Perspectives on Education: Inquiry-based learning

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Inquiry-based learning – what is its role in an inspiring science education?

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> ***"By doubting we come to inquiry, and through inquiry we perceive truth."***
> **Peter Abelard, 1079–1142, French theologian and philosopher**

Learning through inquiry has long been a goal of science education, with its importance articulated as early as 1910 by John Dewey.[1] In recent years, inquiry-based learning has attracted much attention and debate both in the UK and internationally, with government bodies and policies supporting its use – Ofsted, for instance, has commented on its positive effect on student enthusiasm and achievement.[2]

Despite this widespread support there is a need for more robust research and critical debate to consider what inquiry-based learning means in practice and what role it has in an inspiring science education, with many questions to address: What does the science education sector want to achieve through inquiry-based learning? What are the boundaries and limitations of inquiry? How can periods of inquiry be best supported by other pedagogies?

Now is an important time to consider these questions. The National Curriculum for England is currently under review and ministers are clear that the revised version will focus on 'what' to teach rather than 'how' to teach it.[3] Discussions about teaching and learning approaches are, therefore, needed to ensure that we retain the essence, as well as the knowledge, of science.

These issues can be successfully addressed only if stakeholders from across the education sector come together to tackle them in a comprehensive way. Accordingly, in this issue of *Perspectives on Education*, four authors explore these questions from their perspectives as a researcher, a policy maker, an international education expert and a teacher. The first perspective is provided by Jim Ryder of the University of Leeds, who argues that the greatest promise for scientific inquiry lies in supporting students' understanding of the practices of the professional scientist, and that even this educational goal cannot be fully achieved through inquiry alone. Pierre Léna then considers the common lessons that can be learned from the many international inquiry projects, highlighting that, for inquiry to be successful, teacher preparation and training is key. Sue Horner provides the perspective of a policy maker – outlining the difficulties involved in developing clear policy, typically via the National Curriculum, that can be easily interpreted and implemented by intermediaries, especially teachers and awarding bodies. Finally Neil Dixon, an experienced practising teacher, focuses on the rhetoric and reality of inquiry and the challenges to making the ideal an everyday occurrence.

Emerging issues across the four perspectives lead us to the following observations:

1) Variations in the definition of inquiry-based learning in science have compounded the difficulties of researching and even discussing it. An agreed definition should therefore be reached and consistently used, and we suggest the following:

   Inquiry-based science learning sees students learning *through* inquiry, using skills employed by scientists such as raising questions, collecting data, reasoning, reviewing evidence, drawing conclusions and discussing results. When students learn through inquiry they can develop scientific knowledge and they can also learn *about* inquiry, including the processes of science and how to construct reliable, valid and accurate investigations.[4]

   This definition requires that for science learning to be described as inquiry-based, pedagogies that allow students to learn through inquiry must always be present. Importantly, these are not limited to students doing practical work or 'investigations' but also include discussion and the use of secondary sources.

2) Despite widespread support, there is a lack of robust research evidence demonstrating the positive impacts of learning through inquiry. Further research is therefore needed. This should consider the benefits of inquiry, how to most effectively structure learning through inquiry (including combining it with other pedagogies), and how student understanding about inquiry progresses.

3) Teacher preparation is key to ensuring the successful implementation of inquiry, and must cover understanding about inquiry as well as the necessary pedagogical content knowledge to teach through inquiry. Both aspects should be taught during initial teacher training and supported through good-quality continuing professional development courses.

4) Learning through inquiry is closely linked to high-quality practical work. Science departments, therefore, need to be appropriately resourced with the necessary laboratories, consumables and staff.

5) A student's understanding about inquiry is more difficult to assess than other areas of the curriculum, due to both its practical nature and the importance of thinking and reasoning processes. More effort needs to be put into developing appropriate assessments that allow students to show their understanding of scientific inquiry and also how they are able to make such inquiries themselves.

Taking account of these observations in practice requires input and collaboration from researchers, policy makers and educational practitioners. Only through such a joint approach will we be able to successfully develop inquiry-based learning that supports an inspiring science education for all.

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Scientific inquiry: learning about it and learning through it

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Advocacy of 'scientific inquiry' is common in discussions of school science. However, the meaning of this call is clouded by two issues. First, there is often a failure to distinguish between scientific inquiry as a learning aim (what we want students to learn about scientific inquiry) and as a set of teaching/learning approaches (inquiry activities that support student learning). Second, there is often insufficient detail about what teaching/learning approaches might count as scientific inquiry and how these activities would fit within an extended teaching/learning sequence.

Scientific inquiry as a learning aim and a teaching approach

Let us first consider scientific inquiry as a learning aim. In other words: what do we want students to learn about the practices of the professional scientist? Based on the history, sociology and philosophy of science, we might want students to learn about:

- the aims of science (e.g. to develop generalisable theories that explain a wide range of natural phenomena)
- the differing ways in which scientists investigate phenomena (e.g. systematic recording of observations, experiments in controlled laboratory settings, randomised controlled studies)
- how scientists assess the quality of observations and measurements (e.g. conducting tests for repeatability)
- how scientists develop explanations of the natural world (e.g. creative use of analogies between different physical systems)
- how scientists communicate their ideas and resolve disagreements (e.g. peer review and research conference activities).

These are important learning aims for school science. Research shows that students often have very naive views about the practices of professional science.[1] For example, it is common to think of scientific theories as 'little more than guesses', reflecting the use of the term theory in everyday usage, as in 'I've got a theory it'll rain tomorrow'. Students with such a view are more likely to dismiss the theory of evolution with 'it's just a theory, scientists don't really know about how humans developed'.

However, confusingly, the term 'scientific inquiry' is also used to describe a set of teaching/learning approaches. One formulation describes scientific inquiry approaches as "observation, experimentation and the teacher-guided construction by the child of his/her own knowledge".[2] Such an approach is contrasted with 'transmissive' teaching/learning approaches in which the teacher presents science knowledge to the student. This definition incorporates a very broad range of different activities. However, the detail of 'scientific inquiry' approaches, and how these might fit within an extended teaching/learning sequence, is left unclear. Rather, scientific inquiry is often portrayed as a universal, and self-evident, teaching/learning approach.

Supporting science learning through a range of approaches

This view of a universal teaching approach does not do justice to the considerable research into students' understandings of science, and how teaching/learning can be designed to support student learning of science. This work has been conducted by researchers internationally, working in close collaboration with experienced teachers, and constitutes a significant knowledge base within science education.[3] For example, each concept area gives rise to specific misconceptions and associated 'learning demands' for students.[4] These need to be addressed through teacher-led discussions, empirical investigations and group activities. The teacher needs a range of explanations and analogies to give students insights into the world of science.[5]

Most significantly, each phase of the teaching sequence has a distinctive goal, such as drawing out student ideas, introducing the science story or consolidating learning. So, at specific points in the sequence, the teacher may legitimately take on a transmissive role, presenting ideas to the student. Indeed, in many areas of science understanding, such transmissive modes are surely inevitable. For example, it is hard to imagine how anything other than significant teacher direction and presentation will result in students learning about the Big Bang theory of the origins of the universe.

The failure to distinguish sufficiently between scientific inquiry as a learning aim and scientific inquiry as a set of teaching/learning approaches is unhelpful. It is often assumed that achieving scientific inquiry learning aims necessitates a scientific inquiry teaching/learning approach. In some cases this may well follow. For example, take the following learning aim: 'students should understand that testing for the repeatability of measurements in controlled laboratory settings is one method scientists use to assess the quality of data'. This can be addressed effectively through a classroom-based empirical inquiry activity in which students take repeat measurements of the time it takes for a steel ball to fall a fixed vertical distance. In this case the scientific inquiry learning aim aligns with a clearly scientific inquiry teaching/learning approach.

However, this does not always follow. Students need not act like professional scientists in order to learn about the activities of the latter. Consider the scientific inquiry learning aim 'students should understand how scientists use theoretical models to explain phenomena'. This can be addressed effectively through teacher presentation of an episode from the history of science, followed by whole-class discussion. This is a teaching/learning approach that would not typically be characterised as school scientific inquiry. Thus, a scientific inquiry learning aim may not align with an inquiry teaching/learning approach.

The evidence that supports the use of scientific inquiry

What is the evidence that scientific inquiry instructional approaches are effective in supporting students' understandings of science concepts? Here I focus on those research studies that have considered the detail of scientific inquiry teaching/learning approaches as discussed above: recognising the role of student misconceptions, the variety of teaching approaches that might feature within an extended sequence (including transmissive modes where appropriate) and differing teacher roles through these activities.

A recent review of 138 research studies of this kind (largely from the USA) concluded that "there is a clear and consistent trend indicating that instruction within the investigation cycle…which has some emphasis on student active thinking or responsibility for learning, has been associated with improved student content learning, especially learning scientific concepts".[6] However, crucially, the evidence was not overwhelmingly positive. Many studies showed little, if any, positive impact on student learning from the use of teaching sequences employing scientific inquiry approaches (compared with 'traditional' teaching approaches). This provides an important reminder that teaching/learning approaches are but one factor among many. Issues such as teacher knowledge, student aspiration, parental support and assessment strategies also have significant influence on educational outcomes.

The importance of this final point is illustrated by an example from recent history: the introduction of the 'Scientific Investigation' attainment target in the National Curriculum for England and Wales from 1991.

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In secondary schools the requirement to conduct 'whole investigations' within a rigid assessment context led to standardised activities in classrooms (e.g. students measuring the resistance of different lengths of metal wires or the absorbency of paper towels).

These provided little learning or motivation for students, or teachers.[7] Here, scientific inquiry learning aims, teaching/learning approaches and assessment became unhelpfully intertwined.

Thus, the key to moving forward with scientific inquiry lies in working through the detail of what 'scientific inquiry' might mean in achieving specific learning aims within specific classroom and schooling contexts as part of ongoing, extended teaching/learning sequences.

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International evidence shows teacher preparation is vital

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During the 1990s, there was growing interest in rethinking science education to focus on all young students, no matter what their science aspirations. This article will consider the many international projects that have aimed to do this through dissemination and implementation of inquiry-based learning, looking at the common lessons that can be learned. Owing to the interdisciplinary nature of the primary classroom and relatively low pressure from external assessments, inquiry has often been seen as easier to implement at this stage and the majority of the projects mentioned here are therefore aimed at primary level. However, in the context of science for all students, the use of inquiry at the secondary stage should not be forgotten and is a central challenge for the future.

Rethinking school science

Improving science education was important during the 1990s for several reasons: more science understanding was needed than ever before, for playing an active part in modern society and the higher-skilled economy; there were public misunderstandings and doubts about costly research and technological achievements; progress in cognitive science and education research confirmed the need for a stimulating environment and the receptivity of young students for science; and students around the world – especially girls in high-income countries – were losing interest in science as both a subject and a career path. All this led to the conclusion that early science education should be rethought – as strongly expressed in the Rocard Report[1] and the UK Nuffield Report.[2] The question was, then: along which principles should a revised science education be planned?

Developing and implementing an inquiry pedagogy

Between 2000 and 2010, a succession of pilot projects and international meetings positioned inquiry as the preferred pedagogical approach for teaching science. Learning through understanding, rather than more passive learning, implies active observing, questioning, experimenting, hypothesising and self-expression through a progressive mastery of science vocabulary.[3,4] Despite a lack of undisputable and robust research evidence, the strong interest students, parents and teachers showed for the pilot projects led to support for the inquiry approach.[5,6] The basic principles of such a pedagogy were not new; the real challenge was implementation for students across the world.

Learning from international projects

Education is deeply embedded in cultural and social backgrounds, so pedagogical approaches require local adaptation – and time – to produce real and sustained improvements. Yet what can be usefully shared internationally should not be underestimated.

The context of primary school is comparable in most countries. The curiosity of students, irrespective of cultural or social background, is remarkable during this phase of rapid neuronal development. Primary teachers, who are generalists and teach all subjects, see the acquisition of science-specific knowledge as deeply connected to the whole of a child's educational development: for example, science learning can easily be connected with language acquisition – a goal put forward in the project *La Main à la Pâte* in France[7] or the *Proyecto de Alfabetización Científica* in Argentina. Curricula are almost identical everywhere, dealing with natural phenomena easily accessible to observation and experiment (e.g. water, clouds, plants, seasons, light and sound) or simple technological objects. These similarities provide a common foundation over which an inquiry pedagogy can be applied.

The importance of teacher preparation

Perhaps the most important general conclusion to draw is that learning science through inquiry at a young age can be extremely fruitful – as long as teachers are adequately prepared. Converging evidence from the USA, Mexico, China and France shows that it may require as much as five years, with a total of approximately 100 hours of training, for a novice teacher to become an expert, able to disseminate the pedagogy of inquiry to their colleagues.[8] However, even moderately trained teachers can have positive effects using ready-made inquiry teaching resources – such as those prepared by the US National Science Resources Center[9] or by *La Main à la Pâte* (available in many translations).[10] Teachers using these resources soon notice improved motivation of students for science activities, profound changes in the classroom mood and heightened interest among parents. These effects have been particularly noticeable in economically deprived communities, for example in the Chilean *Educacion en Ciencias Basada en la Inidigacion project*.[11] Success requires teachers to have an understanding of the nature of science, seeing it not as a collection of facts to be learned but as a process of thinking, observation and experimentation. This understanding, supported by proper teaching resources, allows teachers to cultivate cognitive progression in their students.

So, teacher training that explains the nature of science and provides the pedagogical knowledge to move beyond didactic transmission appears more fruitful than concentrating on extensive subject knowledge.

It is widely agreed that the best way to provide teachers with a better understanding of science as a process is to place them in situations they will later use with their students. Training sessions organised in China by the Learning by Doing movement,[12] or in some of the 23 European countries that are partners in the Fibonacci Project,[13] are based on this principle. After such training, many teachers declare they did not know – or had forgotten – how science could be interesting and relevant to everyday situations. This develops a better understanding of the experiences of their students and results in changed attitudes about the children in their classes.

Involving scientists in science education

Another salient lesson is the important role that practising scientists and engineers, as well as learned societies and academies, can play in these changes.[14,15,16] Scientists and engineers help to transmit an authentic and lively vision of science. Their help in developing resources and coaching teachers – including coaching through the internet, especially important for far-flung schools in large countries – is critical. This was demonstrated in France with the involvement of the Académie des Sciences over 15 years, and in Chile, China, Turkey, the USA and many other countries that have involved prominent scientists in inquiry projects.[17,18] The involvement of scientists does however require some preparation for them to understand and coach teachers properly, extensively explored by *La Main à la Pâte* in France[19] and also to some extent in the USA.[20]

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The future for inquiry

Millions of children each year, in many countries, have their eyes opened to the beauty of scientific reasoning and knowledge by inquiry projects. But questions remain: Which assessment tools can help to implement inquiry? How can countries increase the involvement of scientists in coaching teachers? For inquiry to flourish, should subjects be separated or should the curriculum be organised by interdisciplinary themes? However, perhaps one of the biggest questions is whether inquiry-based learning can be fully developed for the secondary stage, when the use of mathematics in science and more abstraction become essential. In the context of science for all students, the use of inquiry at this stage should be further explored; since 2006, *La Main à la Pâte* has been doing so through a project of integrated science and technology education.[21] It is by observing, assessing, and developing the preparation of teachers and their practice that these questions will find suitable answers.

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Scientific inquiry: mere pedagogy or real science? And who decides?

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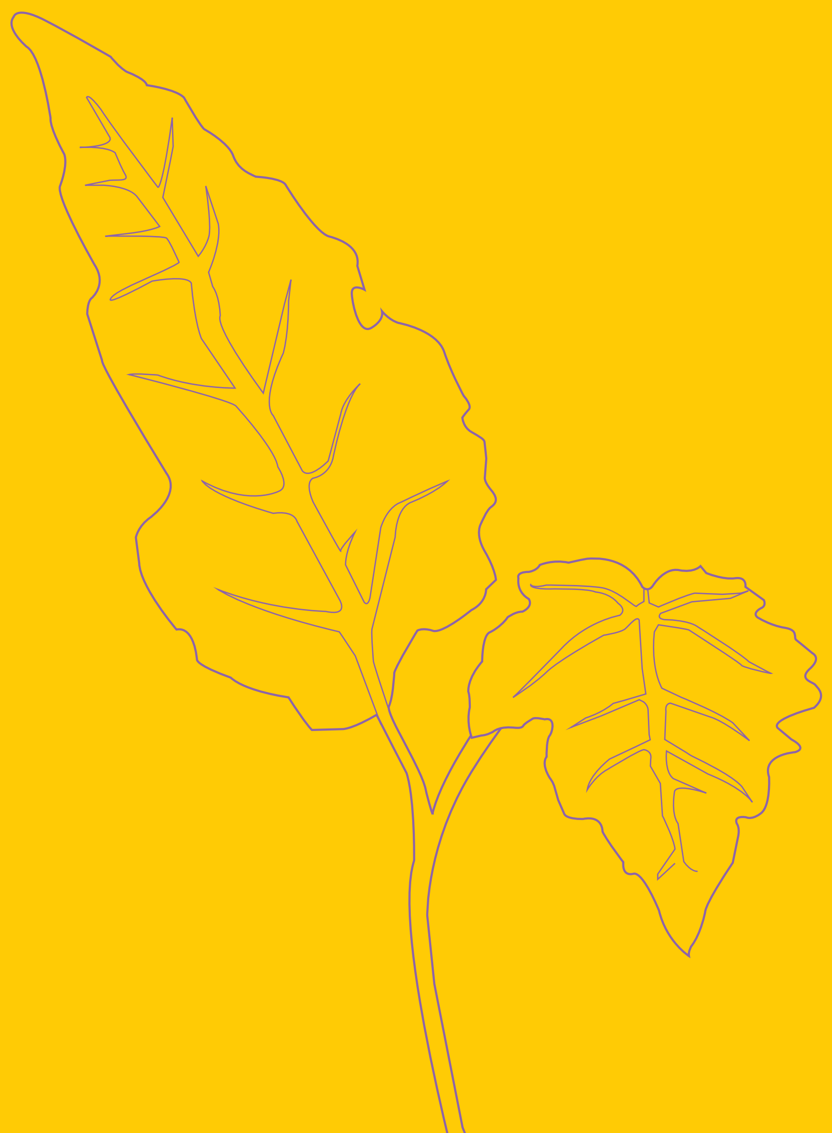

A policy framework – and pedagogy?

A central challenge in writing a National Curriculum is one of definitions: what do we want the core content to be and how can this be best explained to a range of users? This is in addition to the challenge – common to all education policy – of offering a legislative framework that raises standards. For it to be respected, the framework needs to be intellectually cogent, realistic and practical to implement, and to attract sufficient support from the scientific and teaching communities.

One of the conventions of the National Curriculum is that it specifies the matter to be taught but not *how* it should be taught. The supposition that any subject can be 'pedagogically blind' is simplistic for two reasons. First, learning is constructed through pedagogy and the nature of a subject is conveyed by how it is taught. Second, the way the curriculum is written has implications for the classroom: the importance of scientific inquiry is inferred from how it is represented in the National Curriculum. The 2007 curriculum[1] emphasises 'scientific thinking', 'practical and enquiry skills' and 'critical understanding', and these rightly have clear implications for pedagogy.

Scientific inquiry in the science curriculum

The National Curriculum seeks to capture the essence and scope of the study of science in school. Integral to that is the nature of inquiry and its relationship to scientific knowledge, derived through experimentation and observation. Students therefore need to understand not only scientific ideas but also how they are constructed.

Inquiry is essential to the development of scientific ideas and essential for understanding the world. This means that inquiry is more fundamental to real science than other pedagogies or classroom activities. It has always been hard to represent the integration of content and process in the curriculum.

The challenge for teachers is to select teaching methods that promote students' understanding of how scientific knowledge is constructed. This gives greater significance to the pedagogies used in science, as they affect learning in more fundamental ways than those in other subjects may.

Who decides what matters?

The curriculum is a framework that, before being implemented, needs interpretation by intermediaries – such as continuing professional development providers, awarding bodies, textbook writers and teachers. Of course, different intermediaries, with their own views of the subject, may emphasise the aspects they favour. There is a tendency for different groups to argue for content but not process.

What is defined in law is intended to provide a shared understanding of science. It also has to serve many purposes, for teaching and assessment, and a recent criticism of the science curriculum[2] is that lack of detail has led to inadequate guidance for these different purposes. Judgements, however, do have to be made about what is the irreducible core of science. This has been a constant struggle, especially because 'new' areas of knowledge will continue to appear, leading to a temptation to specify too much content. Alternatively, rigorous inquiry could be at the core – enabling students to tackle a subset of knowledge in depth and to develop skills that will enable them to understand science more broadly.

What is progression in science and how can it be assessed?

Progression in inquiry means, for example, students making more rigorous observations, taking account of more experimental variables, analysing more complex evidence and ensuring that conclusions are more scientifically valid. Poor articulation of this progression can lead to repetition rather then progress.

Assumptions about progress are most exposed in assessment. To support learning, assessments should recognise the complexity of a subject, but current qualifications mostly assess knowledge through written examinations and skills through set practical experiments. These methods of assessment do not therefore reflect the integration of knowledge and inquiry upon which science relies.

Recent critical events in assessment have exposed some of the problems:

- GCSEs have recently had to be rewritten as, according to Ofqual, there was too great a reliance on multiple-choice questions.[3] They seemed to focus on recall of information; by age 16 this was not considered sufficiently challenging since it reveals nothing about the thinking required to explain processes, ideas and the significance of evidence.
- Key Stage 2 science tests came under fire because it was thought that a reasonably knowledgeable pupil who had studied no science at all could answer some of the questions based on 'common sense'. There were also concerns that tests were too susceptible to cramming information. Again, as with GCSE examinations, remembering the facts or making simple deductions was considered inadequate.

A completely different model of assessment underpinned the criteria in Assessing Pupils' Progress (APP).[4] Instead of specifying knowledge separately and recognising process, the assessment criteria focus on effectiveness in aspects of inquiry, including 'thinking scientifically', 'communicating and collaborating in science', 'using investigative approaches' and 'working critically with evidence'. This is the best attempt so far to describe progression in these skills. The apparent lack of content in APP initially caused anxiety, but it soon became evident that students could only progress if they used and developed their scientific knowledge. In fact, APP provided a framework within which knowledge was activated and teachers collected more varied and richer evidence of what their students actually knew. This, then, was a way of integrating knowledge and inquiry in assessment.

Techniques for assessment need to be sufficiently sophisticated to support a complex view of learning in science. If scientific inquiry is inextricably linked to knowledge and understanding, then assessment needs to find ways to test this. If not, inadequate assessments will continue to inhibit teaching and learning.

Inquiry and the whole curriculum

The processes of inquiry are not solely the purview of science, with common ground clearly evident in 11 of the 12 subjects in the 2007 National Curriculum (the exception being modern foreign languages). No skills or processes can be learned in a vacuum and, although the kinds of question and the methods of investigation may vary between subjects, students are being asked to undertake similar thinking. Students benefit when connections enable them to develop and apply skills across subjects, since they are not relearning but applying and adjusting their learning to a different context. The importance of these skills is underlined in the QCA's Personal, Learning and Thinking Skills (PLTS),[5] which see 'independent enquirer' skills as essential to success in life, learning and work. Even though these are non-statutory, many schools see them as important for their students, and employers are keen for applicants to demonstrate these skills. Pupils, too, have voiced their preference for active, participatory and collaborative learning, as evidence from NFER[6] and CUREE[7] shows. So, scientific inquiry not only animates learning in science but also contributes to the development of the wider skills needed by all learners.

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What policy can (and can't) do

The National Curriculum seeks to set out what we, the nation, want our young people to know, understand and be able to do. The 2007 version sought to include the necessary knowledge and skills for those who will become scientists or take up science-related work, as well as providing a basis for all students to make sense of the world. Integrating scientific ideas and knowledge with rigorous inquiry methods can promote this, and policy can support this approach. What policy can't do is ensure that everyone agrees and that all the intermediaries interpret the curriculum in the same way.

With the National Curriculum now potentially moving into a new phase, it is the responsibility of all those with a stake in science teaching to use their judgement and autonomy to make sure inquiry is fully integrated into science learning.

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For teachers, there is a rhetoric and a reality to scientific inquiry

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The rhetoric of scientific inquiry is clear and a difficult one to argue with: it engages people's imagination and creativity, and helps with the development of rational thought, communication and problem-solving skills. The government believes in scientific inquiry.[1,2] Teachers believe in scientific inquiry:[3] they love to set their students challenges and support them in developing ways to find out answers for themselves and then in evaluating their experiments within the wider body of scientific knowledge that exists at our fingertips. However, for many, this is not the reality of scientific inquiry and below I consider what the barriers are to this rhetoric becoming reality.

Science teachers are under ever-increasing pressure and scrutiny. They face the daily challenge of providing inspirational learning experiences for every student while maximising and monitoring their progress against the benchmarks set by an overly prescriptive assessment system, not to mention keeping a careful eye on health and safety, reporting to parents and keeping up to date with what feels like the relentless march of change within the political world of education.

What do teachers understand by the term 'scientific inquiry'?

I suggest that a significant number of classroom teachers, including me before researching this article, would struggle to define the term 'scientific inquiry' and explain the distinction between it and 'practical science'. I found it helpful to consider that science education involves both learning science (acquiring scientific knowledge) and learning *about* science (the processes and skills needed to do science). While practical work can be used in a variety of ways in order to help students learn scientific knowledge, Millar[4] points out that practical tasks that are used to develop students' knowledge are essentially acts of communication, not inquiry. We might find it helpful to think of scientific inquiry as doing practical work in which students have had some degree of choice in the planning and implementation of their practical work, and in which the student doesn't know in advance what the outcome will be. Thus, many teachers believe that a key strength of scientific inquiry is its potential in helping students to learn *about* science and the way in which science works.

Reading about the 'theory' of scientific inquiry has led me to reflect on my own practice and the implementation of these ideas in my classroom. I therefore feel it is important that teachers are informed about research and exposed to the supporting theories behind new initiatives, whether advocated by policy makers, researchers or other teachers. This would enable teachers to understand theories as professional educators and successfully adapt them for their students. There is a catch here, though: this requires teachers to have the time to engage in research as well as access to the outcomes of educational research. As we all know, the teaching profession is not one that is awash with surplus time. Teachers love to reflect on classroom practice, discuss and try out new ideas, but my own research into teachers' continuing professional development has helped me to understand that this is often very hard for them to put into practice.

How are teachers currently implementing scientific inquiry?

Issues of definition and understanding are not necessarily a problem for classroom practice. In the primary classroom, we begin to see children deciding, with the support of their teachers, what sort of questions science can answer and how they can collect data to answer their questions about the world around them. The excitement when a genuine experiment produces an expected outcome is contrasted by the challenge faced when it produces unexpected results.

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> Teachers must take responsibility for challenging their students by providing opportunities for them to explore and inquire.”

In the secondary classroom, however, I would suggest that genuine scientific inquiry is rare. Thankfully, the majority of secondary students do frequently engage in practical work, but I feel that the majority of teachers use these activities as a way to engage learners and illustrate concepts that are important for their students to understand. Thus, they are using practical work to *communicate* scientific knowledge and understanding, not to allow their students to *discover* knowledge through inquiry, guided or unguided.

What stops teachers from using scientific inquiry more often?

It seems sensible then to ask why scientific inquiry does not form a more significant part of the secondary curriculum in schools. High-quality practical work, when approached as an investigation that students can control and don't know the answer to, is a cornerstone of teaching through inquiry. However, some schools find that practical investigative science lessons are hard to resource. One reason for this might be a lack of dedicated funding, when equipment and consumables can both be expensive. Another reason could be a lack of technical support, with laboratory technicians being an essential part of a school science department. This point applies as much if not more so to primary schools, which do not have dedicated science technicians. A third possible reason, which imposes restrictions on practical work in general, not just inquiry, could be a lack of specialised laboratory teaching space. It is not uncommon for some science lessons to take place in computer rooms or standard classrooms. Unfortunately, in some schools, class sizes can be restrictive as well, frequently rising above 32, when compared with the maximum class size of 20 as recommended by the Association for Science Education and the House of Commons Select Committee on Science and Technology.[5]

Concerns and misunderstandings over health and safety still exist. In 2005, the Royal Society of Chemistry commissioned CLEAPSS (a national advisory body supporting the teaching of practical science) to investigate the understanding of teachers, technicians and local authority science advisers. They found that 70 per cent of respondents incorrectly believed that it was illegal for students to sample their own blood and 32 per cent incorrectly believed that it was illegal to sample saliva.[6] While it is easy, but not necessarily fair, to blame educational professionals for these misunderstandings, it is plain to see that we now live in a society in which risk avoidance is preferred to risk assessment and risk management. Perhaps some teachers feel that they put themselves at risk of litigation by exposing their students to some of the more stimulating opportunities offered by scientific inquiry, whereas managing risk in more familiar practical activities is less time-consuming. Colleagues at CLEAPSS work very hard to reassure teachers that an awareness of health and safety responsibilities should not curtail practical work, including scientific inquiry.

In my opinion, one of the most significant reasons for the difference between the rhetoric and the reality of scientific inquiry in the classroom is the nature of assessment. For some years now, science teachers have been faced with internally assessed coursework that pretends to be scientific inquiry. In fact, it is a series of hoops that students must jump through, coached by their teachers in how to plan, carry out and evaluate an investigation in order to achieve maximum marks.[7] It is not uncommon for GCSE students to make up an anomalous result in order to give themselves an outlier in their dataset, so that they have more to discuss in the evaluation section. This, sadly, demonstrates the flaws within our assessment system, but it is amusing to see that young people are focused and skilled at succeeding within, or despite, the system that we currently have. It should be said, though, that some genuine examples of internally assessed scientific inquiry do still exist, such as the 'Individual Investigation' in the Salters A Level Chemistry syllabus.[8] However, this can be painfully time-consuming for teachers to mark.

What is the future for scientific inquiry in the classroom?

Matching the reality of scientific inquiry in the classroom with the rhetoric is a significant challenge, but one that will need to be tackled on a number of levels. Teachers must take responsibility for challenging their students by providing opportunities for them to explore and inquire. Carefully phrasing questions is a good place to start, ensuring they are sufficiently open and involving. The systems that currently constrain the creativity of teachers should also be addressed. School leaders should support the resourcing of science departments to remove the restrictions that facilities, technical support and funding currently place on scientific inquiry. At the highest level, our educational system is currently obsessed with assessment, be it for individual students' future academic prospects, league tables, Ofsted, performance management and pressure to raise standards incrementally year on year. This obsession must change if life is to be breathed back into scientific inquiry in the school laboratory.

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