books and things.

Player 1: That's quite a good analogy.

Here there seemed to be a genuine co-construction of an analogy, coinciding with a portion of the activity where the students worked together rather than argued. Unfortunately, the next mooted idea that "rules are like light because…rules make up light basically…" became bogged down in a dispute over whether rules were the same as laws, before ending in a claimed similarity that "you can break light and you can break rules". Further similarities suggested were that "combustion is like a fire because fire is a type of combustion"; that "evaporation is like fuming [as] they both make steam"; "adrenalin is like a brick because when they get up too high they start falling"; and "string is like carbohydrate [as they were both] long…strands". The latter suggestion was challenged, and in response was further specified as "starch is a carbohydrate and starch is a long thin strand and string is a long thin strand".

There was then an extended argument about whether falling could be compared to acceleration. Interestingly, the point of dispute seemed to relate to whether acceleration was inherently limited. One of the teaching assistants intervened in the argument to ask the groups about their understanding of analogy, and was told they were looking for "a similarity" where "something's like something". Spurred on by this the boy proposing the acceleration-falling analogy explained: "I said they're similar because in both of them you're accelerating to a point...I'm sure when you're accelerating you'll stop eventually...and when you're falling". At one level acceleration and falling may seem too similar for this to be considered as a creative link, but it seemed the intended comparison was between terminal motion when falling, and the limits on the velocity of a massive body due to relativistic effects, which potentially at least made an interesting comparison: "if you accelerate fast enough, don't you go as fast as the speed of light and then you go backwards which means that you must've stopped accelerating at some point and reversed direction", and that at this point "some scientists think that everything goes black". Whilst the latter part of this suggestion appeared to reflect an alternative conception, the initial basic comparison seemed sound.

After this rather extended discussion, one of the delegates made a new suggestion that "a cell is like an ant...small things but when they work together they can make up organs...the ants when they work together...". The suggestion was interrupted, but accepted, and it was observed that "the [thing] about this game is that you can make a link with basically anything". The potentially strong analogy here (cells are like ants as cells work together in an organ, and ants work together - in a colony presumably), was not explored further, as one of the delegates had moved on to suggestion that testosterone was like an agent because they both made things happen. The group had time for one more suggestion before the activity was wound up to allow delegates to move from the cafeteria to the science education centre for the main activity for the evening. It was suggested that "chemical reactions are like hell because the common theory of hell is lots of fire...and burning", as "many chemical reactions were caused by a burning heat". In response to a query from another player, the proposing student agreed that he was indeed "saying that hell is exothermic".

DISCUSSION

Generally the students responded to the activity with enthusiasm, and most groups became engaged in the game. As well as several groups of students, a group of accompanying teachers played the game with one of the graduate assistants at one table in the café, experiencing first hand the challenge involved. He later reported:

"The students enjoyed it a lot and it made them question their understanding of a topic. It's very easy to think analogies are singular and absolute. Electricity is like water, chemical reactions like competing for friends etc. It was good to hear some really creative new analogies. Even at the [teacher's] table, we were really stretched and forced to examine some of the concepts more closely than we had before."

The dialogues recorded as the two groups of 14-15 years played the analogy game are certainly intriguing. An issue raised earlier in the Chapter was the nature of 'giftedness' in the English curriculum context. English schools are required to identify a certain proportion of their students as gifted, but largely left to devise or adopt whatever local criteria they feel fit. The students who attended ASCEND were certainly above-average attainers in science, but probably reflected a much broader range of ability or attainment than would be signified by the 'gifted' label in many other educational contexts. However, there are hints here of the kinds of exchanges we might expect of gifted learners. In both groups there were attempts to clarify the scope of what was allowed within the game: was the analogy commutable (if cola is like a chemical reaction, can we assume that a chemical reaction is like cola)? Could identity ('electric current is a flow of electrons') or class membership ('fire is a type of combustion') be counted as a suitable kind of similarity? The suggestion that *being represented by being written on cards* might be a sufficient ground for analogy itself displayed an ability to 'think out of the box'. Some of the suggestion certainly demonstrated a degree of ingenuity: such as considering how things appeared when filmed whilst moving fast as the basis for a comparison.

Evaluating and developing the activity

Some of the suggestions offered by the students seem far form ideal, and this raises an interesting pint about the activity. The students were provided with both the science concepts for which analogies were to be found, and a pool of potential analogue. Although some 'wildcards' were included for students to make their own suggestions, most of the time the delegates were trying to force some kind of comparison from their hand of five science concepts, and seven potential analogies they had been dealt. This explains the odd nature of some of the choices, and raises the issue of what students might have thought of if they were required simply to offer their own everyday comparisons. That would perhaps encourage more originality and so creativity (although also admit disputes about what counted as an everyday idea or entity), and so might be a more productive learning activity. In the context of meeting the game for the first time, the inclusion of a pool of potential analogues was probably sensible, but a development suitable for those who have played the game this way would be to require players to offer their own analogues.

A clear limitation of the game as presented was that it had not been sufficiently set up to ensure that only clear analogies, rather than similarities, would be seen as acceptable moves. Whilst spotting a previously unnoticed similarity between a scientific concept and an everyday idea certain called upon students' creativity, it could be a more valuable activity to ask players to then develop the similarities by analysing the structure of the target and analogue to make parallels explicit. This would be valuable in terms of teaching about the nature of science, as just as logic has nothing to work on without creativity; creativity is only of value when we our creations are subject to analysis and critique (Taber, 2011b). This further stage certainly happened in some of the examples presented above, but not all. Some mooted similarities were not developed ("cola is like a chemical reaction because...some people can drink absolutely loads of it and some people can have absolutely loads of it and other people can't"), and some were left only partially explained ("an ionic bond is like love because it's all about two things being joined"; "a molecule is like Africa because...Africa is one little thing in a mass of other countries and big things that makes up the world"). In some cases, this may have been because the ASCEND delegates were not able to take the ideas further: but perhaps they saw no need to if they understood the task as simply look for, and justify, a "a similarity" where "something's like something".

This could have been addressed by more detailed instructions making it necessary to show a structural similarity between target and analogue, and having a formal teacher-led introduction to the game (not viable in the particular context where we used the game in ASCEND, but certainly possible when the game is used in a more formal classroom context). Again, here, there is the issue of how much to challenge those new to the activity: transcripts may suggest that such a specification could have made the task too challenging for some of this group of students. Whilst the games generally moved along with similes being accepted, it seems likely that a formal requirement to map out an explicit analogy might have made the activity a little too difficult for some players on first meeting the game, and so perhaps not the fun activity it was meant to be. My recommendation to other teachers who wish to adopt or adapt the game with high ability students of this age (14-15 year olds) would be that unless the students were already familiar with analysing analogies it would make sense to initially allow any similarities justified to, and accepted by, the group of players, as occurred in ASCEND. It would then be possible to revisit the game later after

considering some examples of analogies used by scientists, but now with the more demanding expectation that only formally explained analogies would be allowed:

- an ionic bond is like love because two different elements are joined together by an ionic bond and two different lovers are joined together by love
- a molecule is like a bible because a molecule is a complex arrangement of atoms and a bible is a complex arrangement of stories

Despite this reservation, the analogy game did prove successful at engaging students' interest, and encouraging them to apply their imaginations in a way that (though no fault of their teachers) they seldom experienced in their science lessons. Although some of the imaginative suggestions offered by the ASCEND delegates left something to be desired - many were not well thought through, and a number were discarded even as they were being suggested - I do not see this as necessarily a bad thing. Indeed, the context of the game format seemed to elicit thinking in progress: the 'mental cogs' moving though cola as fizzy, to cola as differentially tolerated, to colas as being hard to distinguish. Having creative ideas in science is hard work. Most such ideas transpire to be of limited potential, making it even more important we encourage creative youngsters capable of divergent thinking into science to make sure there is plenty of raw material for the convergent and logical thinking to work on. First we have to have the ideas. Then we have to select those worth working with. Then we have to develop these into something suitably operationalised for testing. Then we have to test out the most promising ideas to see if they prove to support a better understanding of nature. Only a small proportion of our creative ideas will transpire to be genuinely productive in moving science forward - but that is why it is so important we help students to see it is important to think divergently in science; and to be prepared to share 'brave' ideas that may seem a little bizarre; and not to worry about generating ideas that may prove to be 'dead-ends'.

Building upon learners' ideas

In this context, it is worth noting that the creative science teacher could look to adopt some of the ideas produced by learners in this activity, as raw material for further development, thus working with students' ideas in a dialogic way (Mortimer & Scott, 2003) and showing learners that imaginative ideas can have real value in science learning. Of course, this would require some careful eavesdropping during the activity, or asking students to keep records of their accepted analogies (especially if this could be done in a simple format which did not interrupt the spontaneity of the activity).

I will illustrate this with one example from our transcripts, the comparison between falling and acceleration. As suggested above, it would be easy to dismiss this suggestion as not very imaginative: when we fall, we accelerate, so that does not seem a very creative link. However, the crux of this delegate's suggestion was that falling (by implication, in an everyday context, through a resistive fluid such as air) is limited, and that acceleration is also inherently limited in principle according to special relativity. There is certainly a structural analogy that could be drawn upon here (see Figure 3).





Although learning about terminal velocity is part of the secondary school curriculum, it is unlikely that special relativity had been met in formal science lessons (it was certainly not part of the curriculum at this

age), so this suggestion seems to draw upon learning outside school. Again, this is a feature that might be considered typical of (though by no means restricted to) gifted learners. It is possible to represent the target and analogue in structurally very similar ways (as in Figure 3), which not only highlights the analogy itself, but makes it clear that this is an analogy between relationships rather than a superficial similarity. Being able to draw analogies at such a highly abstract level would again seem to be something we might associate with gifted learners. It was also very intriguing that the pattern of relationships here took the form of a negative feedback cycle (where the driver for a change brings about a change that diminishes its own effect), which had been a focus of an earlier ASCEND session (Taber, 2011c). That may be no more than coincidence, but perhaps at some level learning about the analogy between other examples of negative feedback in physical systems may have cued this particular insight in one ASCEND delegate.

In conclusion

The analogy game was one of a programme of science learning activities developed in ASCEND to counter a perceived imbalance in aspects of school science in England, especially when considering the needs of the most capable learners. In effect, science under the English National Curriculum was providing a very limited, and uninspiring, image of science, and one that lacked the opportunities to engage in depth with the complexity of important scientific concepts that were most likely to motivate and challenge gifted learners. Table 1 summarises the types of changes needed to prove suitable science teaching for the most able learners, and which various ASCEND activities attempted to address, at least to provide some enrichment form one group of students, and to show what might be possible in a more flexible curriculum context.

Shift	Notes
From product to	School science education needs to balance learning about the outputs of science (laws,
process	theories etc) with learning about the processes of science
From justification	School science education needs to emphasise the creative process of imagining new ideas as
to discovery	well as the logical process of testing them
From breadth to	School science education needs to allow students opportunities to engage with ideas in depth
depth	in an exploratory mode of study, as well as opportunities to learn key established ideas from a
	range of important topics across the sciences
From cognition to	School science should offer opportunities for learners to develop their self-knowledge of the
metacognition	strengths and limits of existing knowledge, and how it can be used as a starting point for
	development
From analysis to	School science education should provide opportunities for learners to demonstrate divergent
synthesis	thinking, and find new perspectives and linkages, as well as opportunities to deconstruct,
	analyse and critique existing arguments and thinking
From facts to	School science should reflect post-positivist views of science as offering robust but
possibilities	provisional knowledge that is always open to being revisited in the light of new evidence
From prescription	Schools science should provide learners with opportunities to take responsibility for planning,
to responsibility	monitoring and evaluating their learning in science, as well as will opportunities to learn
	well-established procedures from structured teaching.

Table 1: A basis for enriching, or if possible modifying, school science for gifted learners

School science in England has put a great emphasis on teaching children to understand fair testing, but has all but ignored the creative process that produces the ideas that might be worth testing. Our gifted science students (indeed, all our students) are given an impression of science as a discipline that makes heavy demands on memory, but has little use for imagination. Despite this, the analogy game, and other ASCEND activities, demonstrated that our students can be creative in science when the opportunity presents itself. Activities like the analogy game also provide an opportunity for teachers to legitimise and values students' creative ideas in science. That, of course, is not just something that is important in the English context, but should be an aim for all those working to support the development of gifted young scientists in all educational contexts.

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