THE UNIVERSITY of York

IOE LONDON Leading education and social research
Institute of Education
University of London

SCIENCE AND TECHNOLOGY COMMITTEE
Select Committee Inquiry: Practical experiments in school science lessons and science field trips

Evidence submitted by: Ruth Amos and Professor Michael Reiss (Institute of Education, University of London) and Dr Ian Abrahams, Professor Robin Millar and Mary Whitehouse (University of York).

How important are practical experiments and field trips in science education?

Practical work

1. The aim of science is to find explanations that are supported by evidence for the events and phenomena of the natural world. As such, practical work is an essential part of effective science education. Teaching science involves, by its very nature, showing students things or putting them into situations where they can manipulate objects and materials and see certain things for themselves. In this respect a fundamental purpose of practical work in school science is to help students make links between the natural world of objects, materials and events and the abstract world of thought and ideas. Furthermore, by enabling students to undertake practical work for themselves, they are also able to experience firsthand the distinctive way in which much of our current, as well as past, scientific knowledge about the natural world has been derived.

Field trips

2. Whether science is taught in a specialised laboratory (as in many secondary schools) or in a typical classroom with some specialist equipment (as in many primary schools), the fundamental idea is that students are presented with a simplified version of reality in which it is easier for them to be introduced to key scientific ideas. Unless complemented by the richer, messier world outside of the classroom students may fail to connect their classroom learning with the world beyond the classroom. Braund and Reiss (2006) have argued that we can envisage three categories of this outside-of-the-classroom world:

- the actual world (e.g. as accessed by field trips and other visits to see science in use);
- the presented world (e.g. in science museums, botanic gardens and zoos);
- the virtual world (e.g. through simulations).

3. Learning in the actual, the presented and the virtual world can valuably complement learning about science that takes place within school. Even during their school years students spend most of their waking hours outside of school.

Are practical experiments in science lessons and science field trips in decline? If they are, what are the reasons for the decline?

Practical work

4. Practical work is a traditional and well-established part of science education and we are not aware of any research evidence that would suggest that the number of practical experiments is declining. Indeed, Bennett (2003) has claimed that there is little reason to believe that the amount of practical work has diminished from the level reported by Thompson in 1975, who found that one third of all 17-18 age range science teaching time was devoted to some form of practical work, with this rising to one half of science teaching time for students aged 11-13 (Beatty & Woolnough, 1982).

Field trips

5. In the UK, there is consistent and worrying evidence for a substantial decline in science fieldwork over the last 50 years (Lock, 2010). There are a number of reasons for this decline. The science National Curriculum (introduced in 1989) has reduced considerably the autonomy of science teachers and there is a common perception that fieldwork takes students away from what they are meant to be learning in the classroom. Although science fieldwork is actually extremely safe, a small number of high profile accidents on field trips (though usually on adventure courses) have put many schools, teachers and parents off the idea while teaching unions have cautioned about organising field visits in the light of health and safety concerns; perhaps unsurprisingly, teacher confidence in taking students outside is variable (Ofsted/HMI, 2004). There have also been concerns about the consistency of fieldwork training for secondary science pre-service teachers (Kendall, Murfield, Dillon & Wilkin, 2006), while parents/carers often have difficulties meeting the costs of fieldwork, particularly when residential. As a result, students at independent schools are more likely to benefit from field trips than students in the state sector (Association for Science Education Outdoor Science Working Group, 2011).

What part do health and safety concerns play in preventing school pupils from performing practical experiments in science lessons and going on field trips? What rules and regulations apply to science experiments and field trips and how are they being interpreted?

Practical work

6. Risk assessment in the school laboratory is a necessary and important part of ensuring safe practical work. There is no evidence that we are aware of to suggest that teachers' awareness of health and safety issues have led to any noticeable reduction in either the amount or type of practical work used in schools. However, there is some anecdotal evidence, from visits to schools by one (IA) of us, that a small number of teachers have stopped doing certain experiments – for example electro-statically charging a healthy student using a Van de Graaff generator – because they mistakenly believed that to do so is no longer permitted on 'Health and Safety' grounds. Similarly there is evidence from the Royal Society of Chemistry

(2011) that "teachers and technicians have misconceptions about the type of experiments that are banned in UK schools" and that these misconceptions, rather than actual health and safety issues, are causing some teachers not to do carry out practical experiments that would otherwise be acceptable. In many schools risk assessment for practical tasks is now embedded in schemes of work to such an extent that for many teachers health and safety is simply a matter of following the guidance provided in the light of their knowledge of a particular group of students.

Field trips

7. The present rules and regulations that apply to field trips are appropriate, except in a minority of cases where Local Authorities are unduly restrictive. What is more important, and concerning, are the frequent and widespread urban myths about the volume of form filling and the time required to deal with the attendant bureaucracy. The reality is that a risk assessment needs to be carried out and the depth with which this needs to be undertaken should be proportional to the possible harms. Most field centre providers give assistance to schools in completing such assessments.

Do examination boards adequately recognise practical experiments and trips?

Practical work

8. Awarding bodies (examination boards) include some assessment related to practical work in both A level and GCSE sciences. In fact at A level the sciences are an exception to the norm of just four units of assessment. When the QCA consulted about the revision of subject criteria for A level, both the science community and the science education community lobbied for six units of assessment to allow for the assessment of practical work to continue, partly in the belief that if it was not assessed there would be less incentive to carry out practical work and there would be a pressure for more science to be taught in classrooms, rather than laboratories. The current criteria state that 'Each of the internally assessed units at AS and A2 must include the assessment of practical skills' (QCA 2006). The activities assessed range from prescribed experiments to full practical investigations. At GCSE, from 2012, 25% the marks are awarded for 'controlled assessment', which assesses students' ability to plan and carry out tests of scientific hypotheses. Attempts to include the direct assessment of practical skills such as constructing a circuit, setting up a microscope or carrying out a titration have been abandoned as being too difficult to validate.

9. There is substantial anecdotal evidence that some teachers consider the model of assessment of practical work offered by the awarding bodies as a key criterion when choosing which specification to adopt – not because they think it is the best on educational grounds but because it will be the easiest for their students to score good marks on, and the easiest for them to mark and administer.

Field trips

10. It is difficult to overstate the importance of the specifications (syllabuses) set by the awarding bodies at GCSE and A level in driving teacher practice. One of us (MR) has spent twenty years with very little success trying to get fieldwork to be a required part of A level biology courses. From the awarding bodies' point of view, this is too risky a strategy. Such compulsion would almost certainly lead to a loss in the number of candidates taking their courses as too many teachers would be likely to move their students to courses that did not require fieldwork.

11. The GCSE criteria for Additional Science and for Biology include the requirement that "specifications must require learners to demonstrate knowledge and understanding of fieldwork techniques to explore the relationships between communities of organisms and their environments" (Ofqual 2009).

12. This means that fieldwork techniques should be incorporated into schemes of work so that students are able to answer questions in examinations.

If the quality or number of practical experiments and field trips is declining, what are the consequences for science education and career choices? For example, what effects are there on the performance and achievement of pupils and students in Higher Education?

Practical work

13. What should be noted here is that whilst the amount of practical work has remained relatively constant the way in which it has been assessed at GCSE level since 1987 has led to an emphasis on investigative exercises of a very narrowly conceived kind – chosen in order to make it as easy as possible for students to score high marks. These are widely seen (Donnelly et al., 1996) not to have much educational value, and to present a flawed image of the science enquiry process. They have, however, squeezed out illustrative practical work, designed to enhance understanding of scientific concepts and phenomena, and to develop skills in using scientific equipment and procedures. Indeed, our experience is that many teachers of biology, chemistry and physics in Higher Education say that students come with almost no hands-on experience of handling common bits of scientific equipment.

14. Even though there is a lot of practical work being undertaken it is important to recollect that the reported *preference* for doing practical work amongst many students *within* science lessons (Abrahams, 2011) does not necessarily imply that practical work is an effective means of motivating large numbers of students to pursue the study of one or more science subjects in the post-compulsory phase of their education. For whilst these students undeniably *do* like practical work, their reasons for doing so appear to be primarily that they see it as preferable to non-practical teaching approaches that they associate, in particular, with more writing.

Field trips

15. Many reviews of science education in the UK and other developed countries show that although school students begin their secondary science education with enthusiasm, by the time they leave school most of them are glad to leave school science, all too often describing it as boring or irrelevant (Osborne & Collins, 2000). In contradistinction, field trips in science are often extremely motivating for students. A recent, large-scale evaluation of residential science field trips for over 30,000 11-14 year olds from 850 London schools from 2004-2008 (Amos & Reiss, in press) found that that students' collaborative skills and other social relationships were strengthened and persisted back to school. Gains were strongest in social and affective domains alongside high levels of conceptual engagement, while there were also cognitive gains. There were particular benefits for students from socially deprived backgrounds who gained from exposure to authentic learning environments.

What changes should be made?

Practical work

16. Rather than simply suggesting that teachers should do even more practical work than they are currently doing there is a need to focus on how to improve the effectiveness of the practical work that science teachers already use, even if the result of this means that they end up doing less, but more effective, practical work in their lessons. This approach is primarily what the Getting Practical: Improving Practical Work in Science (IPWiS, 2011) project has been about in that it was essentially designed to encourage teachers to reflect more fully and deeply on the learning objectives of the practical activities they use and, in particular, the kinds of thinking that such practical work requires of students if it is to be effective in developing conceptual understanding. A key way to achieve this is to help science teachers not only to see, but also to use, practical work as both a 'hands on' *and* 'minds on' activity, rather than the essentially 'hands on' activity that it is currently widely seen to be (Abrahams & Millar, 2008). The impact of such a change would be that students would not only 'do practical work' but would actually understand *why* they were doing it and what they were learning from doing it – something that is frequently less than clear to many of them – as well as being better able to *understand* and *explain* what they see and do using the scientific terminology and ideas that explain the phenomena and/or data that they produce.

17. Whilst the IPWiS evaluation has shown that one short CPD programme cannot transform practice, it did show how systematic reflection on practice, focusing on aspects of the design of practical activities that research suggests are critical to effectiveness, could and did stimulate significant changes in practice. There is therefore a need for coaching and on-going support, not only in the form of sustained long-term continuing professional development – ideally in the national and regional science learning centres – but also extensively within Initial Teacher Training programmes, if substantial and durable change to the effectiveness of practical work in school science is to be achieved.

18. There is a also a need to recognise that science is primarily about understanding the natural world – and the natural world, outside of the school science laboratory, does not contain a large number of exciting bangs, flashes and pops. If we can show students that the real excitement of science comes from *understanding* those phenomena, then we might in fact succeed in motivating more students towards an intellectually fascinating subject.

Field trips

19. The subject criteria for A level biology (including AS) should require at least one field trip to be undertaken. Serious consideration should be given to making some form of learning out of the classroom compulsory for A level (including AS) chemistry and physics too. While these subjects do not need field trips in the way that biology does, they benefit greatly from such learning experiences as chemistry trails and industry visits (Braund & Reiss, 2004).

20. Science students, whether at primary or secondary level, training to receive QTS (Qualified Teacher Status) should be trained more rigorously than is often the case at present to take students on science field trips.

21. The science National Curriculum, which is currently being revised, should clarify the relationship between learning science inside and outside of the classroom and provide age-appropriate requirements for learning science outside of the classroom.

Is the experience of schools in England in line with schools in the devolved administrations and other countries?

Practical work

22. Our experience is that the use and perceived value of practical work varies not only from country to country but also from school to school, and often from teacher to teacher. The UK is, however, one of a very small number of countries in which school science lessons are taught predominantly in laboratories rather than classrooms, and one of even fewer in which schools typically have science technicians to support the practical work undertaken by teachers. Whilst we are unaware of any systematic study that compares the amount or type of practical work used in different countries, it is widely recognised that more practical work is carried out in school science teaching in the UK than in most other countries.

Field trips

23. We are unaware of any rigorous study comparing field trips in different countries. Our experience is that the situation in most developed countries is that same as in England, namely that there is general willingness to allow science field trips to take place, and a realisation that they can have considerable benefits, but organising them at secondary school is typically left to individual teachers / science departments. The result is that field trips remain the preserve of the minority of students fortunate enough to have an enthusiastic science teacher who believes in the value of such trips. Over time, the number of such teachers is probably declining.

References

Abrahams, I. (2011). *Practical work in secondary science: A minds-on approach*, London: Continuum.

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science, *International Journal of Science Education,* 30 (14), 1945-1969.

Amos, R., & Reiss, M.J. (in press). The benefits of residential fieldwork for school science: insights from a five-year initiative for inner-city students in the UK, *International Journal of Science Education*.

Association for Science Education Outdoor Science Working Group (2011) *Outdoor Science: A co-ordinated approach to high-quality teaching and learning in fieldwork for science education*, Shrewsbury: Field Studies Council and King's College London.

Beatty, J.W., & Woolnough, B.E. (1982). Practical work in 11-13 science: the context, type and aims of current practice, *British Educational Research Journal,* 8 (1), 23-30.

Bennett, J. (2003). *Teaching and learning science: A guide to recent research and its applications,* London: Continuum.

Braund, M., & Reiss, M.J. (Eds) (2004). *Learning Science Outside the Classroom*, London: RoutledgeFalmer.

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: the contribution of out-of-school learning, *International Journal of Science Education*, 28, 1373-1388.

Donnelly, J., Buchan, A., Jenkins, E., Laws, P., & Welford, G. (1996). *Investigations by order: Policy, curriculum and science teachers' work under the Education Reform Act*, Nafferton, UK: Studies in Education Ltd.

Getting Practical: Improving Practical Work in Science (2011). http://www.gettingpractical.org.uk , Accessed 7 May 2011.

Kendall, S., Murfield, J., Dillon, J., & Wilkin, A. (2006). *Education Outside the Classroom: Research to identify what training is offered by initial teacher training institutions*, Research Report 802, London: National Foundation for Educational Research/Department for Education and Skills.

Lock, R. (2010). Biological fieldwork in schools and colleges in the UK: an analysis of empirical research from 1963 to 2009, *Journal of Biological Education,* 44, 58-64.

Ofqual (2009). *GCSE subject criteria for biology*, Ofqual/09/4663.

Ofsted/HMI (2004). *Outdoor Education: Aspects of good practice,* London: HMSO.

Osborne, J., & Collins, S. (2000). *Pupils' and parents' views of science in the school curriculum*, London: King's College.

QCA (2006). *GCE AS and A level subject criteria for science* QCA/06/2864.

Thompson, J.J. (Ed.) (1975). *Practical Work in Sixthform Science,* Oxford: Department of Educational Studies, University of Oxford.

Royal Society of Chemistry (2011). http://www.rsc.org/ScienceAndTechnology/Policy/Bulletins/Issue5/SurelyThatsBanned.asp, Accessed 8 May 2011.

Ian Abrahams
Ian Abrahams is a lecturer in Science Education in the Department of Education at the University of York. His research interests are in the areas of practical work and teachers' attitudes to science education. He recently led the evaluation of the DCSF funded Getting Practical: Improving Practical Work in Science project.

Ruth Amos
Ruth Amos is a lecturer in Science Education at the Institute of Education, University of London. Prior to moving to Institute, she taught in London schools for 11 years. Her research interests include global dimensions in education, learning outside the classroom, and collaborative partnerships between schools and informal educators.

Robin Millar
Robin Millar is Salters' Professor of Science Education at the University of York. He has directed and/or participated in several major research projects, including the EU Labwork in Science Education project. He made an invited presentation on the role of practical work in school science to a National Academies Committee in Washington, DC in 2004. He recently helped to design the instruments and approaches used to design the CPD programme for the Getting Practical: Improving Practical Work in Science project.

Michael Reiss
Michael Reiss is Professor of Science Education and Associate Director (Research, Consultancy and Knowledge transfer) at the Institute of Education, University of London. He has received funding for research on science practical work and field trips from the DfES, DCSF and the Field Studies Council.

Mary Whitehouse
Mary Whitehouse is Project Director for the Twenty First Century Science Project at the University of York. Her research interests are in the area of external assessment of science and physics. She has been Chief Examiner for GCSE Physics and GCSE Science as well as Principal Moderator for AS Physics at OCR.