

Science-Teacher Education Advanced Methods National Workshop Report for Scotland

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Giving Science Education a Lift

Executive Summary

Background

The first phase of the S-TEAM project at the University of Strathclyde – evaluating the state of the art of inquiry-based science teaching and education in teacher education institutions and schools in Scotland – is now well advanced. Phase one identifies the opportunities for and the constraints facing either the implementation or increase of inquiry-based science teaching activity in schools, in the process investigating impressions from current practice in classrooms, from teacher education courses, the policymaking context, as well as the implications for the S-TEAM project itself. All teacher education institutions within Scotland were invited to take part in a one-day workshop at the University of Strathclyde in Glasgow; representatives from the Scottish Government, Her Majesty's Inspectorate of education, a leading science centre, the Early Professional Learning project, and of course the teaching profession itself were also in attendance, giving a total of 19 participants.

Key Findings

The curriculum and assessment background to promoting advanced methods in science education in Scotland comprises the *Curriculum for Excellence (CfE)* initiative. The conference participants generally framed their contributions with this in mind. The findings suggested that the *CfE*, while still in its infancy, is generally supportive and encouraging of investigative science lessons, the range of possible activities that could count as investigative, and in the diversity of the ways in which scientists work. There was however some concern about the relationship between the *CfE* and Scotland's portfolio of upper-secondary school examinations, as yet unspecified in policy, and thus leaving open to question the degree to which the new curriculum will continue to support investigations as it currently is. Over emphasis on summative assessment through grading and examinations tend to work against the spirit of investigative activity in the science classroom, a practice that depends on a more sophisticated formative approach. There is the associated danger that schools may continue to garner exam success with more traditional teaching methods with the consequence that *CfE*, though clear enough in its intention to promote investigation / inquiry and creativity, could 'crystallise' into typical assessment styles. Teaching would then be guided by this and genuine investigative activity would be unlikely to develop in the face of the relative certainty (for teachers) of more 'direct' methods.

The experience of the workshop delegates suggests that there are current examples of investigative science work in schools, and that these tend to be enjoyable for learners - exciting, good fun, etc. This affective dimension of learning is important and points to the need for S-TEAM to develop indicators that can accommodate affective engagement. Other 'harder' indicators could also be developed as discussion revealed that examination results and pupil uptake of science (girls in this case, helping to change possible preconceptions) could benefit from inquiry based activity. The efficacy of investigative activity in the classroom, however, is unlikely to be fully caught by the strictly quantitative. A further consideration is that S-TEAM could develop indicators that go beyond an immediate research function to operate in such a way as to contribute to the learning of teachers in the classroom through the capacity

for practitioner self-evaluation. For example, the critical evaluation of investigative activity that a cohort of initial science-teacher education students have already completed for the project, as part of their professional portfolios, has since been commended by teacher educators as being an effective intervention in its own right.

The early results from this indicator confirm the existence of a number of implicit components of developing confidence in undertaking investigative activity – for example, knowledge of the subject curriculum, class, resources, and so on – and teaching methods, from structured additions to the more opportunistic and ad hoc, that practitioners employ. While arguing that teachers could and ought to accommodate a degree of inquiry in their teaching, a critical caveat is that beginners benefit from protected exploratory practice prior to their full teaching post and need space themselves to investigate and explore; it is reasonable for them to exercise restraint in their first year until their confidence is fairly secure.

Implications

1. Promote inquiry in teaching by using examples of existing good practice and by working with experienced teachers in order to take lessons back from them to beginners.
2. Develop purpose specific indicators of inquiry and reflection that go beyond an immediate research function to contribute to the learning of (new) teachers through a capacity for the self-evaluation of the use of innovative methods in the classroom.
3. Collate video examples of inquiry as it happens in the classrooms of student and practising teachers, as well as stories and reflective discussion about how it happened, so as to learn how teachers solve the problems of introducing more investigative approaches into lessons.
4. For the development of teachers' knowledge base in science, create a typology of investigative knowledge and experience comprised of the following levels of scientific perspective, upon which the project's activities might draw:
 - The socio-historical nature of science.
 - Contemporary research activity in science.
 - Initial teacher education in science.
 - Experienced teaching of science.
 - Beginning teaching of science.
 - The child's classroom experience of science.
5. For the ongoing practical application of inquiry-based research, continue to pursue, interrogate and engage with existing examples of inquiry-based methods and resources for the duration of the project.

Workshop Overview

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The University of Strathclyde, Glasgow

Introduction

The purpose of the workshop was to begin the process of identifying areas of opportunity and constraint regarding inquiry-based teaching of Science, for beginning Science teachers in particular. The workshop brought together key stakeholders and knowledgeable experts in the policy and practice of Science teaching and teacher education. Their task was to consider the current position and also what potential innovations might be required for beginning teachers, for teacher educators, and for the S-TEAM project itself, if inquiry in Science is to become an integral component of practice in schools. This workshop report attempts to cover the main conditions, constraints and opportunities regarding the transition in teaching methods towards more inquiry – or investigative activity, a more commonly used description in the Scottish curriculum – in our schools¹.

The argument as to the value of inquiry in science teaching have to be mediated by acknowledgement and understanding of the interactions between the exigencies of practice, the urgings of policy and the very debate on the nature of science itself. This report reflects the inputs and efforts of multiple authors and note-takers to capture a wide range of informed perspectives presented at the workshop, and the authors have sought to extend the discussion, where appropriate, with reference to literature. We have also occasionally referred to the observations gained from a survey of 46 science student teachers in the Initial Teacher Education Programme at Strathclyde, based on their impressions of investigative teaching during an initial two week professional placement, as well as from a critical evaluation of investigative activity that these same students were asked to complete for the project as part of their professional portfolios at the end of a subsequent six week placement.

The positions within the report are inevitably subject to a reading as a singular, academic voice, invoking a determinacy that may not reflect the often dialogic, participatory nature of the discussion at the workshop. A more legitimate representation of the views expressed would be the unexpurgated record of the day, thus affording the reader her own understanding of the sometimes quizzical hints that arose in the occasionally disorderly buzz of conversation – but we have aspired to extract a briefer, more orderly and honest enough account of the emergent ideas. The academic predisposition for a leading, positivistic, and monologic narrative is itself derived from a misconception of science as a ‘process systems metaphor’ (Usher 2001: 52) which projects an image of research as being an ‘ahistorical, apolitical and technical activity [...] carried out by abstracted, asocial, genderless individuals’. We

¹ The photograph of the Finnieston Crane overlooking the river Clyde in Glasgow on the front of this report is perhaps suggestive; for during the age of steam, this was one of the giant-cantilever cranes that lifted Springburn’s newly engineered locomotives onto ships for export to new horizons around the globe.

are not, therefore, averse to the S-TEAM project recognising a depth and complexity of opinion in the workshop discussions, that might even evoke:

a model which allows us to play within the dialectic and to pursue paradox, first to one side, then the other: one which allows us to welcome divergent reasoning that permits many simultaneous, different and contradictory answers, rather than a single solution to every special problem (Rappaport cited in Stronach et al 2002: 115).

Like quantum physics, which in the last century has shown that the behaviour of the atom depends on probabilities rather than on binaries, Rappaport's vision for social science proposes the disarticulation of traditional humanist narratives of truth and progress. For just as the 'natural quantum rhythms of life undermine any stability and constancy that [...] language strives to foster' (Rodriguez 2002: 6), so the current evidence (McNally & Blake 2010) suggests that learning to teach is about *becoming* a teacher, a developmental task that is not after all reflected in statements of professional competence, but which invokes instead 'a far-reaching type of learning, implying what could be termed *personality change* and characterised by simultaneous restructuring in the cognitive, the emotional, and the social dimensions' (Illeris 2004: 84). Would it be any the less credible in that case if the impetus for the promotion of inquiry in beginning science teaching was to be made 'not through a cool, calm and logical scientific insight' (Gribbin 1998: 37), but, like the revolutionary step that the physicist Max Planck took towards a theory of quantum mechanics, as 'an act of desperation mixing luck and insight with a fortunate misunderstanding of one of the mathematical tools' (ibid.) at the project's disposal? Thus, we intend to pursue reasoned argument and sensible development but are ever open, as Einstein was, to loose opportunism (Feyerabend 1993).

The Delegates

Nineteen delegates attended the one-day workshop at the University of Strathclyde. Speakers from five of Scotland's (seven) teacher education institutions, as well as from the Scottish Government, Her Majesty's Inspectorate of education, a leading Science Centre, the Early Professional Learning project, and practitioners discussed investigative science from a variety of perspectives. Quotations are largely verbatim, with minimal editing only to preserve continuity and anonymity (throughout, square brackets are used to indicate that words or sections have been omitted from or inserted into a quotation).

The following provides an overview of the major agencies and organisations that attended the workshop, as well as a summary of the results of the survey of students that was conducted.

Early Professional Learning (EPL) Project

The project, directed by Professor Jim McNally of the University of Strathclyde, ran for four years (2004-7) and was funded by the Teaching and Learning Research Programme (TLRP) of the Economic and Social Research Council (ESRC) in the UK. Its aim was to develop a new model of teacher learning in the first and subsequent years of professional life. The project employed a team of six teacher-researchers

seconded to the project for one and a half days per week, which enabled rich data to be collected from the participating schools and new teachers.

Her Majesty's Inspectorate of education (HMIe)

The inspectorate is responsible for quality assurance 'on the ground' through school visits and reports. HMIe has responsibilities to evaluate the quality of pre-school education, all schools, teacher education, community learning and development, further education and local authorities. It also publishes reports of interest to the public and professionals about services for children and evaluates child protection services. It is thus a source of extensive evidence about performance in and of schools. It does not, however, evaluate individuals. Recently, the use of self-evaluation tools has been stressed as part of the inspection and quality improvement process.

Initial Teacher Education (ITE) Survey

Initial teacher education is the preferred term for the time spent by pre-service or student teachers in TEIs (see below) gaining either a concurrent four year Bachelor of Education (BEd) degree or a one year Postgraduate Diploma in Education (PGDE). Teachers must have one of these qualifications in order to work in schools, although there are sometimes exceptions for incoming teachers from other national contexts, these are dependent on GTCS approval. ITE is subject to the Standard for Initial Teacher Education which is a set of benchmarks to which TEIs must adhere in their course provision.

Of 82 PGDE Science students in the Department of Curricular Studies at the University of Strathclyde in 2009/10, 46 completed the S-TEAM 'Questionnaire on Investigative Science in your Placement School'. Based on observations gained from an initial two-week professional placement, the questionnaire (see appendix 4) asked participants to: 1. Describe an example of investigative science that you observed or took part in; 2. Describe the atmosphere in the classroom during the investigation (for example, what do you think the pupils got out of it?); 3. Describe an opportunity that was missed, but in which you could have supported investigative work; 4. Based on what you've seen, what are the main constraints on or opportunities for introducing investigation into a lesson?

Of the students who completed the questionnaire, 30 provided examples of investigative activity that ranged from those which appeared to involve prescribed experimentation ('Investigating osmosis using visking tubing and distilled H₂O/sucrose solution') to more open-ended practical learning ('school adopted "you choose" classes. This was a designated double period for S1/S2. It allowed kids to do practical work with no coursework'). The resulting atmosphere in the classrooms ranged from the underwhelming ('they weren't as enthusiastic as I thought they would be'), to interested ('kids were interactive, not bored'), to thoroughly enthused ('100% engagement. "Hands on" has to be the way to teach science, with follow up "write ups" [...] Kids love kit & love to play with it'). Twelve respondents suggested opportunities for (or enhancements to) investigative work ('pupils asking great questions and teachers avoiding answering them or exploring them further'), while the

factors that were most often cited as barriers to introducing investigative work were time (n 27) and resources (n 9).²

Scottish Government Education Department (SGED)

Previously known as Scottish Executive Education Department (SEED) and prior to that it was the Scottish Office Education & Industry Department (SOIED). SGED is responsible for some central administration of education including a role in the allocation of induction teacher placements. Most of the day to day administration of teaching and schools is devolved to GTCS and the LEAs.

Teacher Education Institutions (also known as Institutes of Higher Teacher Education)

All teacher education in Scotland is now the responsibility of Universities, which have absorbed what were previously teacher training colleges. There are seven TEIs:

- University of Strathclyde (www.strath.ac.uk)
- University of Glasgow (www.gla.ac.uk)
- University of Edinburgh (www.ed.ac.uk)
- University of Aberdeen (www.abdn.ac.uk)
- University of Dundee (www.dundee.ac.uk)
- University of Stirling (www.stir.ac.uk)
- University of the West of Scotland (www.uws.ac.uk)

The TEIs provide initial teacher education (ITE) through a mixture of concurrent degrees and post-graduate qualifications, including some at masters and doctoral-level, and also make a contribution to Continuing Professional Development (CPD) for teachers in-service, including the Chartered Teacher Programme.

² A comprehensive analysis of the results of the survey is in preparation.

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1 Practitioner Perspectives

The workshop provided two sets of perspectives on what happens in schools. First, there are the direct experience and reflections of practitioners and second, there are impressions of practice from those who are in regular contact with teachers of science in schools.

1.1 What is the current state of practice in schools?

There is a range of experiences and views that may best be illustrated through what might be described as perspectives from either end of a theory-practice spectrum. At one end this draws on a narrative account of specific experience in the science classroom. The teacher, with a few years of teaching experience has a class for a period of time that allows a degree of freedom in what is taught and opts for topics – and indeed methods – that may generate more interest. In depicting the activities that take place, the description is graphic and colloquial and conveys a sense of rich inquiry by pupils, without any attempt to relate to any prior theoretical position.

I've taught kids soldering, wiring up blue LEDs into a little bread board you know, or they had been doing a little bit of soldering to connect up a little battery pack or something.

We've done investigations into which colour of light is best for growing plants ... once a week, a little bit of water in, had a quick look at the plant, they decided how they knew the plant had grown, they thought greenness was the best indicator, so we ended up with a green chart, you know it was like Dulux but so many more greens and every week they would try and categorise the green, like how healthy, how good was this plant.

... Did things like colonising another planet in the solar system. They went away and they found out about the solar system, I gave them a quick tour with some open source software so that we kind of had an idea of how big the solar system was ... what was your evidence for something having an atmosphere, was it opaque looking, did you see lots of craters? ... All this kind of stuff and they went on the NASA, the European Space Agency websites and they came back to me with a video.

We just did these things inside the boxes that photocopying paper comes in and I stashed it at the back of my classroom

At the other end of the spectrum, a practitioner with many years of experience identifies a theoretical model (Feist 2006) that may assist in conceptualising and guiding inquiry-based practice. This consists of a progressive typology connecting scientific thinking to development in learning, from observation through cause and effect to reasoning and hypothesising (see appendix 3). This perspective may well become useful as we explore actual experiences and instances in the project for some

common themes that may assist teachers in making practical sense of what it is possible to do as inquiry in the science classroom. But the account of practice is also accompanied by reflections that may serve as grounds for theorising too.

There is a diversity of ways that scientists work and a diversity of ways in which science is done and what we've got in Scotland at the moment is we have practical investigations [...] and very, very narrow way of how science operates [...] straight hypothesis, formulation and testing, and I think there is a real dishonesty there [...] it's not how scientists work all the time [...] I'd like us to have a broad view of how to do investigative work [...] to acknowledge that science is often very haphazard [...] almost having a wee carry on in your classroom can be just as valuable as structuring things with hypotheses.

There is also a hybrid perspective of preliminary theorising that draws on the sharing of views in a mixed group of practitioners and the literature (McNally 2000; 2006). This suggests that there a number of implicit components of confidence – e.g. knowledge of subject curriculum, class, resources, and so on – and teaching methods, from structured additions to the more opportunistic and ad hoc, that practitioners employ. While arguing that teachers could and ought to accommodate a degree of inquiry in their teaching, a critical caveat is that beginners benefit from protected exploratory practice prior to their full teaching post and need space themselves to investigate and explore; they should exercise restraint in their first year until their confidence is fairly secure.

2 Impressions of Practice

The following impressions of practice surfaced in the workshop discussions across the full range of participants, including university teacher educators, Her Majesty's Inspectorate, representatives from the Scottish Government and science centres, as well as practitioners. The sections that follow occur more or less as they arose in discussion at the workshop.

2.1 Science disciplines as pedagogical constraints

Many teachers of science were often constrained by the 'three pillars of school science' – chemistry, physics and biology – and needed to be reminded that there is a 'lintel' across the top labelled environmental science. In extreme cases, individual teachers could be in a silo and one way to move out of that silo was through inquiry-based science. Visits to Science Centres could show the way and perhaps start people off on more interdisciplinary working. This is actually encouraged in the new *Curriculum for Excellence (CfE)* policy; the International Baccalaureate has environmental systems as a science option that draws on chemistry, physics, biology, geology and oceanography to give an excellent science curriculum overview of how the world works as a big system – this may be reflected in environmental physics, for example, as one of the sections in the new Higher and Advanced Higher Physics. It was noted, however, that similar such precedents tended not to effect much change in pedagogy.

2.2 Definition and discourse

It was recognised that there were a number of overlapping terms: inquiry, investigation, problem solving, open ended, exploratory. Work on problem based learning had yielded categories of learning, of there being a solution, a range of solutions and also no simple solution. A problem is that some think of problem based learning in terms of the need to solve the problem. An exploration of what teachers do and think in practice – as this project work package seeks to do – is seen to be of greater priority at this stage and so there is no insistence on greater clarity at present, other than to be aware of the definitional vagueness. We hope to arrive at some kind of realistic understanding of what inquiry could mean for teachers, particularly beginning teachers, and recognise that inquiry does not have to be some large scale investigation, involving control of variables and hypothesis testing.

Teachers also had to handle different discourses – their own day-to-day professional language, the language of curriculum documents, the language of theory and academic life, the language of the pupils themselves. Even seeing connections or recognising conceptual congruence across these discourses is demanding and so conflict and confusion are more likely.

2.3 We do it anyway

Teachers could well ask ‘so what’s new?’ or claim that they do it anyway – and there is evidence that this is the case (HMIe 2008). From the various perspectives, we could all recall the entreaties of previous curriculum documents – for effective lessons in science ‘include activities and tasks that actively involve pupils and offer challenge’ (DfES 2002: 2) – and also cite examples of inquiry based learning, but also agree that practice is highly varied from the excellent and inspiring to the near absence of practical work at all. Snapshot reports can be misleading of course but it was noted that a recent survey by the Royal Society of Chemistry (RSC 2006) expressed concern about the lack of practical work in schools. Another issue is whether claims made by others actually do meet criteria – yet to be evolved – of what constitutes such practice. For science, activities that are hands on and open ended for pupils (HMIe 2008) offers a reasonable starting point, but we might suggest that there should also be evidence of science content and sense of purpose or pupil engagement. We are mindful of Hodson’s (1993) distinction between learning science, learning about science and actually doing science. However, these are simply preliminary ideas and subject to further exploration of different examples of practice.

2.4 Engaging pupils

It was generally agreed that children are naturally curious and that this is a natural springboard for inquiry based learning in the classroom.

They are just really curious, they just want to find out stuff and creating an atmosphere in the classroom where the curiosity is one of the great values of your science classes [...] it’s one of the most valuable things you can do as a teacher ... I wonder what’s under this, I wonder what happens if you do this, what happens if we open up and look under this stone. What’s there? That can start at a very early stage in children’s education, just embracing curiosity.

This was balanced by a) the question of in ‘how many classrooms in Scotland is there an atmosphere of curiosity’ b) whether the initial curiosity, as nurtured in a good nursery or early stages classroom, somehow disappears as they grow and progress through the school system c) acknowledging that channelling curiosity in science with older children presented genuine challenges to teachers. At its most pessimistic:

What we have effectively done over the years is actually taking this young curiosity that is there and effectively just killed it off, particularly by the time they get into first and second year of secondary school.

A more optimistic take was to simply keep try to tap into that natural inherent curiosity:

Taking a load of junk into a classroom ... get the conversation going ...how does this vacuum cleaner work? ... Everytime something goes wrong, it is an opportunity for learning and perhaps we should capitalise on that more than we actually do.

There is a strong argument however that listening to the pupil voice is critical. This can be seen in teacher discourse:

it is only when you listen in to all their conversations that you actually realise what it is they know, what they don't know, what it is that they want to know, how they might go about finding that out;

and in the more formal discourse of policy:

the important thing is we are meeting the needs of all children ...and differentiating and appreciating that everybody has got different needs and different abilities and choosing what is correct for the individual child [...] it is important we have got the suite of qualifications there for that purpose.

2.5 Perceived benefits of inquiry

The limited experience we could draw on suggested that investigative work could be enjoyable, exciting, good fun, etc. These affective dimensions of learning are important of course and so pointed us to the need to develop indicators that could accommodate affective engagement – of which there is experience in the project work package team (McNally & Blake 2010). It is also worth noting the correlation between positive emotional engagement and more open ended thinking that has been identified (e.g. Hascher 2009). Other 'harder' indicators could also be developed as discussion revealed that examination results and pupil uptake of science (girls in this case, helping to change possible preconceptions) could benefit from inquiry based activity:

Surprising, we got a sudden intake of girls and bear in mind it's the bottom set that suddenly in a class out of 15 we had 10 girls and we had never had girls in Int1 Physics before. But getting girls soldering, I honestly thought that they wouldn't want to do that.

2.6 Barriers to teacher engagement

More attention was paid to discussing what causes might lie behind the low level of inquiry type work in science classrooms. *Science: A portrait of current practice* by HMIe (2008: 9) reviews the extent to which current practice in science is successfully promoting the four capacities of *Curriculum for Excellence*, and is clear that practical, investigative learning activities 'form the key to developing successful learners in science'. Despite drawing on the evidence of the inspection of primary and secondary schools between 2004 and 2008, the portrait is unclear about the depth or breadth of the provision of practical work in Scottish schools, though it does concede that in 'secondary schools, too often, young people were not sufficiently active in their learning' and that children's 'skills of scientific investigation were too limited' in primary schools also (HMIe 2008: 11; 26). Ironically, one of the Post Graduate Diploma of Education (PGDE) students surveyed explained that (during their professional placement) they 'never saw much [investigation] due to [preparation for] an HMI visit' to the school. Variation in the provision of inquiry work is however a complex picture with a number of reasons outlined in the sections that follow.

2.7 Time out from the prescribed curriculum

The time and freedom to try out ideas, to experiment with an investigative pedagogy, may be perceived as being unavailable with a class following a prescribed curriculum. In the preliminary survey of 46 PGDE science students undertaken by the University of Strathclyde for the S-TEAM project, and based on impressions from these students' initial two-week practice placement, n27 (59 per cent) cited limitations of time ('to get through the course', for example) as being a major constraint in introducing investigative activity into classes observed. This is normally associated with the need to cover adequately the content for a national examination, and the concomitant prospects of employment and entry to higher education.

Why would you not then take that up with other classes you teach if it seems to work so well?

Purely because of the time factor, it just takes so long ...it's only because I had the bottom set that I had the time.

Associated with this too was the 'tyranny of the right answer' that acted against any tendency to explore, and of perhaps still 'getting there by a very different route'. A teacher might therefore feel compelled to ignore more interesting methods; so it requires confidence to go 'down the by-ways and still get to where you are heading'. There is a challenge in persuading, with the right kind of evidence, that inquiry and examination performance are not mutually exclusive, in somehow reconciling contradictions which are only imagined. Indeed, in view of the persisting focus on examinations as measuring progress in science, it seems almost incumbent upon S-TEAM to go beyond any simple quantification of exam results in attempting to deduce the benefits of investigative activity, to be imaginative instead in developing indicators of performance in other domains, e.g. classroom environments, or affective relationships.

2.8 Assessment

The *Curriculum for Excellence* in Scotland for science is, on the face of it, encouraging of investigative science lessons, the range of possible activities that could count as investigative, and in the diversity of the ways in which scientists work. However, to maintain this spirit, it was recognised that there was a need for assessment not to focus on rewarding the acquisition of atomised facts. This is rewarded by the current assessment system but investigative learning is not a pathway to success here and so is not favoured within it. Furthermore, there is a danger in driving curriculum change through examinations, as teachers will then focus on getting the pupils through – a problem also experienced in mathematics where in-service has been dedicated to finding the investigation that was easiest for the pupil to pass in formal assessments. However, as the following exchange between teacher educators in physics and mathematics suggests, even then there are opportunities for exploring questions raised by the pupils, but current curriculum and assessment restraints make this 'risky' in the eyes of many teachers.

Do you still think there are opportunities when you are teaching mathematics, teaching pedagogy, to follow up some of the children's questions or to present situations which can be investigative?

Absolutely.

Do you think that happens often enough?

No, because my final words are that the SQA [Scottish Qualifications Authority] rule the roost and schools are judged by their exam results, as long as they get there is all that is important.

Can they get there but still embrace occasional opportunities?

Too risky, they just don't have time, what happens if it doesn't work and 'I've got to go over that ground again and I'm losing even more time' [...] Social constructivism is proven to be the way we learn, the evidence, [the] research is all behind it and there is a superb chapter from a book by Gerard Brophy on [...] a science lesson, biology in fact, that was done purely by investigation on seeds/plants [...] The guy's results really improved and it was very risky – he said that, he kept saying he was scared 'they [his class] wouldn't get this, they wouldn't get that', but it worked. But try telling that to a practising teacher.

In short, in both science and mathematics, over prescribed curricula and assessments may only permit teachers to carry out investigations when they have unusual degrees of motivations to do so. It may even be naïve, say Hofstein and Lunetta (2003: 44) to think that teachers' will 'shift toward inquiry and the development of meaningful practical knowledge until such outcomes become more visible in the tests that increasingly drive what teachers [...] think is important'. While it is the case that the policy initiative *Assessment is for Learning* was viewed as 'fitting [...] absolutely perfectly' with inquiry (and the evidence of the EPL project sample was that 82.9 per cent (n 58) of beginning teachers of all subjects found this initiative helpful to their development), the question remains, to what degree will the *Curriculum for Excellence* continue to be as supportive of investigations as it currently is, or will assessments come along that destroy that spirit.

2.9 Health and safety

In recent years there has been due and legitimate regulation that has removed some of the more hazardous practical work and requiring risk assessment but this is used at times to justify why practical work is not done: 'primary school definitely suffers from [the] urban myth about what you can and can't do with a glass jar in the classroom, and some of that comes from individual school policies and some comes from local authority edicts'. The situation in schools was compared to industry where assessing severity meant considering the worst case and how often it happened before – if it had not actually happened then 'you didn't have to worry about it'. It seemed that schools and councils do not consider kind of frequency of incidence – perhaps

some teachers too – and this tended to minimise the first hand direct experience that the children have:

I came across one where a second year class throughout the whole school, second years and first years were not allowed to use Bunsen burners on their own ...if you take a bunch of experienced science teachers, how many of them have actually had these theoretical accidents?

2.10 Material barriers to pupils experiencing practical work

Discussion at the workshop revealed a variable picture of practical work, with regret being expressed at the sight of ‘children [who] haven’t had the practical experience compared to some places where children are obviously well [provided for in this regard]’. It was acknowledged that there are ‘various [...] quite complex’ reasons for this inconsistency. Although the science portrait (HMIe 2008) mentioned above does not explicitly position variation in practical or investigative work in relation to access to laboratories and equipment, there is reason to suggest that the material circumstances of classroom accommodation and resources do have an effect.

I think quite often some classes are shunted about all over the school as well and maybe the teacher might not be familiar with where stuff is, I know certainly all our young QTs [qualified teachers] who would come in wouldn’t have a dedicated classroom.

Of the 46 ITE students surveyed, n9 (19 per cent) suggested that resources (e.g., the ‘complexity of equipment needed’ in a biology lesson) were a barrier to undertaking investigations in the classroom. This may be indicative of an unnecessarily sophisticated interpretation of investigative activity that possibly takes as its logical conclusion Cern’s Large Hadron Collider and thus assumes an expensive tariff of materials, as opposed to the simpler way in of ‘taking a load of junk into a classroom [in order to] get the conversation going’. Indeed, one of the ITE students surveyed offered as a basic example of inquiry, a ‘mystery box’ exercise in which pupils ‘felt inside a box and had to use their observational describing words to describe [the] object to the rest of [the] class’. While commendably off-the-cuff, and perhaps open to definitional debate as to its conception of investigation, funding policy on the other hand, ‘as in Scotland [...] that gives a school several laboratory technicians [and which it is presumed] leads to a greater likelihood for hands-on inquiry learning than is possible under funding that provides no such supporting conditions’ (Fensham 2009: 1077), may not necessarily enhance the opportunities for practical investigation in the way that some might think.

You go into the lab and the technician has put something out and the first thing we [ITE lecturers] do is play around with it and [...] what [do] we do when kids come in – ‘Don’t touch that!’ And that’s partly because it takes so long to set it up sometimes. So getting back into this idea of here is the equipment, just play with it, fumble, time to begin [is laudable].

2.11 School level considerations

The practitioner perspective available to the workshop suggested that school ethos and school organisation may each have a strong and perhaps competing influence on the practice of inquiry in the classroom. In view of the structural exigency of these discourses, it was agreed that sight should not be lost of either pupils' needs or the complexity for S-TEAM of gauging improvements produced by investigative activity.

Although it was accepted that a school's interpretation of the curriculum and qualifications framework could drive change either in the direction of, or away from investigative activity, evidence emerged of the existence of possible informal openings within the prescribed timetable, and the importance therein of the ethical and opportunistic practice of the individual.

The whole curriculum thing can be such a bind. I've been King of the bottom set second year class every single year since I've been there [...] Now the thing is, we have to get to this second year exam, which for some strange reason is in February [...] as a rule, I'm kind of glad that it is relatively early in the year, but the trouble is they [the class have] also filled out their option form: 'what are we going to do next because I'm not doing physics, and I don't want to do chemistry, and I'm not doing biology next year, what are we doing?' So I go to the head of the science faculty who gives me 50 quid and somehow I do a loaves and fishes thing and that 50 quid gives me something that I can do open ended investigation on right up until the timetable change in June. And I absolutely love that time of year, because I discuss with them [...] 'what sort of thing will we do?', and you can get them talking [...] you can actually have fun, and they have fun.

It is important to realise, of course, that fun as applied to teaching and learning in the above is probably not conceptualised as 'the purpose [...] but part of the process' (Gray 2010: 122) of meaningful education. Likewise, when asked to describe what for them was the main constraint to introducing investigative activity into a lesson, one of the PGDE students surveyed by S-TEAM felt that her placement school was 'too focussed on grades', which resulted in 'more wrote [that is, rote] learning, less fun learning'.

In the face of a curriculum bound by the constraints of assessment, it was felt that the individual practitioner might be required to be 'independent and motivated' in maintaining his or her ideals in a school for whom the lesser orders of achievement might be viewed as problematic. But rather than being so much of a prescription or template for prescribing what should be delivered to learners, the curriculum was conceptualised as 'a space' within which there might exist 'various problems to solve', as in, for example, meeting the learning needs of pupils, supporting them in developing scientific thinking and supporting them in developing an understanding of scientific concepts and theories. Insofar as addressing the 'needs' of pupils was felt to depend on enterprise and ethos within the classroom, this was recognised as perpetuating the difficulty for S-TEAM in 'getting a grip on what is happening when you do good investigative teaching'; that is, in avoiding the measurement say of attainment in science using statistical methods that may not have power enough to

detect the effects of an investigative intervention, while still identifying an effect greater than ‘I feel a bit better about doing science’.

2.12 Science in primary schools

There was a focus on the apparent **discontinuity** in the application of science learning from nursery to primary to secondary school. The nursery school was exemplified as a ‘more open forum’, and better able to respond to and indeed activate learners’ creativity and interest in science ‘on a day to day basis’. This dynamic however was perceived as becoming ‘narrower and narrower’ as learners progressed through primary and secondary schools, where ‘you don’t see a lot of planning [in] response to what the children come back to us [teachers] with’. According to HMIe (2008: 11), good curricular links in science between primary and secondary schools was in the main ‘poorly developed’, which, ‘together with the lack of reliable assessment information gathered at the primary stages, affected continuity in learning when young people entered S1’.

As you go up through primary school, teachers feel less confident in responding to pupils responses because they are not quite sure where it is going to lead [...] and whether they can cope with it [...] Science gets scary as you move closer towards primary seven and they [teachers] feel less confident. They can cope with turning over stones and looking at what is underneath and maybe sorting things with legs from things without legs and different colours, but once it gets beyond that then they feel that they can’t do it. Not that they can’t do it, they feel they can’t.

This may be further reflected in the fact that HMIe (2008: 26) found that learners’ attainment in a ‘representative’ sample of ‘primary schools inspected often had weaknesses, set against appropriate national 5-14 levels. Attainment was generally satisfactory up to P4 but declined thereafter through P6 and P7’.

There was considerable debate as to whether the **lack of confidence** in primary school teachers could be attributed alone to a shortfall in scientific knowledge. Although subject knowledge (in biology, for example) was identified as tending to exist in ‘little pockets that people [primary teachers] know quite well, [...] with] huge areas that they lack the same first hand experience [...] in’, the same was also said to be true for secondary school teachers. Quite apart from the absence of technical support in primary schools, a good primary teacher, it was suggested, would be someone who ‘knows their limitations; they know what they know in science and they know what they don’t know’.

I wonder if part of the thing about the reported confidence of the primary teaching in relation to science is something to do with the culture of the primary school as much as anything else. I reported on the UCAS points that [primary] B.Ed [bachelor of education] undergraduates had at point of entry, and on average it was 132 points which is a fantastically high number in science alone, that was without looking at mathematics at all. So there was an academic, scientific capability that was apparently being denied in the staffroom by classroom practitioners.

A potential barrier to primary school teachers adopting innovative methods in classroom practice might therefore be framed as an institutional or perhaps ideological resistance to addressing ‘what they don’t know’. Indeed, an example was given, from research, of a primary practitioner of some thirty years experience who at the time of questioning was still depending on content from an initial teacher education programme to provide the epistemological basis of his or her science lessons; in the face of this interlude, the scholastic capacity of as little as ‘14 hours face-to-face contact on the B.Ed programme and seven on the PGDE programme for primaries’ appeared somewhat contracted.

As an example of promoting a view of ‘science as constructed, rather than given or absolute, knowledge’ (Summers 1992: 29), secondary PGDES students, it was explained, are rotated in some institutions between physics, chemistry and biology topics, and thus deliberately taken out of ‘their comfort area[s]’:

they are not confident and they are very aware that ‘I really need to brush up my skills quite heavily here’, not only in terms of content but also in approaches in pedagogy [...] My experience is that they are not over-confident in what they feel they are good at, they are aware that there is limitation.

For all that this is an ‘epistemological stance’ that Summers (1992: 29) might strongly support, he does avoid taking his argument into the ontological nature of teaching, which was however aired during the workshop discussion:

I worked as a microbiologist. I think it really gave me a confidence in handling equipment, you know you had to do things, fix things to be independent in the classroom [...] and I wonder if it is something to do with the way you see yourself, that you know that you have worked in this capacity [...] I just wonder if it is something to do with identity, you can actually see yourself being that person, whereas the vast number of people who come through the primary course see themselves as teachers rather than teachers of science or scientists.

That the confidence of teachers of primary school science might thus be seen to have ‘something to do with [the] identity’ of those who see themselves simply as teachers rather than teachers of science or scientists, might yet require of the S-TEAM project a methodology that articulates the nature of both epistemological and ontological developments in pedagogy as they apply to real scientific contexts and real classroom situations (Benner and Wrubel 1989).

3 Practice in Initial Teacher Education

It was the opinion of the workshop that much good practice exists in schools, and similarly in teacher education institutions, meaning that it would be important for S-TEAM to capture pre-existing approaches to investigative activity that could be taken forward on a national scale. The potential of this kind of data at the disposal of teacher educators is such that newly qualified teachers, who were conceived as being a constant against the backdrop of an evolving science, might then be in a position to function as ‘emissaries’ of good investigative practice.

3.1 Prior experience of student teachers

In a poll of the scientific experience of undergraduate initial teacher education students carried out informally by a delegate at the workshop, it transpired that ‘very few of them had done much more than the prescribed practicals for higher biology and quite a lot of them had done very little in standard grade over and above their prescribed investigations’. Although it would be premature to conclude that the role of lab work in science education is not thus as self-evident as might be supposed (Hofstein & Lunetta 2003), the poll could perhaps reflect the view that teachers are ‘not well informed about new models of learning and their implications for teaching and curriculum’ (Hofstein & Lunetta 2003: 45), so that while ‘excellent examples of teaching can be observed, the classroom behaviors of many teachers continues to suggest the conventional belief that knowledge is directly transmitted’ (ibid.).

The modification of such behaviour may depend, it was said, on the ‘young teacher’s perceptions of legitimacy and knowledge’, as well as where that ‘knowledge is best situated’. While it might be argued that the ITE process has the opportunity to cultivate students’ enthusiasm for more innovative practices by way of the ‘predominant push for research’, the necessary engagement by university departments with the realities of the teaching profession entails an acceptance that new teachers initial developmental task is in the order of becoming ‘socially encultured’ within the school, the department, and most especially perhaps the classroom: ‘they’ve got to win acceptance, they’ve got to gain that status of being a teacher, and you [the new teacher] will do what you have to do to get that’.

3.2 Loss of idealism in school

When asked if they could identify what in their observations were the main constraints on teachers in introducing investigation into a lesson, the PGDE students that were questioned for the project reported a ‘lack of inventiveness, imagination’; ‘No open questioning of pupils. They are required to submit correct answer’; ‘Hassle – More bother than it’s worth’. It would be injudicious indeed to attempt to deduce from this alone the likely effects, say, of the conservative forces of competitive performativity (Ball 2003) on the teachers concerned; nevertheless, a ‘certain degree of sadness’ was expressed by teacher educators at the workshop who had witnessed the enthusiasm with which student teachers entered professional placement – the

willingness to adopt ‘any methods that are suggested [...] to motivate their pupils’ – only to see it,

channelled down very narrow alleyways to conform to the principal teacher, or rather curriculum needs, or what have you – you’re seeing these students churning out the same thing time after time, and their initial [...] enthusiasm] has just sort of gone and they don’t regain it [...] they are conforming, first of all, to the teachers in the schools, and they lose so much and it happens very quickly in the space of six weeks.

While Tobin and McRobbie (cited in Van Driel et al 1998: 679) might describe as ‘cultural myths’ such imperatives as the ‘transmission of knowledge and the maintenance of the rigor of the curriculum’ in determining science teacher’s classroom practice, it does remain the case (according to one teacher educator) that ITE departments do not ‘pay [...] and promote’ beginning teachers, ‘so conforming to the school system is likely to enhance their career opportunities more than pleasing you, [the teacher educator, will]’.

3.3 In partnership with the profession

It was acknowledged that teacher education institutions are perhaps not sufficiently well developed in their partnerships with schools in order to operate from an informed position and one which best serves the needs of the teaching profession: ‘the capacity to embrace the school partners in a detailed and extensive way really isn’t threaded into [...] the standard for initial teacher education’. A fundamental question for universities involved in teacher education was identified, then, as being what can be improved and how can it be done in partnership with schools? Indeed, the important task of reducing the ‘institutional and cultural barriers that inhibit communication between [...] science education communities and developing appropriate professional development and engagement systems’ (Hofstein & Lunetta 2003: 46) would allow for a more certain measurement of the impact of teacher educators – ‘most people think that new teachers coming out are doing rather well and we might claim, well, that is because we are doing a good job, because the standards are there’ – as well perhaps as initiating, more legitimately, the question of the extent to which teacher education can ‘engage new teachers in more advanced ways of thinking and different ways of thinking’.

3.4 A framework for different ways of thinking

For one teacher educator, the issue had less to do with an explicit improvement or advancement in the ways of new teachers’ thinking, than of providing a framework for different ways of thinking, of ‘visible thinking’, and which begins with the premise of identifying what ‘excites’ the individual about a given phenomenon:

I thought that was actually a very good word to use because it is not a word that we often use [...] How often do we ask them ‘what does it make you think, what do you wonder about it, what might happen?’ [...] Encouraging that sense of curiosity again. Those students [...] had maybe 45 minutes, they

probably did three or four of these activities, but they were very simple, like just a simple basic series on parallel circuits: what did they notice? [...] Actually getting them to think and realise [that] quite often they don't know [...] is a step forward and probably giving the students the confidence to say 'well I don't know what we [will] find out' [...] Yes, they need to be experts in some sense, but [they] also they need to have this awareness [of being able] to say 'well, I don't know about x, y or z'.

Beginners are known to benefit from protected exploratory practice prior to their full teaching post and do need space to investigate and explore (McNally 2006). Research by Kind (2009) was raised in this regard by one delegate as exemplifying the value of exploration, particularly beyond subject specialism. In gauging the extent to which the confidence of trainee science teachers was influenced by teaching within and outside their specialist subjects, Kind (2009: 1557) challenges the “‘subject specialists are best’ assumption’ with evidence (albeit limited in breadth) that familiarity bred from subject expertise can cause the teaching of beginners to become a means of transmitting (consequently positivistic) scientific fact; teaching outside specialism, however, often resulted in more successful lessons precisely because beginners had to explore a wider range of knowledge sources, ‘including, crucially, advice from experienced colleagues’ (ibid. 1529).

3.5 Technology and literacy

The new and developing technology of information and communication presents an opportunity for new kinds of pedagogy and learning experiences in the Science classroom. There is of course the danger of just using technology because it is new and available to teachers across the curriculum. Good teaching sees beyond novel technologies to a sense of what they can offer to pupils' learning, to how they can enthuse and include the widest possible range of learners. Already, it seems, there is over-use of PowerPoint. *Curriculum for Excellence* outcomes might be interpreted too narrowly: everything gets 'PowerPointed'. Even if the facility is available, sitting through 20 PowerPoints would not be a stimulating experience. An interesting alternative was reported, namely the use of flip cameras and video in the collection of information and evidence by pupils in 'a sort of big zip-up plastic portfolio'. A problem with a 'bottom set' in particular is the conventional dependence on writing as the means of recording and communicating – an over-emphasis that inhibits and stifles creativity. Experience has suggested that moving to this use of new technology for recording and communicating improves the motivation and participation of pupils in Science. Indeed the method is being extended to higher ability sets.

Other forms of evidence like video, for example, have been successful in that we are currently planning *Curriculum for Excellence*. We're implementing it this year, but we are almost developing it as we go and I've convinced the chemists and biologists that we need to get some of these *flip* [video] cameras in, that we don't have to struggle to get things taken in jotters. In fact we are not even using jotters this year, we are doing everything in a sort of big, zip-up plastic portfolio and we're just gathering evidence [...] we're going for artefacts, we're not even bothering with a jotter anymore and that in itself is helping because [...] you're always starting off the lesson [by saying], 'draw

this apparatus, get a ruler, draw this table, write your results in that table', and you're almost putting blinkers on them before you start doing anything. What we're trying to do is open up a bit of creativity.

The disavowal of a 'formal writing frame' is indicative perhaps of a more innovative form of pedagogy, in which the emphasis on print literacy as a prerequisite of learning might increasingly be seen as a disservice to pupils' development (Carrington 2008). The obligation in a *Curriculum for Excellence* is for the production of 'successful learners, confident individuals, effective contributors and responsible citizens'. What twenty-first century citizens appear to require is a 'broad, qualitative grasp of the major science explanations [...] ideas [that are] integrated into an overall explanatory account or picture, rather than the fragmented pieces of knowledge' (Millar 2007: 1507), such as might adequately be contained within tables and jotters – the kind of detail which many pupils find off-putting and which some commentators in fact suggest is rarely ever required (ibid.).

The use of technology in the example above usefully confirms the necessary consideration of what might be viewed as a conflict between the continuity and intermittency of learning in science – which is particularly relevant in view of time being regarded as a major constraint in introducing investigative activity into lessons ('Class didn't last long enough to finish the work', was how one of the students surveyed described their experience). Video-based evidence in this case, though examples of pod-cast and web-based artefacts were also discussed, appears to present learners and practitioners with the capacity to act creatively and quickly by providing the flexibility to adapt and restructure learning outcomes, as well as by offering a range of technical tools to use in the presentation of skills and knowledge development. Within the spatio-cognitive deterritorialization that some see as an effect of working in online environments or with new 'flip' or 'flash' or mobile technologies, the learner might thus be provided with the opportunity for a broader reflection on science explanations rather than the periodic, tabular or atomistic learning offered by more traditional paper-based methods, and which (in the words of another student questioned) can result perhaps in 'too much chunking & trying to squeeze too much into one period'.

4 The Policy Context

In Scotland, the latest stage of the Government's present policy initiative is the newly published *Curriculum for Excellence: Building the Curriculum 3, a framework for learning and teaching* (The Scottish Government 2008). This initiative sets out a number of purposes in learning science, what young people will do, the skills young people will develop, and a statement regarding scientific literacy, as well the broad features of assessment in sciences. Unlike previous curriculum initiatives, the *CfE* is less reliant on content in expressing learning outcomes and instead focuses more on learning experiences. However, as the examples in appendices one and two show, it does set out the background in scientific content in which these experiences are to be based.

4.1 The political discourses of a *Curriculum for Excellence*

From its foundations in the late 1990s (Scottish Consultative Council on the Curriculum in Hodson 2002), policy discussion of a *Curriculum for Excellence (CfE)* might be thought to have converged around possibly competing discourses of 'economism' (Althusser 2001) and citizenship, insofar as a 'totality of experiences [... that put] the learner at the centre of the curriculum' (The Scottish Government 2008: 11) is suggested as the means of developing school leavers as 'successful learners, confident individuals, effective contributors and responsible citizens' (The Scottish Government 2008: 7). Yet, in the context of science curricula generally, and a critique of political naiveté in science education particularly, Fensham (2009: 1080) suggests that the interplay of such discourses may lead to policies for science education with the potential for conflagration 'depending on whether the dominant demand is for the next generation of scientific experts or whether it is for the scientific understanding of the public at large'. Perhaps it is unsurprising then that for all that the *CfE* 'aims to achieve a transformation in education in Scotland by providing a coherent, more flexible and enriched curriculum from [ages] 3 to 18' (The Scottish Government 2008: 3), the interface between the curriculum and the nation's examinations, which 'becomes of key significance' (ibid.: 15) at ages 16 to 18, remains unwritten; to quote a delegate at the workshop, the curriculum 'falls off a cliff' at the commencement of the learner's portfolio of qualifications.

4.2 Prescriptions of policy

Neither the Scottish Government nor the S-TEAM project is new in seeking to increase the impact of investigative activity in the science curriculum. Scientific inquiry, writes Jenkins (2009: 73), is 'now a matter of practical and academic interest on a global scale', one of the 'few overarching themes' to cut across school science curricula around the world (Abd-El-Khalick 2004: 399), and whose potential for providing both authentic experiences in science and inductive learning were methodologies of note for the European Commission's education working group set up in 2001 (Jenkins 2009), as well as in the same organisation's *Renewed Pedagogy for the Future of Europe* as recently as 2007 (ibid.). Now, in a *Curriculum for Excellence: Sciences, Experiences and Outcomes*, it is said that learning in the

sciences should enable students to ‘develop the skills of scientific inquiry and investigation using practical techniques’ (The Scottish Government 2009a: 1); and, lest there be any doubt about the Scottish Government’s commitment to either inquiry or investigation, these terms are, between them, referred to twenty-six times in Learning and Teaching Scotland’s six page companion guide, *Curriculum for Excellence: Sciences, Principles and Practice* (The Scottish Government 2009b).

For the practitioner unfamiliar with the component parts of an inquiry or investigation in science, the *CfE*’s *Principles and Practice* (ibid.: 3) are not necessarily straightforward:

The main approaches to science inquiry are:

- observing and exploring – careful observation of how something behaves, looking for changes over time and exploring ‘what happens if...?’ and ‘how could I...?’ questions
- classifying – through identifying key characteristics
- fair testing – through identifying all possible variables and then changing only one while controlling all others
- finding an association – linking two variables to determine relationships.

Such are the poorly understood complexities of translating instructions like these into classroom practice, that they risk becoming ‘statements of intended or desired, rather than actual, reform’ (Jenkins 2009: 67); and while it may be generally accepted that ‘reform documents do not operationally define inquiry learning and teaching’ (Abd-El-Khalick 2004: 399), it is still something of a surprise that despite the global discussion surrounding the place of inquiry skills in the classroom, the *CfE* cites no published arguments on the matter. Indeed, in a study of policy documents in the UK, Osborne et al. (in Jenkins 2009) found that the prescriptions of policy tended to be sufficiently broad to pose a challenge to curriculum implementation, which, at the workshop, became a question of ‘how we can deliver something [like the *CfE*], which is a national framework, by passing it over to local authorities’ given what he regarded as existing ‘fundamental flaws’ in the consistency of national and continuing professional development in Scotland – a point that has since been confirmed by HM Inspectorate of education, who found that improved approaches to continuing professional development are ‘not yet consistent across all schools and authorities’, nor connected clearly enough to ‘improvements in children and young people’s learning’ (HMIe 2009: 3).

4.3 Policy and the nature of science

Preliminary research by one teacher educator had revealed that new graduate teachers possessed ‘a very unsophisticated vision’ of the nature of science. Over time, it appears, they do come to accept the ‘idea that a theory is something that is very tentative’, however:

[their initial] understanding of it is very much, I would say, what the general public would understand by it, so I think we are finding probably that they don’t really have a sophisticated understanding of what science is and if they

have been undergraduates, probably haven't done a lot of true investigative science.

The emphasis on procedure in the *CfE*'s approaches to science inquiry appear to have the effect of separating teachers from what might be considered as authentic scientific experience precisely because they are indicative of 'a given bank of recipes and routines, typically of an undemanding nature' (McNally 2006: 426), and thus likely to 'negate the spirit of investigative work' itself (ibid.). Ravetz (1997: 10) explains that the more intuitive and informal styles of investigation, which he sees as 'operating closer to our experienced reality [and which therefore] tend to be considered as "soft"', are 'systematically squeezed out by imitations of physics'. In *CfE*, this vista of reduction may be apparent in the movement away from initial explorations of "what happens if...?" and "how could I...?" questions', and the move towards young people taking part in:

a range of scientific investigations and inquiries which develop their understanding of the underlying scientific concepts appropriate for third and fourth levels. They will take a more quantitative and formalised approach to investigations and inquiries. As learners plan and design their investigations, they identify a number of key questions, formulating hypotheses and predictions based on observation or their knowledge (The Scottish Government 2009b: 4);

For example, investigations and inquiries will become more evaluative, deal with an increasing range and complexity of variables, and involve collecting and analysing increasingly complex information (The Scottish Government 2009b: 5).

Here the homogenizing tendencies of the focus on the 'more quantitative and formalised', on 'plan and design', on 'formulating hypotheses', on the 'evaluative', and on the 'range and complexity of variables' betrays something of a tyranny of transparency (Strathern 2000); or indeed 'the tyranny of the right answer' over the human desire to 'stop and explore':

We know this is where 'we' [the class] are heading, but you might get there by a very different route. Quite often it is the case that this is where 'we' are going, this is the right answer, and you ignore all the other perhaps more interesting stuff to get there, so [it would be important] to have the confidence to go down the by-ways [of investigation, knowing] you can still get back to where you are heading.

The destination of a *Curriculum for Excellence* however appears to be away from 'creating an atmosphere in the classroom where curiosity is one of the great values [...] it's not really there in *Curriculum for Excellence* is it – how to be a curious citizen?' (biology education lecturer, S-TEAM workshop). Away, that is, from pedagogies that might nurture the spirit of inquiry by cultivating 'a classroom environment where it is intellectually, socially and academically rewarding for students to pose thoughtful questions' (Chin & Osborne 2008: 35) – a vision of science teaching as a process of enquiry into inquiry, to misquote Shwab (in ibid.) – and towards instead 'old formal qualification structures' (science education

researcher, S-TEAM workshop), which depend more on the ‘default pedagogy of most science classrooms across the globe [...this being] one of transmission’ (Chin & Osborne 2008: 35). And with ‘no easy way to move from one to the other [...] a lot of teachers are disillusioned [...] because they see their work [in stimulating inquiry] as being wasted once the kids get to that [assessment] stage and they [the teachers] have to go back to a more conventional way of doing things just to get through the exams and then get them to the next stage [of moving] into university’.

4.4 Determining the benefits of investigative activity

There is, it was said, a ‘general question about what it is that we are improving by introducing inquiry, or bringing back inquiry, or stimulating inquiry’. The current fashion amongst policymakers for science for citizenship (Jenkins 2009) has been derided as being ‘fit for the pub’ (Jenkins 2009: 77), with classroom discussion of ‘scientific “issues”’ being regarded as no ‘substitute for undertaking real science in laboratory conditions’ (ibid.). Yet it is the apparent reassertion in *CfE* of a discourse of economic determinism, of those science teaching practices that are amenable to ‘reporting attainments to the pupils themselves, to their parents, to those who may teach them subsequently and to potential employers and, in aggregated form, to policy makers and the general public’ (Black 1995: 466), that now threatens to hinder investigative pedagogy. Taking Ravetz (1997: 13) at his word, this may indeed show that the closer one approaches to policy issues, ‘the more that the physical science recedes into the framing of the problem, and the more that issues of policy, equity and lifestyle obtrude’. The problem for the S-TEAM project may be in framing the benefits of investigative science, when:

You can’t measure it through exam results; that’s not really been seen to work in the past. So what is it that we are actually improving? Is it kids’ engagement with science? Is it kids’ perceptions of science, or their conceptual understanding of things in science, or might it be that we are improving their ability to take exams? We don’t really know, but we’ve got to find some indicator of progress. Is it the school ethos that is being improved, is it a better kind of learning culture that is being encouraged? How can we measure that? Is it kids’ own attitudes to learning? What is it that inquiry does that is good and how can we indicate that? I don’t like to use the word ‘measure’ because then that starts making it quantitative, but at some point we will have to ... we will have to describe it better.

Ironically, it is for precisely the reasons of this debate that the head teachers’ union, School Leaders Scotland, has criticised *CfE* as being ‘unworkable in secondary schools’ (BBC 2009), citing, on the one hand, the curriculum’s failure to reduce the time spent on assessment, and, on the other, the impossibility of measuring its key objectives of citizenship, pupil confidence and pupil contribution. The depth of such contestation among those for whom science education is important is suggested by Fensham (2009: 1079), who explains that political, economic and subject maintenance demands tend to govern the detail of a curriculum’s content and assessment, while cultural, social and individual demands are ‘often given prominence in the preambles to a curriculum as some sort of consolation prize’. The science education research

community, he cautions, ‘puts a great deal of effort into studies that relate to the lower three demands’ (ibid.).

4.5 The legitimacy of knowledge

What then can be determined about the benefits or purpose of advocating investigative science in the classroom if, as seems to be the case, a discourse of economism holds the upper ground in a *Curriculum for Excellence*? In the experience of a physics education lecturer at the workshop, many schools retain traditional teaching practices into which with only an occasional ‘fun [...] CfE lesson’ is introduced. Moreover, this delegate suggested that ‘having some sort of evidence base in order to use as an idea by which we can convince others [...] has never been a great success [previously]’; he noted that it was the reporting of good practice from local authorities or from HMIe, or examples of factors common to high performing schools that tended instead to be most influential. The difficulty of conveying the purpose of inquiry to student teachers was recollected: ‘they had enough to think about [...] they were just keeping them [the pupils] busy, getting through the work’. Examinations of course may be a ‘barrier to investigative learning’, because of the difficulty of persuading those who would listen of the ability of investigative learning to deliver ‘specific learning outcomes’. Indeed, practises that involve transmitting large amounts of scientific information to memory or conducting prescribed laboratory experiments were first ‘handed down from major universities to high school science programs in the 1920s and 1930s because these universities claimed that high schools were not adequately preparing students to pursue university studies’ (Abd-El-Khalick 2004: 416); students who do go on to pursue scientific careers and thus ‘engage in authentic scientific inquiry, have [therefore] usually amassed an extensive and specialized knowledge base, and mastered a set of articulated manipulative, cognitive, and metacognitive skills. Is it then safe to assume that such knowledge and skills are not relevant to doing authentic science? Probably not’ (ibid.).

The motivation for adopting investigative practices might then become a test of the legitimacy of where such knowledge comes from:

One of the issues I have with the students that have just started this year is that they have been really good learners, they have been really good in [their own] schools and they have learned that learning outcomes are important, that learning little atomised facts are important, that utilitarian learning is what’s got them to university in the first place, and that’s an important thing for them. And when they go into their practice [they see] that little atomised facts of learning are going to be what they are going to build their career on, and they perhaps don’t see investigative learning as being able to deliver that – they don’t have confidence in the [investigative] method to deliver that type of learning outcome.

I certainly think that there is a need for some sort of evidence that [this type of learning outcome] can take place, that it is successful and the evidence doesn’t need to be academic; and in fact you could maybe argue that academic evidence wouldn’t make that much impact in teachers’ practice, that it needs

to be anecdotal to an extent, or from their peers, or from people they are working with, [evidence] that it actually is worth doing and it can deliver.

5 Conclusion: Issues and Implications for the S-TEAM Project

This report began with the concern to identify areas of opportunity for and constraint in promoting inquiry in the pedagogies of beginning science teachers. It concludes now by asking what is required of ‘introducing inquiry or bringing back enquiry or stimulating enquiry’, if it is the case that one cannot easily ‘measure it through exam results, because that’s not really been seen to work in the past, so it is probably not going to work now’.

5.1 Promoting inquiry in teaching

We are informed of course by evidence that some teachers presently conduct investigative pedagogy in the science classroom, and it would indeed impoverish the stated aims of the project to overlook existing good practice: to fail to work with experienced teachers in order to take lessons back from them to beginners, or to fail to engage with existing means of promoting innovative practice. We know such practice exists from the discussion at the workshop; from *Science: A portrait of current practice* by HMIe (2008); and from the initial data gathering of S-TEAM itself, in for example the critical evaluation of investigative activity that PGDE science students were asked to complete for their professional portfolios:

Unfortunately this investigation was in the prescribed curriculum and was not triggered from the pupils, however during the investigation pupils did ask questions like: ‘what would happen if the length of the pendulum string is changed?’ and ‘will height of swing affect the time for the swing?’ Pupils then investigated these factors in their groups. This was a great opportunity to take the investigation away from the prescribed investigation.

Although this investigation was relevant to the energy topic and a great addition to the normal science lessons, it does not seem to be a good example of an investigation in ‘real-life contexts’. It does however have appropriate emphasis on planning, collecting evidence, observing and measuring, recording and presenting, and interpreting and evaluating.

While this beginning teacher might critique the relevance of the investigation to ‘real-life contexts’, the fact that it could engage with questions raised by the pupils (while still showing evidence of scientific thinking in the planning, collecting, observing, measuring, and so on, of data) could make it a good example of the ‘real-life context’ of the classroom. What made this investigation a ‘great addition’ to the lesson? We might speculate, from many responses to the PGDE student survey, that it could have been due at least in part to the atmosphere generated in the classroom – ‘excitement, loud, buzzing’; ‘created an AAAH! moment’; ‘[pupils] enjoyed the challenge’; ‘Lively! V. noisy lesson but students worked well & next few lessons benefited from them having done the investigation themselves’ – as well perhaps as its ability to provide, within the prescribed curriculum, an opportunity in which an investigation did support the development of scientific thinking.

Teachers are more likely to be enthused by and so adopt practices that they see other teachers having success with, or by developing practices to solve problems they have

themselves identified. This may compel the project to interact with and through practitioners in order to demonstrate the ‘added value’ in the advanced methods that it seeks to promote; in for example, aspects of scientific thinking not supported by common teaching practices, in connecting with the work of professional scientists, in advancing more authentic activities, in exemplifying scientific thinking more clearly as a metacognitive goal for pupils so as to demonstrate that while ‘At the time [...] the classroom investigation may have] seemed noisy and pupils didn’t get much out of it [...] The next day the pupils performed very well!’

5.2 Purpose specific indicators of inquiry and reflection

This report has asked, on a number of occasions,

what is it that we are actually improving? Is it kids’ engagement with science, is it kids’ perceptions of science or their conceptual understanding of things in science, or might it be that we are improving their ability to take exams? [...] is it the school ethos that is being improved, is it a better kind of learning culture that is being encouraged [and] how can we measure that? Is it kids’ own attitudes to learning – what is it that inquiry does that is good and how can we indicate that?

There was concern among participants at the workshop – particularly among the practitioners –that it was not yet clear how assessment policy will develop in relation to inquiry (despite the position of the latter in the literature for the *Curriculum for Excellence*), or if HMIe will encourage investigations with much vigour if schools are continuing to get exam success with more traditional or direct teaching methods. That is to say, there was the concern that should CfE ‘crystallise’ into typical assessment styles, teaching will become guided by this; if assessment can be achieved without genuine investigative activity, then it is unlikely to be developed in the face of the relative certainty (for teachers) of traditional methods.

It is perhaps to the credit of HMIe that they recommended that S-TEAM avoids attempting to measure pupil achievement or exam outcomes, and thinks instead ‘about teacher attitudes and how we could measure those: is teacher confidence in doing inquiry based work improving; has it improved as a result of CPD, or ITE?; were gains of some kind made?’ This will require to be released into being softer phenomena (e.g. teacher confidence, classroom atmosphere, scientific literacy) that may prove harder to measure. In thus designing indicators of progress, S-TEAM should avoid the large-scale, context-independent measurement of outcomes in science, which would likely require to be developed quantitative instruments, crystallising around the experimental method, with statistical power enough to discern the effects of an intervention by S-TEAM.

The efficacy of investigative activity, we might speculate, is unlikely to be any more amenable to description by ‘predictive theory, universals, and scientism’ (Flyvberg 2006: 224), than it is by exam results; and nor indeed should S-TEAM simply develop indicators whose foci are directed chiefly or implicitly towards internal and/or research evaluation and measurement. If the project is to compete with the concerns about assessment that are expressed above, then its indicators would do well to

contribute to the learning of (new) teachers (differentiated at the level of context and practice) through a capacity for the self-evaluation of the use of innovative methods by the individual practitioner in the classroom; that is to say, the proposed indicators might function also as formative instruments for teachers' own professional development. This would be to take advantage of the fact that new teachers often make better sense of the language that colleagues and pupils use than they do of the official language of policy or professional standards (McNally et al. 2008). It would build also on the work of the EPL project, which found that participating teachers used results from the project's classroom environment survey to effect self-evaluation, in some cases (as in the example from the teacher that follows) changing their practice according to their pupils' responses:

[the classroom environment survey] was quite helpful because it raised a couple of points about things that they [the pupils] were doing in class and how they were kind of doing them maybe differently. We were about to start on a new course for the second years and it hadn't quite been written yet, so with that class I sat down and spoke to them and said, 'well you raised these things and I know that you don't like doing this or that'. So we spoke about things and actually discussed what they would actually like to do and kind of based the new course roughly round that, which is something that we were planning to do anyway but didn't realise that they felt that strongly about it, so it was quite good to get input from them.

The narrative data from the EPL project reveals how new teachers think about children over the first few months of teaching. There is little mention of pupils' achievement or performance in tests, but more discussion about getting to know and interacting with them in fairly fundamental and productive ways. This may provide the foundation from which S-TEAM can argue for 'concrete, context-dependent' (Flyvberg 2006: 224) knowledge exchange through the development of useable tools for teacher self-evaluation; that is, by supporting the learning of new teachers through practicable 'research-based teaching' that can uncover the 'educational quality of [innovative] classroom processes in contexts of meaningful action' (Elliot 2001: 572).

5.3 Teacher accounts and images of actual practice

One of the principal drivers of S-TEAM is the opportunity to exchange ideas and develop a highly practical application of inquiry research in partnership with teachers. It is important that the project maintains close links with practitioners in order to be able to translate academic research for use in a much wider and more meaningful context, as well as actually record and disseminate the use of that research in and through the classroom. S-TEAM will develop methods (or conceptual frameworks) that are apposite to the problems raised by teachers in introducing more investigative approaches, as well as ways of evaluating the teaching strategies used to solve these problems.

If the project is to be successful in developing or informing innovative teaching practices, it will be important for it to recognise that teachers are not only more likely to come up with these when they have the background knowledge and conceptual

tools to do so, but also (reiterating) that teachers are more likely to adopt practices that they see (or hear) other teachers having success with, or by developing practices to solve problems they have themselves identified. In order to learn how teachers solve the problems of introducing more investigative approaches into lessons, we intend to capture, on video, examples of inquiry as it happens in the classrooms of student and practising teachers, as well as stories and reflective discussion about how it happened. Recognising that teachers learn from each other through their normal working practices (Yandell and Turvey 2007), beginning teachers might thus be availed of real life examples of pupils and teachers using investigative skills, including discussion, reflection and evaluation of those experiences, while the project too might be availed of a tangible multiplying effect of engaging with even a few teachers.

5.4 Knowledge base in science

Teachers' knowledge base was identified as being a significant means of conveying information about cutting-edge science to pupils and, by extension, the public generally, on the understanding that teachers' subject knowledge does require regeneration and reinvigoration on a constant basis. Through projects like S-TEAM, Scotland's universities would appear to be in the strong position of being able contribute meaningfully to this process. Be that as it may, as part of supporting a knowledge base for science education, academic knowledge could be made more accessible so that those teachers actively engaged in developing practice can employ it as one of the tools for solving pedagogical questions. For example, teachers do not ordinarily have access to academic literature – can S-TEAM draw attention to (or even remedy) this limitation?

The University of Strathclyde was identified, in particular, as carrying out pioneering work in science and engineering that could inform teachers' knowledge. Its research into sustainable energy may be an example of an area for engagement by S-TEAM:

We thought we would go round and talk to these people and get a sense of what they are doing, maybe [capture] some video clips of what they are doing, and make that available. This is, allegedly, cutting edge science, and teachers are the very people to take that and translate it into a language and form that children could understand [...] a lot of this sort of thing is about alternative energy which is not necessarily high technology, a lot of it is intermediate technology [...] Short of making people [that is, beginning teachers] scientists for a few weeks or months, which might not be a good thing anyway, they would see things through the eyes of actual working scientists [...] and maybe get some insight into the actual lived experience.

While the lived experience of science was not said to be 'misrepresented' in accounts of experimental investigation, disquiet was expressed at the 'narrow' formulation of the discipline, which tends to converge around an uncritical acceptance of the primacy of hypothesis testing leading to theory generation:

I think there is a real dishonesty there. That's not how science always operates and it's not how scientists work all the time. In fact they almost never work

like that. I'd like us to have a broad view of how to do investigative work, I'd like us to acknowledge that science is often very haphazard and there is a lot of chance there, and [...] having a wee carry on in your classroom can be just as valuable as structuring things with hypotheses.

An alternative view was expressed, however:

We may be underplaying the focus on hypotheses, the observing part, the categorising parts, and the paths of recognition parts, which are just as important and we also maybe don't focus on the theory building aspects as well of science. It's a tricky situation, how you get kids to build theories, whether you want them to go with their own theories, or to match up with the theories that are already in science. But that is part of the process as well, and of course once you have other theories, that feeds back into the process of doing science as well. Hypotheses don't come from anywhere necessarily, they come from theory.

A challenge for S-TEAM may be in admitting both of these views. Jenkins (2009: 79) suggests as much in acknowledging that the outcomes of inquiry-based teaching remain unclear partly because they 'are often confused and embrace the affective as well as the cognitive'. On the one hand, inquiry led science can be undertaken without the need for hypothesis testing, generated at its most ideal by a question from a pupil, and followed through by drawing on the teacher's confidence and knowledge base for the purpose simply of 'see[ing] what happens'. On the other hand, earlier research (McNally 2006) suggests that this move may depend on such components of confidence as invoke knowledge of the subject and curriculum, knowledge of the class, and knowledge of equipment. The first of these, especially when allied to notions of conveying information about cutting-edge science and the actual work of research scientists, may yet require some knowledge of hypothetico-deduction. It is in order to encapsulate these diverse requirements, that S-TEAM proposes a typology (at this stage preliminary) of investigative knowledge and experience, upon which the project's activities might draw, and which will be comprised of the following levels of scientific perspective:

- The socio-historical nature of science.
- Contemporary research activity in science.
- Initial teacher education in science.
- Experienced teaching of science.
- Beginning teaching of science.
- The child's classroom experience of science.

5.5 Existing examples of inquiry and resources

This report, we suggested in the introduction, may represent an important step for S-TEAM towards a clearer view of innovative teaching and learning in science. A rudimentary online search reveals however that this is an endeavour upon which others too have embarked, though without the crucial focus on beginning teachers and their everyday practice. Given that the objective of S-TEAM is the practical application of inquiry research, these are sources which the project will pursue,

interrogate and engage with in the months ahead. For the moment, the list of resources and initiatives that follows is restricted to those which were mentioned in discussion at the workshop; to go further at this stage would take the might of Amtrak; we are possibly more akin to Flying Scotsmen.

Projects

Dundee University - Rich Tasks for Teaching and Learning Science

Curriculum for Excellence is soon to be ‘rolled out’ in Scotland. It has identified four capacities: pupils to become successful learners, confident individuals, responsible citizens and effective contributors. It is hoped that the environment in which pupils learn, their choice of learning and teaching approaches, and how their learning is organised will help them develop these four capacities. For many teachers *CfE* is going to bring with it various challenges. This project is timely in that it will provide teacher professional development to help teachers meet some of these challenges in a creative and innovative way through the use of rich tasks.

<http://www.azteachscience.co.uk/projects/dundee-university-rich-tasks-for-teaching-and-learning-science-innovative-project.aspx#overview>

Harvard University - Visible Thinking

Visible Thinking is a flexible and systematic research-based approach to integrating the development of students' thinking with content learning across subject matters. An extensive and adaptable collection of practices, Visible Thinking has a double goal: on the one hand, to cultivate students' thinking skills and dispositions, and, on the other, to deepen content learning. By thinking dispositions, we mean curiosity, concern for truth and understanding, a creative mindset, not just being skilled but also alert to thinking and learning opportunities and eager to take them.

http://pzweb.harvard.edu/vt/VisibleThinking_html_files/VisibleThinking1.html

Concept Cartoons

Concept cartoons are a new approach to teaching, learning and assessment in science. They were created by Brenda Keogh and Stuart Naylor in 1991 and feature cartoon-style drawings showing different characters arguing about an everyday situation. They are designed to intrigue, to provoke discussion and to stimulate scientific thinking and may not have a single ‘right answer’. They are available with background science notes for teachers. A typical Concept Cartoon has the following features:

- visual representation of scientific ideas
- minimal text, in dialogue form
- alternative viewpoints on the situation
- scientific ideas are applied in everyday situations
- the scientifically acceptable viewpoint is included in the alternatives
- the alternatives are given equal status

http://www.conceptcartoons.com/index_flash.html

Websites

Fizzics with Mr. Mackenzie, <http://mrmackenzie.co.uk/>

‘The Journey to Excellence is a professional development resource in five parts. It describes how early years centres, schools and services for children and young people can enable all learners to learn and achieve. The first four parts are print publications: Aiming for Excellence, Exploring Excellence, How good is our school?/The Child at the Centre and Planning for Excellence. The website is part 5 of The Journey to Excellence. It presents videos of excellent practice from across Scotland and a range of other resources for use in reflection, discussion and planning for transformational change.’ <http://www.ltscotland.org.uk/journeytoexcellence/index.asp>

AstraZeneca Science Teaching Trust, ‘this site reports on exciting developments, provides excellent resources for Continuing Professional Development and offers a growing range of teaching and learning resources’. <http://www.azteachscience.co.uk/>

Science Centres

Dynamic Earth, Edinburgh: <http://www.dynamicearth.co.uk/>

Glasgow Science Centre, Glasgow: <http://www.glasgowsciencecentre.org/>

Stratosphere, Aberdeen: <http://www.satrosphere.net/>

Sensation, Dundee: <http://www.sensation.org.uk/>

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Appendices

1. Extracts from *CfE: Sciences, Principles and Practice*

Purposes in learning science

- develop a curiosity and understanding of their environment and their place in the living, material and physical world
- demonstrate a secure knowledge and understanding of the big ideas and concepts of the sciences
- develop skills for learning, life and work
- develop skills of scientific inquiry and investigation using practical techniques
- develop skills in the accurate use of scientific language, formulae and equations
- recognise the role of creativity and inventiveness in the development of the sciences
- apply safety measures and take necessary actions to control risk and hazards
- recognise the impact the sciences make on their lives, the lives of others, the environment and on society
- develop an understanding of the Earth's resources and the need for responsible use of them
- express opinions and make decisions on social, moral, ethical, economic and environmental issues based upon sound understanding
- develop as scientifically literate citizens with a lifelong interest in the sciences
- establish the foundation for more advanced learning and, for some, future careers in the sciences and the technologies.

What young people will do

- ask questions or hypothesise
- plan and design procedures and experiments
- select appropriate samples, equipment and other resources
- carry out experiments
- use practical analytical techniques
- observe, collect, measure and record evidence, taking account of safety and controlling risk and hazards
- present, analyse and interpret data to draw conclusions
- review and evaluate results to identify limitations and improvements
- present and report on findings.

Scientific analytical thinking skills

- being open to new ideas and linking and applying learning
- thinking creatively and critically
- developing skills of reasoning to provide explanations and evaluations supported by evidence or justifications
- making predictions, generalisations and deductions
- drawing conclusions based on reliable scientific evidence.

Developing scientific literacy

- developing scientific values and respect for living things and the environment
- assessing risk and benefit of science applications
- making informed personal decisions and choices
- expressing opinions and showing respect for others' views
- developing informed social, moral and ethical views of scientific, economic and environmental issues
- developing self-awareness through reflecting on the impact, significance and cultural importance of science and its applications to society
- demonstrating honesty in collecting and presenting scientific information/data and showing respect for evidence
- being able to read and understand essential points from sources of information including media reports
- discussing and debating scientific ideas and issues
- reflecting critically on information included or omitted from sources/reports including consideration of limitations of data.

What are broad features of assessment in sciences?

Assessment in the sciences will focus on children and young people's knowledge and understanding of key scientific concepts in the living, material and physical world, inquiry and investigative skills, scientific analytical and thinking skills, scientific literacy and general attributes. Teachers can gather evidence of progress as part of day-to-day learning, and specific assessment tasks will also be important in assessing progress at key points of learning.

From the early years through to the senior stages, children and young people will demonstrate progress through their skills in planning and carrying out practical investigations, inquiries and challenges, working individually and collaboratively, and describing and explaining their understanding of scientific ideas and concepts. They will also demonstrate evidence of progress through their abilities and skills in reasoning, presenting and evaluating their findings through debate and discussion, expressing informed opinions and making decisions on social, moral, ethical, economic and environmental issues.

Approaches to assessment should identify the extent to which children and young people can apply these skills in their learning and their daily lives and in preparing for the world of work. For example:

- How well do they contribute to investigations and experiments?
- Are they developing the capacity to engage with and complete tasks and assignments?
- To what extent do they recognise the impact the sciences make on their lives, on the lives of others, on the environment and on society?

Progression in knowledge and understanding can be demonstrated, for example, through children and young people:

- providing more detailed descriptions and explanations of increasingly complex scientific contexts and concepts

- using a wider range of scientific language, formulae and equations
- presenting, analysing and interpreting more complex evidence to draw conclusions and make sense of scientific ideas.

They will demonstrate their progress through investigations, inquiries and challenges, and through how well they apply scientific skills in increasingly complex learning situations. For example, investigations and inquiries will become more evaluative, deal with an increasing range and complexity of variables, and involve collecting and analysing increasingly complex information.

Through developing these skills, children and young people will demonstrate growing confidence and enjoyment of the sciences. Assessment should also link with other areas of the curriculum, within and outside the classroom, to allow children and young people to demonstrate their increasing awareness of the impact of scientific developments on their own health and wellbeing, society and the environment.

<http://cfe.wikispaces.com/Science>

2. Extracts from *CfE: Sciences, Experiences and Outcomes*

Planet Earth					
	Early	First	Second	Third	Fourth
<p>Biodiversity and interdependence</p> <p>Learners explore the rich and changing diversity of living things and develop their understanding of how organisms are interrelated at local and global levels. By exploring interactions and energy flow between plants and animals (including humans) learners develop their understanding of how species depend on one another and on the environment for survival. Learners investigate the factors affecting plant growth and develop their understanding of the positive and negative impact of the human population on the environment.</p>	<p>I have observed living things in the environment over time and am becoming aware of how they depend on each other.</p> <p>SCN 0-01a</p>	<p>I can distinguish between living and non living things. I can sort living things into groups and explain my decisions.</p> <p>SCN 1-01a</p>	<p>I can identify and classify examples of living things, past and present, to help me appreciate their diversity. I can relate physical and behavioural characteristics to their survival or extinction.</p> <p>SCN 2-01a</p>	<p>I can sample and identify living things from different habitats to compare their biodiversity and can suggest reasons for their distribution.</p> <p>SCN 3-01a</p>	<p>I understand how animal and plant species depend on each other and how living things are adapted for survival. I can predict the impact of population growth and natural hazards on biodiversity.</p> <p>SCN 4-01a</p>
			<p>I can explore examples of food chains and show an appreciation of how animals and plants depend on each other for food.</p> <p>SCN 1-02a</p>	<p>I can use my knowledge of the interactions and energy flow between plants and animals in ecosystems, food chains and webs. I have contributed to the design or conservation of a wildlife area.</p> <p>SCN 2-02a</p> <p>Through carrying out practical activities and investigations, I can show how plants have benefited society.</p> <p>SCN 2-02b</p>	<p>I have collaborated on investigations into the process of photosynthesis and I can demonstrate my understanding of why plants are vital to sustaining life on Earth.</p> <p>SCN 3-02a</p>

Planet Earth (continued)

	Early	First	Second	Third	Fourth
<p>Energy sources and sustainability</p> <p>Learners explore types, sources and uses of energy and develop their understanding of how energy is transferred and conserved. They consider the relevance of these concepts to everyday life. They explore the nature and sustainability of energy sources and discuss benefits and assess possible risks to form an informed view of responsible energy use.</p>	<p>I have experienced, used and described a wide range of toys and common appliances. I can say 'what makes it go' and say what they do when they work.</p> <p>SCN 0-04a</p>	<p>I am aware of different types of energy around me and can show their importance to everyday life and my survival.</p> <p>SCN 1-04a</p>	<p>By considering examples where energy is conserved, I can identify the energy source, how it is transferred and ways of reducing wasted energy.</p> <p>SCN 2-04a</p> <p>Through exploring nonrenewable energy sources, I can describe how they are used in Scotland today and express an informed view on the implications for their future use.</p> <p>SCN 2-04b</p>	<p>I can use my knowledge of the different ways in which heat is transferred between hot and cold objects and the thermal conductivity of materials to improve energy efficiency in buildings or other systems.</p> <p>SCN 3-04a</p> <p>By investigating renewable energy sources and taking part in practical activities to harness them, I can discuss their benefits and potential problems.</p> <p>SCN 3-04b</p>	<p>By contributing to an investigation on different ways of meeting society's energy needs, I can express an informed view on the risks and benefits of different energy sources, including those produced from plants.</p> <p>SCN 4-04a</p> <p>Through investigation, I can explain the formation and use of fossil fuels and contribute to discussions on the responsible use and conservation of finite resources.</p> <p>SCN 4-04b</p>
			<p>I can investigate the use and development of renewable and sustainable energy to gain an awareness of their growing importance in Scotland or beyond.</p> <p>TCH 2-02b</p>		

Forces, electricity and waves					
	Early	First	Second	Third	Fourth
<p>Forces</p> <p>Learners first develop an understanding of how forces can change the shape or motion of an object, considering both forces in contact with objects and those which act over a distance. They investigate the effects of friction on motion and explore ways of improving efficiency in moving objects and systems. Study of speed and acceleration of an object leads to an understanding of the relationship between its motion and the forces acting on it. This is linked to transport safety. Learners develop their understanding of the concept of buoyancy force and density.</p>	<p>Through everyday experiences and play with a variety of toys and other objects, I can recognise simple types of forces and describe their effects.</p> <p>SCN 0-07a</p>	<p>By investigating forces on toys and other objects, I can predict the effect on the shape or motion of objects.</p> <p>SCN 1-07a</p>	<p>By investigating how friction, including air resistance, affects motion, I can suggest ways to improve efficiency in moving objects.</p> <p>SCN 2-07a</p>	<p>By contributing to investigations of energy loss due to friction, I can suggest ways of improving the efficiency of moving systems.</p> <p>SCN 3-07a</p>	<p>I can use appropriate methods to measure, calculate and display graphically the speed of an object, and show how these methods can be used in a selected application.</p> <p>SCN 4-07a</p> <p>By making accurate measurements of speed and acceleration, I can relate the motion of an object to the forces acting on it and apply this knowledge to transport safety.</p> <p>SCN 4-07b</p>
	<p>By exploring the forces exerted by magnets on other magnets and magnetic materials, I can contribute to the design of a game.</p> <p>SCN 1-08a</p>	<p>I have collaborated in investigations to compare magnetic, electrostatic and gravitational forces and have explored their practical applications.</p> <p>SCN 2-08a</p>	<p>I have collaborated in investigations into the effects of gravity on objects and I can predict what might happen to their weight in different situations on Earth and in space.</p> <p>SCN 3-08a</p>	<p>I can help to design and carry out investigations into the strength of magnets and electromagnets. From investigations, I can compare the properties, uses and commercial applications of electromagnets and supermagnets.</p> <p>SCN 4-08a</p>	

<https://is-ewdssps.ces.strath.ac.uk/cfe/CfE%20Science%20Experiences%20and%20outcomes/Forms/AllItems.aspx>

3. Aspects of Scientific Thinking

Scientific thinking/scientific mind (Adapted from Feist 2006)		Curriculum for Excellence: Sciences, 'Principles and Practice' and 'Experience and Outcomes'		
Attribute/skill	What it involves	Explicitly identified?	Implicitly identified?	Notes and related capacity/ies (if any)
<i>Observation</i>	Using all sensory modalities – hearing, tasting, feeling, smelling and seeing- to input information	Yes, although not in terms of all senses	Although the components of this group are identified individually and explicitly in the 'Experiences and Outcomes' document, it is less clear that they are conceived as developing into the more complex and dynamic interrelationships of science (see next column) However, Principles and Practice document hints more strongly at this.	It is argued that these five attributes or skills recapitulate human development – babies start with observations, then categorisation and so on. Language development also dramatically adds to the preverbal forms. However, once all are in place they have dynamic relationships with each other – observation is affected by causal thinking and so on. In science, so the implication appears, they have become particularly well developed and integrated with some of the other features below.
<i>Categorisation</i>	Classifying information from observations into meaningful systems	Yes		
<i>Pattern recognition</i>	Seeing patterns of relationships between different things and events the classified information refers to (E.g. Thing A is always found with Thing B. Event Y always follows Event X)	Yes		
<i>Hypothesis formation and testing. As develops in scientists, becomes an ability to systematically test hypotheses.</i>	Arises initially from pattern recognition. Begin to expect world to behave in certain ways and test these expectations	Yes, although not clear if more systematic testing of a series of hypotheses specified. However, this is likely to occur in more extended investigations	Is this an issue of simple versus advanced investigations, the latter being more grounded in scientific theory and the former more in everyday concerns? If so, which is appropriate to our aims? Age group differences?	
<i>Cause and effect thinking</i>	Arises initially out of pattern recognition and/or hypothesis verification. (e.g. recognition of pattern that Y follows X or verification of this as a hypothesis leads one to think about causes). More sophisticated when one realises that co-variation is necessary, but not sufficient, for causality.	Yes		Therefore, as they are such a fundamental part of human thinking, they can probably be argued to contribute to all four capacities.

Scientific thinking/scientific mind (Feist 2006)		Curriculum for Excellence: Sciences, 'Principles and Practice' and 'Experience and Outcomes'		
Attribute/skill	What it involves	Explicitly identified?	Implicitly identified?	Notes and related capacity/ies (if any)
<p><i>Ability to separate and co-ordinate theory and evidence.</i></p> <p><i>Not ignoring/recognising the importance of disconfirmatory evidence.</i></p> <p><i>Realising one's thinking may be wrong and in need of revision.</i></p>	<p>I have put these together as they seem related. In relation to these, Feist discusses avoiding confirmation bias, not ignoring disconfirmatory evidence outright, and avoiding distorted interpretations of evidence to fit preconceptions. We might want to add distinguishing examples from principles.</p>	<p>No, unless we take 'openness' (Principles and Practice) equate to at least, some of this.</p>	<p>Yes, but only for those whose conceptions of investigations and science teaching generally, incorporates them already</p>	<p>All capacities</p>
<p><i>Visualisation</i></p>	<p>Feist identifies thought experiments, models and diagrams. I wonder if he has overlooked graphs, charts and tables. This table, for example, is an attempt in visualising a relationship.</p>	<p>Yes for diagrams, charts. Less clear on other features</p>		<p>Not sure. Indirectly to all through its part in scientific thinking?</p>
<p><i>Making the implicit explicit in one's thinking.</i></p> <p><i>Developing control of thinking and representations - metacognition.</i></p>	<p>Again these seem related. In Feist's scheme, implicit is more sensory bound thought. By making these implicit representations explicit by redescribing them, they become available for thought and modification. This is part of metacognition, along with becoming aware of and directing one's thought processes.</p>	<p>Not in this form</p>	<p>Yes, page 4 Principles and Practice</p>	<p>All capacities, since part of all thought?</p>
<p><i>Ability to use metaphor and analogy</i></p>	<p>Analogy – seeing how something (target) is like something old (source). Metaphor – an 'as if' comparison. Think about X as if it was Y. Both useful in hypothesis and theory formation, thought experiments, creativity and problem solving. Provide useful constraints to solutions to problems by focussing strategies</p>	<p>No</p>	<p>Yes, but only so far as the scientific theories/explanations the young people are aiming to master are based on metaphor and analogy.</p>	<p>Do we expect young people to develop their own analogies and metaphors in their investigations or adopt those already used by scientists?</p> <p>All capacities, since part of all thought?</p>
<p><i>Use 'confirm early-disconfirm late' heuristic</i></p>	<p>Apparently many successful scientists when formulating theory look for confirming evidence first (makes it a 'goer'), then seek to find evidence and arguments against it.</p>	<p>No</p>	<p>No</p>	<p>Not sure. Indirectly to all through its part in scientific thinking?</p>
<p><i>Collaborative (distributed reasoning)</i></p>	<p>Based on long-term analysis of weekly lab meetings (Dunbar). Apparently, an important process is the sharing of reasoning and ideas that goes on in the more informal settings (behind the scenes in hallways, etc.) and is the result of input from, many people.</p>	<p>No</p>	<p>No</p>	<p>Can we hope that young people discuss their investigations informally in the playground, etc?</p> <p>All capacities, but particularly effective contributors?</p>

4. Questionnaire on Investigative Science in your Placement School

PGDE/Joint honours _____ Specialist Subject _____

The following four questions are about your early impressions of investigative work in your placement school (please interpret the term 'investigative' broadly).

1. Describe an example of investigative science that you observed or took part in.
2. Describe the atmosphere in the classroom during the investigation (for example, what do you think the pupils got out of it?).
3. Describe an opportunity that was missed, but in which you could have supported investigative work.
4. Based on what you've seen, what are the main constraints on or opportunities for introducing investigation into a lesson?

If you are willing to take part in a brief research interview about your experiences, please provide your name and email address: _____
or contact Allan at a.blake@strath.ac.uk (all information will be kept strictly anonymous).

Thank-you for taking the time to answer these questions. If you have any additional comments please enter them overleaf.

5. PGDES Critical Evaluation of Investigative Activity in Science

As well as forming part of your professional portfolio, the following task will contribute to the research of the S-TEAM project.

In *A Curriculum for Excellence: Sciences Experiences and Outcomes*, it is explained that learning in the sciences will ‘develop the skills of scientific inquiry and investigation using practical techniques’ (p1). For example, in the section on Planet Earth: Biodiversity and interdependence, it is suggested that ‘through carrying out practical activities and investigations, I [that is, a pupil] can show how plants have benefited society’ (p2).

And in its report *Science: A portrait of current practice* (2008), HMIe advises that children and young people need to develop ‘practical investigation and inquiry skills within a range of relevant and real-life contexts with an appropriate emphasis on planning, collecting evidence, observing and measuring, recording and presenting, and interpreting and evaluating’ (p9), and be able to ‘apply their learning in hands-on practical activities, [...] to develop their awareness of the impact of science on their own lives and society at local, national and global levels (p25).

With these aspirations in mind, give a brief account and evaluation (around 200 words say) of an investigative activity in science that you witnessed or experienced directly during your school experience; you might, alternatively, give an account and evaluation of an opportunity that you *might* have taken to carry out an investigative activity.

(We are particularly interested in examples of investigative work that are less associated with more routine practical work, such as measurement, specific techniques, or standard experiments in a prescribed curriculum, though they may arise from such tasks – and especially interested in investigations that are the result of a question asked by a pupil, or those which incorporate a degree of open-endedness or an uncertainty of outcome, even if only for the pupil).

In addition to filing your evaluation as part of your professional portfolio, please email a copy to Allan Blake of the S-TEAM project: a.blake@strath.ac.uk. For the purpose of the S-TEAM research, everything that you write will be treated in confidence. Every person and every place will be made anonymous in discussion and publication.

Many thanks for your most valuable contribution.

6. PGDES Critical Evaluation of Investigative Activity in Science, an example

S-TEAM Project/PGDES Professional Portfolio Task:

A Critical Evaluation of Investigative Activity in Science

The following account arose from an end-of-lesson plenary discussing a standard S1 investigation into the conversion of E_P to E_K using a ramp and small plastic 'sledge'. *(The sledge is allowed to slide down the ramp from various heights (E_P) and the distance travelled is used to give an indicator of E_K .)*

The pupils seemed to enjoy watching the sledge slide down the ramp onto the workbench (and occasionally onto the floor). They were enthusiastic when carrying out the practical and were keen to take more results than required! This interest and enthusiasm made them eager to take the investigation further.

During the plenary, one pupil asked, **“What would happen if the sledge had wheels?”**. This question was opened up to the class and the pupils were given a chance to talk it over. Most were able to predict that, if the sledge had wheels, it would have more E_K as there would be less friction acting on the sledge's surface and slowing it down.

After discussing friction, the next question was, **“What would happen if we put butter all over the ramp?”**. As before, the class predicted that the sledge would have more E_K as the butter on the ramp's surface would reduce friction and allow the sledge to travel faster.

Unfortunately, we could not carry out either of these extensions to the investigation as we ran out of time. We also had no wheels. And no butter.