ITE Guideline for Teacher Educators in Inquiry-based Science Teaching

Introduction

This paper is a first draft of a Guide for Science Teacher Educators in Initial Teacher Education. It lays down a set of arguments in support of Inquiry-based Science Teaching as sections to be further developed. It also includes a number of references, apposite quotes and exploratory small scale research. The intention is that the paper will be used as a basis for the development of a website that will have links to:

- the sections as briefer chunks of text less than a page
- quotes from a range of sources
- video / audio clips from a range of sources
- published papers from research, policy and practice (hyperlinks)
- other useful websites

The Science Curriculum in Scotland tends to refer to investigations in Science so inquiry and investigation are used interchangeably in this paper.

1 Why is inquiry-led science education important?

We can look to a number of sources to support the case for inquiry or investigation in science teaching. There is a substantial body of evidence and argument in the education literature, some of which argue that it is so fundamental that it should be at the very heart of science teaching (Woolnough 1991), that experiencing science as investigation is to understand the very nature of science (Shapiro 1996), that it meets the need to *do* science as well as to learn science and learn about science (Hodson 1993). There are also reservations about whether inquiry is justified in principle (e.g. Kirshner, Sweller and Clark 2006) but they do not tend engage with the reality of science classrooms or the successes of teachers and pupils, even in terms of inquiry-based learning. Often writers needlessly polarise positions on inquiry and fail to recognise the complexity of teaching and the fact that teachers employ a range of approaches that cover traditional transmission, resource-based learning, field work and even, ideally, inquiry in their science classrooms and other sites of learning. However, this body of literature has had little effect on advancing inquiry as a method of teaching Science. The writing of academics – and perhaps indeed the inquiry-type of activities of some teachers – has not reach as far as changing practice in schools on the whole, leaving a gap that the current project seeks to bridge.

Science itself is perhaps too often presented as inexorably sequential and rational in its generation of knowledge. There is so much knowledge that the required knowledge content of the science curriculum tends to dominate syllabus statements, textbooks and other resources that teachers tend to use. Yet there is much evidence that the development of knowledge by scientists owes a great deal to unplanned events and chance connections.

> trying to interpret the future directions of science, it helps to remember that the great discoveries are rarely the outcomes of deliberate searches for universal answers, but more often the unanticipated dividends of careful research focussed on modest, specific questions (American Physical Society)

> In 1900 Planck made the breakthrough (towards a theory of quantum mechanics), not through a cool, calm and logical scientific insight, but as an act of desperation mixing luck and insight with a fortunate misunderstanding of one of the mathematical tools he was using (Gribbin 1998: 37)

> the most exciting phrase to hear in science, the one that heralds the most discoveries, is not 'eureka!', but 'that's funny…'" (Isaac Asimov source?, science fiction writer and research chemist)

Admittedly, the scientists have a solid grasp of their discipline and bring this advanced knowledge to their inquiry but, at a more elementary level, learners in school do have knowledge in development through a planned science curriculum. Even at this level, questions arise which may be pursued from a base of knowledge and practical technique, as and when it is covered – or perhaps some time after coverage - in a particular science curriculum.

It is this openness to questions and the opportunity to pursue some of them at least that brings inquiry into science education and thus into the learning experiences of pupils – and their teachers. These activities are typically not grand designs – they need not and probably should not be – but they are the early play of an education in doing science, of doing what scientists do. The questions are likely to be modest of course but are also likely to emerge from prescribed work and be of specific interest at that time. If the questions are caught in the moment, are relevant to their work, and pupils are judged ready to follow through on the question, then there is a real chance of very 'successful learning' (one of the four capacities of the new curriculum in Scotland). Whether learners or teachers employ the conventional discourse and categorisation of scientific procedure – observation, hypothesis formation, variables, method and so on…is not important at this stage. These concepts and terminology will emerge in due course in the hands of the educated teacher of science. What is important is that the 'received' terminology of scientific method does not obstruct or impede the initial impetus of inquiry and fracture the integrity of the endeavour as a holistic experience in context. The teacher can introduce points of scientific method as and when pupils are judged ready to use and understand such language. This leads us to the question of the 'educated' teacher of science, a central purpose of the S-TEAM Project and of this guide for the start of that education.

2 Getting started

In a modest pilot study of student science teachers on school placement, we asked about their early experiences of opportunities for investigative work in the science classroom. We required only brief responses but they nevertheless give examples of what is possible, even in the early stages of their development as teachers:

> The next lesson in the series looked at the use of chromatography in the separation of different inks or dyes. A pupil asked if the ink in the felt tip pens the class were using was one ink or a mixture of different inks. This presented an opportunity to carry an experiment to determine which inks made up the colours in the class's favourite felt tip pens. The pupils were especially surprised at the presence of bright blue or yellow ink in a black felt tip pen. This final experiment really cemented the notion that a mixture is something which can be separated in pure substances. I found the use of relevant real life examples was invaluable for explaining relatively abstract concepts and cemented the pupils understanding.

> An investigative task I carried out with a first year class was an investigation into the pH of soft drinks. This was a great task which was very simple to set up and the kids really enjoyed. It was relevant to their lives and they were very keen to find out the pH of their drink of choice! This obviously tied in well to the Acids and Metals topic and got the children to use pH paper, measuring cylinders and practise recording their results……. This investigation allowed the children themselves to discover that the fizzy drinks had a high acidity and they then started asking questions such as "what does that do to your teeth?" etc which led nicely on to a lesson with photos of corroded and damaged teeth. The kids all wanted to test their own juice and left the lesson talking about how they "won't be drinking that again"…... Questions about what could be done about it led on to the pH of toothpaste which we then tested in the next lesson … The lessons were fun and easy to manage because the children were so involved.

The examples from the students suggest that getting started may be much easier than we have so far thought. We ourselves have identified components of confidence for teaching investigative science and suggested caution in its introduction (McNally 2006), but the opportunities for inquiry appear to be closer than we had realised and the possibility of actual practice much earlier in the development of new teachers. What is clear is that the standard activities within the science syllabus itself often have within them the potential for feasible inquiry and achievable success. They are there in front of you and need not take much if any extra time; indeed some prescribed activities are investigative in form or can be made so through a simple rephrasing of the aim or purpose. Examples of this need to be provided from the existing curriculum across the sciences in due course.

There were of course reports from the students in which they were unable to pursue inquiry or it was deemed unfeasible. Of the 28 students we sampled, a few reported that the required resources were not readily available or that inquiry was discouraged by colleagues because of pressure of time or examinations:

> 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.
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> Unfortunately throughout my school experience I did not witness an "investigative learning "activity. The pressure of meeting deadlines and ensuring the adequate preparation of students for upcoming exams constricted teachers from deviating from focusing upon these priorities.
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> I did notice in the learning outcomes of the S1 and S2 topics that there were investigations outlined and suggested for pupils to carry out. However, I did not see any being utilised by the teaching staff. I asked members of staff if they had or ever used the investigations and received similar responses from each of them; that due to a lack of time, they very rarely if at all, used the investigations. The teachers felt that they were generally pressed for time to complete each topic and test the students

It is often claimed that the enthusiasm and idealism of new teachers is curtailed by a prevailing culture of conservatism in schools but, though we have given the only three examples of this above (from 28), it is not clear if the remarks were particular to that activity or meant as a general point. We would not, therefore, want to invoke that rather untested assertion that teachers in school discourage students on placement, in developing our case for promoting inquiry in science classrooms. Many may well be doing investigative work without either realising it or reporting it - or they may simply think it is not worth making a fuss about it.

3 Some examples from more experienced teachers

Another point to make here is that beginning teachers probably benefit from engagement with the experiences of more experienced colleagues, directly so during placement, but also indirectly through second hand contact with their accounts. Such accounts would be of actual experiences and take a variety of forms e.g. text, audio or video. They would probably be fairly brief (perhaps five minutes maximum) and act as a basis for discussion by students. One of our STEAM colleagues (WP ref?) already has some evidence to suggest that student teachers engage well with brief video clips of teachers in action in the classroom. We acknowledge that source and would suggest from our own experience of working with beginning teachers and researching their learning experience that this approach should be pursued as an important element in the education of the nascent teacher of science. It may also be that a conceptual model of experienced teachers' thinking can also be introduced to students at this stage, one that clearly accommodates the range of actual examples given and discussed. Although some tentative progress has been made on such theorising (e.g. McNally 2006), there is still some way to go on developing an empirical basis of support for any strong theoretical claims. During 2010-2011, we shall be in contact with groups of experienced teachers and should be able to offer further ideas and evidence for this development.

4 Types of engagement

What do we know of how student teachers engage with Investigative Science? From our modest pilot study (ref ?) we have first of all learned that some of them already do or can engage. Our analysis of their brief reports suggests that their engagement may be categorised - still to further discuss and develop this as a possible typology. Initial thoughts are that how the inquiry is originated is important. We have found origins of investigative activity in:

- a prescribed curriculum topic
- close and parallel relation to or arising from the prescribed curriculum topic
- ideas that are separate from a curriculum topic

The actual initiation of the inquiry needs some human agency of course. In the case of the prescribed curriculum topic, the teacher is the main agent, drawing on the curriculum as written. The degree to which children engage with a prescribed topic is largely determined by teacher disposition. There may well be cases where little engagement takes place, despite the efforts of the curriculum writers. Then there are situations where opportunities for inquiry are recognised in the course of following the prescribed activities. This may come from the teacher or from a question by a pupil. Both are important origins and may well have different motivation and other characteristics. There is a possible argument that if a teacher sees opportunities then she is more likely to be disposed to nurturing the formation of questions by children and indeed the pursuit of them, where feasible. Investigation can therefore be teacher-led or pupil led with teacher support – and are there different levels of teacher support?

We would question, however, whether the larger scale investigations required through formal assessment schemes do in fact foster a spirit of investigation. Gott and Duggan (2002), for example, claim that the obsessive quest for reliability and consequent focus on the readily measurable has neglected the need for what counts as valid, worthwhile scientific activity in the classroom and has inhibited open-ended practical science. In arguing that doing science is an untidy, unpredictable, idiosyncratic activity that depends crucially on tacit knowledge, Hodson (1992) condemns skills-based assessment of investigative practical work as philosophically unsound (not science), educationally worthless (trivialises learning) and pedagogically dangerous (encourages bad teaching).

There is no obvious basis for categorising types of investigative activity at different levels. This would imply grades of difficulty or of sophistication or of pupil impact and so on. These are not yet clear and perhaps do not matter. Nor have we yet examined differences according to year or stage of learners (and no Primary Teachers yet), though we do have examples from S1 to S6.

5 Connections to a bigger picture

Learning Science through inquiry is vitally important but there are other ways of learning. There are times and topics when the teacher may judge that other methods are more appropriate. Inquiry-based learning as a practical 'hands-on' experience is also an essential part of developing an understanding of the nature of science, through participation in the process as well as in making meaning of 'content'. However, not all questions can be followed through in practical way in school so there should be space for pupil discussion. Indeed discussion should have a place in its own right. Perhaps because of the amount of knowledge that has accumulated in Science and the need to ensure that pupils obtain an adequate grounding in that knowledge, covering that knowledge base as curriculum content tends to dominate both curriculum and pedagogy in Science to a greater extent than other subjects and areas of the curriculum. It is argued that teachers of Science have difficulty in managing discussion in the classroom (Bryce & Gray 2004; Day 2010). Yet there are so many potential opportunities for discussion, particularly from contemporary life where there are major advances in Science and social and ethical issues that are often raised by these advances. The science underpinning these advances should be brought into the classroom by the teacher as accessible knowledge and discussion by pupils encouraged. There is much to be learned by teachers of Science from teachers of other subjects on how to manage discussion. In Initial Teacher Education, therefore, student teacher of Science need the opportunity to practise and observe classroom discussion, both on placement and within their university programme under the tutelage of university tutors who themselves may need to develop their own understanding. Current developments in co-operative learning may be a useful reference.

We might also expand this section to include reference to the development of scientific ideas as a historical perspective, the biographies of scientists and indeed the philosophy of Science. If an education in Science is to be more authentic, then we could argue that students ought to practise and promote a more authentic science through inquiry, discussion and engagement with more topical and human dimensions. This would require that they be introduced into ITE, as an introduction to the nature of science - practically through experiences and principles such as those covered above in this paper, but also theoretically and philosophically; and that this be continued into teachers' professional development post-qualification.

6 What will persuade teachers?

Perhaps the most persuasive evidence comes from teachers themselves – from their stories, observations and interactions. This paper supports and illustrates that argument and recommends that development of a pedagogy of inquiry or investigation is more likely to develop if teachers are supported in real or virtual interactions, centred on actual experiences but also incorporating an understanding of Science which shows scientists as people asking and pursuing questions in different ways.

A common reservation is that examination performance would suffer if time is given to activity which is seen as non-essential. Accounts from practising teachers who achieve both good examination results and a high level of pupil engagement in Science – enjoyment, satisfaction, further study of Science – may be important in persuading teachers that examinations and inquiry are not polar opposites but reconciliable responsibilities of teachers and elements of good teaching in Science. There is scope for the development of indicators that may be used formatively by teachers for this purpose. Within the S-TEAM Project itself (WP5), such indicators are being developed.

7 Scientists talking about their science

Some quotations from Scientists have been included in this paper. This could be further extended within a website and also include currently active scientists, using video clips of interviews. For example, a Strathclyde research scientist working on the Linking of Renewable Energy Sources into Power Networks remarked that often it was 'learning as you go … (that the work) … is a bit non-linear … (sometimes … you are just doing stuff …seeing what happens …you try something, it fails, you talk to someone else…you come across a good paper… you go back to the theory'. A project might start with saying 'let's put panels on people's roofs and see what we get … (leading to) … why don't we change the tariffs and observe results of that? …different things ideas have to be tried out … with solar panels the energy is affected by clouds, dirty rain, degradation of panel materials, wavelength of light'. The incorporation of more such examples - from actual interviews and from more readable narrative accounts by scientists or about science - not just in text, but in other media that could be linked to the website e.g. video clips, would bring the real activity of scientists closer to the discourse of teachers and pupils in schools.

8 Being realistic

There is clearly greater scope for extensive support in post-qualification CPD. Within ITE, there is an opportunity right at the start to introduce new teachers to inquiry and to at least lay the foundations for the development of good practice. However the difficulties have to be recognised. The demands from the policy makers, schools themselves and of course student teachers with immediate concerns about qualifying are all realistic and relevant. The development of the website as a universally accessible resource with links to other valuable sources would be a priority. Structured input would have to be limited and manageable, so a minimum recommendation might be a package which incorporates:

1. introductory lecture
2. practical workshop session
3. protected experience of teaching investigatively
4. small assignment requiring reflection on the experience
5. 2/3 seminars introducing perspectives on the nature of science, history of scientific ideas, biographies of scientists
6. set of required readings introducing theoretical perspectives

A final thought on the recruitment of students:

> "The disciplines of science and technology are often perceived as being difficult, and the results obtained by pupils are frequently used as selection criteria – a worrying phenomenon for both pupils and their parents. Better educational methods are necessary to overcome these obstacles and to convince them of the positive intrinsic value of science and technology, and the jobs associated with this field. **However, teachers are often recruited on the basis of their specific competence in certain subjects and not on the basis of their teaching ability." (**Sgard 2007, p.19)

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