PRACTICAL WORK IN SCIENCE: A REPORT AND PROPOSAL FOR A STRATEGIC FRAMEWORK

SCORE

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BACKGROUND

The importance of practical work in science is widely accepted and it is acknowledged that good quality practical work promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding. It is also acknowledged that in the UK more practical work takes place in science lessons than most other countries. However concerns have been expressed by sections of the science community, industry and business that schools in general are not doing enough practical work and that its quality is uneven.

This report into practical work in science in the UK during 5-19 education reviews evidence and, based on its key findings, proposes a strategic framework for enhancement of the practical work in science in schools and colleges.

SOURCES OF EVIDENCE

Between September 2007 and June 2008, SCORE engaged with a wide range of stakeholders in order to explore three main questions:

- What is meant by practical work and what is its purpose?
- What are the factors that facilitate good quality practical work and the barriers that militate against it?
- What are the key elements that need to be addressed in order to improve the quality and the scope of practical work in science across schools and colleges?

Evidence was drawn from four main sources: a literature review, an open call for evidence, online surveys of teachers and technicians and a series of stakeholder workshops. Throughout, the process for gathering and analysing evidence has been iterative with each stage building on earlier steps.

KEY FINDINGS

1. There is overarching agreement that 'practical activities' can be put into three broad groups: core activities, directly related activities and complementary activities. Practical work in science includes the core activities and the directly related activities. The complementary activities are important in supporting the development of conceptual understanding in science through practical work.

   ### Practical work in science

   Core activities
   Investigations
   Laboratory procedures and techniques
   Fieldwork

   Directly related activities
   Designing and planning investigations
   Data analysis using ICT
   Analysing results
   Teacher demonstrations
   Experiencing phenomena

   ### Complementary activities

   Science-related visits
   Surveys
   Presentations and role play
   Simulations including use of ICT
   Models and modelling
   Group discussion
   Group text-based activities

2. The importance of practical work in science is widely accepted and it is acknowledged that good quality practical work promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding.
3. There is a strong commitment to high quality practical work in science among teachers, technicians, and other stakeholders alike.
4. There is a wide range of good practical work in science taking place across the UK but there are indications that the situation could be improved by extending good practice and focussing on the quality, rather than just the quantity, of practical work.

5. Effective pedagogy is at the heart of improving the quality of practical work in science. When well planned and effectively implemented, practical work stimulates and engages students' learning at varying levels of inquiry challenging them both mentally and physically in ways that are not possible through other science education experiences.
6. Many teachers indicated that they felt confident doing practical work but there was a very strong indication that this was because they had been able to gain experience over a period of time.
7. There is well-documented evidence of the shortcomings of equipment funding and replacement of laboratories which require continued monitoring and should be addressed as part of wider strategy and improvement in facilities.
8. Although there are currently no serious threats to practical science from health and safety requirements, there is a negative impact resulting from perceptions as to the restriction imposed by health and safety concerns, particularly regarding field trips. This latter situation needs to be addressed and kept under review as new legislation, pupils' behaviour and a lack of technical support can result in significant reductions in practical work in science.
9. Although many teachers expressed dissatisfaction with the amount of time and resources for practical work in science and reported falls in provision, the time devoted to it is still substantial, with 80% indicating they spent more than 40% of lesson time at KS3 doing practical work, though only 56% and 45% reporting that they spent more than 40% of time at KS4 and KS5 respectively.
10. There was concern expressed that teachers did not necessarily feel confident in carrying out practical work outside their specialist discipline. The importance of mentoring of inexperienced teachers was noted as a way of building confidence.
11. Subject-specific professional development, or rather the lack of it, has been highlighted in other reports. More specifically the questionnaire responses indicated that, although 21% of teachers had engaged in CPD specifically related to practical work in the last year, over 40% indicated they could not remember 'ever' receiving CPD on practical work. Opportunities for training and professional development for teachers and for technicians, to support practical work, need to be improved and teachers and technicians engaged with these.
12. The use of ICT is a vexed question that exposes inherent tensions. There is, however, an underlying consensus that ICT should supplement and enhance practical work not replace it. How this is to be done is not well understood and many respondents to the questionnaire did not see ICT as a way of improving practical work.
13. Current assessment demands are damaging and restricting practical science; 66% of the respondents to the questionnaire indicated that the amount of practical work at KS4 had been reduced in recent years. Lack of experience and/or understanding of the aims of the new GCSE courses appear to have adversely affected the amount of practical work at KS4 in a considerable number of schools.

RECOMMENDATIONS – DEVELOPING A STRATEGIC FRAMEWORK

The importance and value of practical work in science has again been re-enforced during this project, and the potential for improving its quality is recognised. The major challenge is to take advantage of this underlying support and to integrate the strengths of the existing good practice with the potential for future opportunities.

The findings support a strategy which:

a. improves the effectiveness of existing provision through improved dialogue and awareness of initiatives and an agreed definition of what is considered to be practical work in science;
b. embodies a strong communications strand – for dissemination of information, including details of support, that is available to support practical work and engages in debate about ways in which practical work in science can be further improved;
c. strengthens support and professional development specifically focused on improving practical work in science thereby building capacity and sustainability;
d. is based on evidence which can better define the problems, support the monitoring and evaluation of the impact of the strategy during its implementation and influence existing and future policy-making.

The strategy should include five strands as follows:

a. **Leadership and management** through the establishment of a 'management group', convened by SCORE, with a membership that includes, for example, SCORE members, representatives of DCSF, DIUS, National Network of Science Learning Centres, Secondary National Strategy, SSAT, CLEAPSS, the Gatsby Charitable Foundation and industrial partners.
b. **Communication and dissemination** to raise the profile of practical work and to maximise the awareness of the support that is available to support practical work in science.
c. **Facilities and resources** to bring together the best advice on facilities and resources to support practical work in science.
d. **Developing professional expertise in practical work in science**, principally through existing mechanisms. It is essential that there is some dedicated resource (human and financial) to ensure that the practical work elements are not lost because of other pressures.
e. **Research and evidence** to better inform future developments and monitor the impact of any interventions. In particular further consideration needs to be given to the detail required of a wider benchmarking of the current state of practical work in science in schools and colleges.

1 BACKGROUND

The importance of practical work in science is widely accepted and it is acknowledged that good quality practical work promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding. Although there are examples of good practice in schools, concerns have been expressed by sections of the science community, industry and business that in general the amount of practical work has declined and, more importantly, that its quality is uneven. These concerns were specifically raised by the STEM High Level Strategy Group (HLSG) which agreed that, "there is a need to forge the work that is already in train into a focused strategy to promote high quality practical work in school science" and that SCORE should lead on a piece of work to:

- raise the profile of practical work in science and engage stakeholders in the debate;
- map out the current situation;
- provide the basis for a consensus as to what is meant by practical work in science and the development of a strategy;
- propose plans for the implementation of the strategy.

Initial discussions with a wide range of stakeholders through a combination of email and workshops established that the central concern was the need to ensure the quality of practical work in science and identified a number of key questions that needed to be addressed. These were defined as:

- What is meant by practical work in science?
- What are the aims and purposes of practical work in science?
- What is the impact of good practice and effective pedagogy?
- What are the factors that facilitate good quality practical work and the barriers that militate against it?
- What are the opportunities for developing and extending practical work in science?
- What are the key elements that need to be addressed in order to improve the quality and the scope of practical work in science in schools and colleges in England?

This report presents the outcomes of the work, proposes the framework for a strategy and provides the basis for the development of a detailed implementation plan to be supported by the Department for Children, Schools and Families in England. The outcomes will also form the core element of Action Programme 10 identified as a priority under the implementation of the STEM Programme.

It should be noted that many of the issues relate to the whole of the UK and that organisations and individuals from throughout the UK have contributed to the discussions during the preparation of this report, bringing valuable perspectives and evidence to the debate. The proposals for the funded programme, however, are restricted to England.

2 SOURCES OF EVIDENCE

The preparation of this report has been an iterative process, through early meetings and discussion papers within SCORE, a review of existing research literature, two online questionnaire surveys, a call for evidence from stakeholder organisations and individuals, and three workshops and electronic discussion involving other stakeholders.

The focus of all lines of enquiry has been practice in England but relevant research and evidence from elsewhere has been reviewed for its possible application to England. Although the original focus identified by the HLSG related specifically to the 11-19 phase of education, this report also draws on evidence from the 5-11 phase because contributors strongly argued the importance of ensuring that high quality practical work was an integral element in all science teaching and learning regardless of phase. It should be noted, however, that due to constraints of both funding and time the collection of evidence does not claim to be comprehensive but taken together it is very informative and provides a sound basis for further developments.

2.1 REVIEW OF RESEARCH LITERATURE

2.1.1 METHODS

The literature review was undertaken by Dr Justin Dillon from King's College London and a summary is presented here. The full review is available on the SCORE website www.score-education.org. Given the restricted time available, the review highlights the critical issues in the debate rather than presenting a definitive compendium of the literature.

The approach taken to reviewing the literature involved several parallel steps:

- Searching the major electronic bibliographic database (Google Scholar) for references to: 'practical work in science'; 'science inquiry'; 'science enquiry'; 'investigative work in school science'. This search resulted in a primary database of the literature, etc. As a way to ensure that all relevant material was identified, Google Scholar was also searched for references to research that had cited the primary database.
- The most recent review (Lunetta *et al*. 2007) of the literature on practical work in school science was identified and this was used to search for further references not revealed by the original search.
- Searches were made of relevant websites (for example, Ofsted and the Royal Society) for additional documents, press releases, etc.
- Recent books on practical work were also identified and skimmed (for example, Abrams *et al*. 2008).

2.1.2 SUMMARY OF FINDINGS FROM THE LITERATURE REVIEW

DEFINITION OF PRACTICAL WORK

There is confusion in the broader science education community about the definition of 'practical work'. This confusion makes discussions about the value of 'practical work' difficult. A variety of terms exist to describe practical work, many of which are frequently used with little clarification. For example, *Science in the National Curriculum* uses several terms with little attempt to explain their meaning: *'Practical and enquiry skills'*, *'practical and investigative activities'*, *'independent enquiry'* and *'experimental work'* (Qualifications and Curriculum Authority 2007a/b).

The most recent published review of the literature (Lunetta *et al*. 2007) on learning and teaching in the school science laboratory gives what it calls a classical definition as:

> *…learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world (for example: aerial photographs to examine lunar and earth geographic features; spectra to examine the nature of stars and atmospheres; sonar images to examine living systems).* (Lunetta *et al*. 2007).

This inclusive definition might act as a starting point for clarifying terms in the UK science education community.

PURPOSE OF PRACTICAL WORK IN SCIENCE

There are many espoused purposes for doing practical work in school science. Some of the most frequently stated by teachers are:

- to encourage accurate observation and description;
- to make phenomena more real;
- to arouse and maintain interest;
- to promote a logical and reasoning method of thought.

Since the introduction of the National Curriculum in England and Wales, four other aims have become more commonly stated by teachers:

- to practice seeing problems and seeking ways to solve them;
- to develop a critical attitude;
- to develop an ability to cooperate;
- for finding facts and arriving at new principles.

There is no clear consensus that the broader science education community agrees on the aims and purposes of practical work in science.

THE IMPACT OF PRACTICAL WORK

In general, teachers and students are positive about 'practical work'. For example, in a recent NESTA survey (n=510), 99% of the sample of UK science teachers believed that enquiry learning had a positive impact (83% - *'very'*; 16% - *'a little'*) on student performance and attainment (NESTA 2005, p.5).

The quality of practical work varies considerably but there is strong evidence, from this country and elsewhere, that:

> *When well planned and effectively implemented, science education laboratory and simulation experiences situate students' learning in varying levels of inquiry requiring students to be both mentally and physically engaged in ways that are not possible in other science education experiences.* (Lunetta *et al*. 2007, p.405).

Evidence of effective practice in the use of practical work comes from a range of studies. For example, White and Gunstone's (1992 quoted in Lunetta *et al*. 2007) study indicates that '*students must manipulate ideas as well as materials in the school laboratory'*. There is a growing body of research that shows the effectiveness of 'hands-on' and 'brains-on' activities in school science inside and outside the laboratory.

There is evidence that practical work can increase students' sense of ownership of their learning and can increase their motivation.

There is evidence that the teacher's role in helping students to compare their findings with those of their peers and with the wider science community is critical.

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Abrahams and Millar (2008, forthcoming) argue that,

> *…teachers need to devote a greater proportion of the lesson time to helping students use ideas associated with the phenomena they have produced, rather than seeing the successful production of the phenomenon as an end in itself.*

This finding has implications for pre-service and continuing professional development for teachers.

Students (and their teachers) need to understand something about the nature of science if they are to appreciate the limits and value of practical activities. The evidence suggests that teachers appear to adapt their practices slowly when faced with new curricula such as *Twenty First Century Science.* This finding also has implications for pre-service and continuing professional development of teachers.

EVIDENCE ON PRACTICAL WORK IN UK SCHOOLS

International comparisons (such as TIMSS) indicate that students in the UK spend more time on practical activities than do students in most other countries. The evidence seems to suggest that the amount of practical work in schools in the UK has not varied substantially in recent years. For example, in NESTA's survey of 510 UK science teachers, while 42% thought that the amount of practical work had increased over the preceding ten years, 32% thought the opposite (NESTA 2005, p.7).

There is some evidence that a significant number of students in the UK see science experiments as being enjoyable. For example, an online survey of students (n=1,450) reported that in terms of enjoyability of school science activities, the top three were *'going on a science trip or excursion'* (85%), *'looking at videos'* (75%) and *'doing a science experiment in class'* (71%) (Cerini *et al*. 2003, p.10).

but

When asked to choose the three methods that were most useful and effective in helping them to understand school science, 32% of respondents to an online survey chose *'doing a science investigation'* and 38% chose '*doing a science experiment in class'*. However, the two approaches that were regarded as being most useful and effective were *'having a discussion/debate in class'* (48%) and *'taking notes from the teacher'* (45%) (Cerini *et al*. 2003, p.10).

There is strong evidence that the current assessment regime in England and Wales has had a major impact on the amount and variety of practical work that many teachers carry out. There are growing concerns that the amount and quality of practical work carried out in schools have both suffered as a result of the impact of the national tests in science. This is the key finding in this review.

There is a *'chasm'* between what teachers identify as their outcomes before lessons and the outcomes that their students perceive.

Students fail to perceive the conceptual and procedural understandings that were the teachers' intended goals for the laboratory activities.

Students spend too much time following *'recipes'* and, consequently, practising lower level skills.

IMPLICATIONS

Advocates of more practical work in school science need to be clear about why they take this position and what types of activity they want to see happening. Woolnough and Allsop (1985) suggested three categories which might aid discussion about practical work: exercises, experiences and investigations.

Training in using practical activities might include developing teachers' understanding of theories of learning (such as the role of cognitive conflict), the use of argumentation in science and assessment for learning.

Training might usefully focus on the need to develop an awareness of the ranges and types of practical work, of the need to be clear about the purpose of activities carried out in school science education, and of how to assess learning outcomes.

Training, both pre-service and in-service, needs to be refocused and supported by more effective resources than are currently available.

In addition, we note that more practical work in science does not necessarily mean better practical work.

2.2 SURVEYS BY QUESTIONNAIRE OF TEACHERS AND TECHNICIANS

Two questionnaires were used to elicit responses from individual teachers and technicians. Both questionnaires used a web-based survey tool and were available UK-wide through the ASE website. The initial survey was designed for teachers in the 11-19 phase and provided the major source of data. This is in line with the overall focus of the initial concerns surrounding practical work in science.

The 11-19 questionnaire was completed by 1103 teachers and technicians. The survey was designed for teachers and was also drawn to the attention of technicians. Approximately (some respondents did not clearly identify themselves as such) 200 technicians responded, but it should be noted that some of the questions are not relevant to technicians and so were omitted by them. Approximately 14% of respondents were from the UK nations other than England (see Appendix 1) reflecting the fact that practical work is an issue of wider interest.

The primary survey was conducted using the same facility and was completed by 185 teachers and others involved in primary science. The principle purpose of this survey was to inform ASE's response to the current review of the primary curriculum in England, as well as to find out about practical science. Only the responses to the latter questions are presented and discussed in this report.

2.3 EVIDENCE SUBMITTED BY ASSOCIATIONS AND INDIVIDUALS

An open call for evidence was issued in order to encourage members of SCORE, other organisations and individuals to respond to a set of questions about the nature and purpose of practical work, the opportunities and barriers to high quality practical science and what needs to be done to support it, by government and its agencies, and by the organisation responding. 21 organisations and six individuals made submissions. A further ten teachers sent brief email observations on the survey. Respondents are listed in Appendix 2 and their comments and proposals are include in the discussion presented in the following sections alongside that of the surveys.

2.4 SUMMARY OF THE EVIDENCE BASE FOR THIS REPORT

Between March and August 2008, evidence for this report has been gathered from SCORE, a review of existing research literature, two online questionnaire surveys, a call for evidence from stakeholder organisations and individuals, and three workshops and electronic discussion involving other stakeholders.

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Regardless of the detailed issues and concerns raised, all the evidence indicates that the role of practical work in science is highly regarded and that getting the quality right in all schools, whatever their location or situation, must be the top priority. There is also a good base from which to develop in that the extent of practical work in England exceeds that of most other countries outside the UK and that there are many examples of existing good practice. Therefore an important element in the collection of the evidence was the need to better define the issues that had been raised and led to this report.

This section of the report brings together the three lines of evidence and considers them in relation to the key questions set out in Section 1.

3.1 WHAT IS MEANT BY PRACTICAL WORK IN SCIENCE?

'Practical work' and 'practical science' are terms that mean different things to different stakeholders. In order to inform the proposed strategy, this report considers a variety of definitions of 'practical work in science' and presents a clear and agreed definition.

3.1.1 EXISTING DEFINITIONS OF PRACTICAL WORK

The scope of the literature review included consideration of existing definitions of 'practical work'. As noted in Section 2.1.2, the review of literature concluded that,

> *There is confusion in the broader science education community about the definition of 'practical work'.*
>
> *This confusion makes discussions about the value of 'practical work' difficult.*

In writing the literature review Dillon argues that the National Curriculum's use of terms has not been sufficiently precise and recommends a 'classical definition' used by Lunetta *et al.* (2007) stating that practical work is

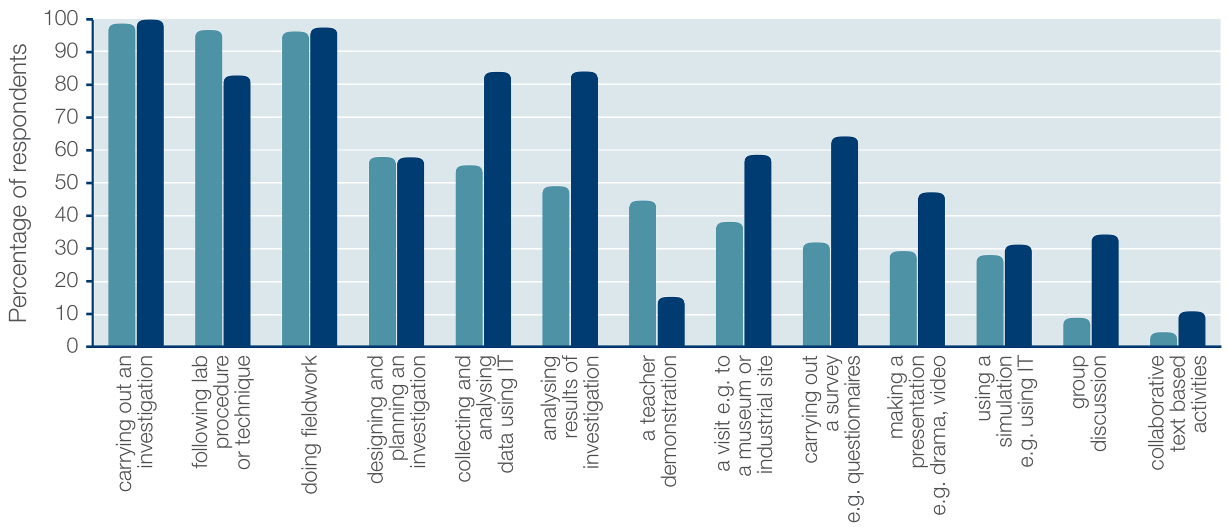
> *..learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world.*

3.1.2 AGREED DEFINITIONS OF PRACTICAL WORK

The views of current practitioners and other stakeholders on their definition of 'practical work' were also explored through the questionnaires, submitted evidence and during stakeholder workshops.

The questionnaires endeavoured to identify what teachers considered to be practical work in terms of specific activities rather than overarching statements. Both the primary and secondary survey respondents were offered a list of 13 different types of activity (Figure 1). Two of these, investigations, and fieldwork were almost unanimously accepted as being seen as practical work. Also receiving majority support for inclusion were: laboratory procedures and techniques, collecting and analysing data using IT, designing and planning an investigation – though there are significant differences between primary and secondary responses.

Figure 1: Questionnaire responses: what do you consider practical work to be?



Those offering individual views mentioned similar activity categories in answer to the question 'What do you consider practical work to be?' (Table 1). The individual responses ranged from the inclusive: *doing things with stuff* (an 11 year-old quoted by HMI), *anything not theory* (the BA) to the specific: *building instruments* (Meteorologists), and *showing the distinctive nature of the different sciences and giving career orientation* (Pharmacologists).

Table 1: Submitted evidence: what do you consider practical work to be?

	Open respondents % (n=30)
Laboratory procedures and techniques	86
Investigating	50
Analysing results	43
Fieldwork	33
Designing and planning	26
Teacher demonstration	23
Data analysis with IT	20
IT simulations	20
Presentations	13
Models and modelling	7
Visits	3
Survey	3
Group text-based	0

Other individual respondents concentrated on processes rather than activities, and the questionnaire respondents agreed with this approach; around half approved of designing and planning, data collection (including using ICT), analysing and evaluating. Eight secondary teachers added modelling to the survey list.

It should be noted that this order of importance does not necessarily relate to the amount of time spent on these activities.

3.1.3 DIFFERENCES BETWEEN PRIMARY AND SECONDARY PHASES

The two groups differed more widely over what other activities should be included, primary teachers being significantly more inclusive e.g. two thirds would include a survey, compared to only one third of secondary teachers. The exception to this is the role of teacher demonstration. Included by almost half of secondary teachers, only 15% of primary consider that this is practical science. (It appears that the 'hands on' in primary are most emphatically the children's not the teacher's!)

3.1.4 COMPLEMENTARY ACTIVITIES

Some individual respondents considered that a number of activities such as discussion and text-based activities are useful complements to practical activities. However, they expressed concerns that they sometimes become substituted for practical work. The key issue, as a number of respondents stressed, is the importance of the link between the hands-on experience of the real world and the theoretical or conceptual framework of science (often called 'brains-on') – as the submission from Durham University put it, the need to *'observe through scientific spectacles'* which may not happen through undirected practical experience.

3.1.5 CONCLUSIONS

In conclusion, most stakeholders would accept a definition of practical work in science which includes investigation/enquiry and laboratory/fieldwork procedures and techniques. There is some concern that too wide a definition may reduce pupils' opportunities to engage with the physical world, but general agreement on the importance of activities which link these to the concepts, theories and context of science. A potentially significant difference is between primary and secondary teachers with respect to the role of teacher demonstration.

KEY FINDINGS

1. There is overarching agreement that ‘practical activities’ can be put into three broad groups: core activities, directly related activities and complementary activities. Practical work in science includes the core activities and the directly related activities. The complementary activities are important in supporting the development of conceptual understanding in science through practical work. In summary:

Practical Work in Science

Core activities
Investigations
Laboratory procedures and techniques
Fieldwork

Directly related activities
Designing and planning investigations
Data analysis using ICT
Analysing results
Teacher demonstrations
Experiencing phenomena

Complementary activities
Science-related visits
Surveys
Presentations and role play
Simulations including use of ICT
Models and modelling
Group discussion
Group text-based activities

3.2 WHAT ARE THE AIMS AND PURPOSES OF PRACTICAL WORK IN SCIENCE?

Practical work in science can clearly have many purposes. These were identified in the literature review and explored through the questionnaires.

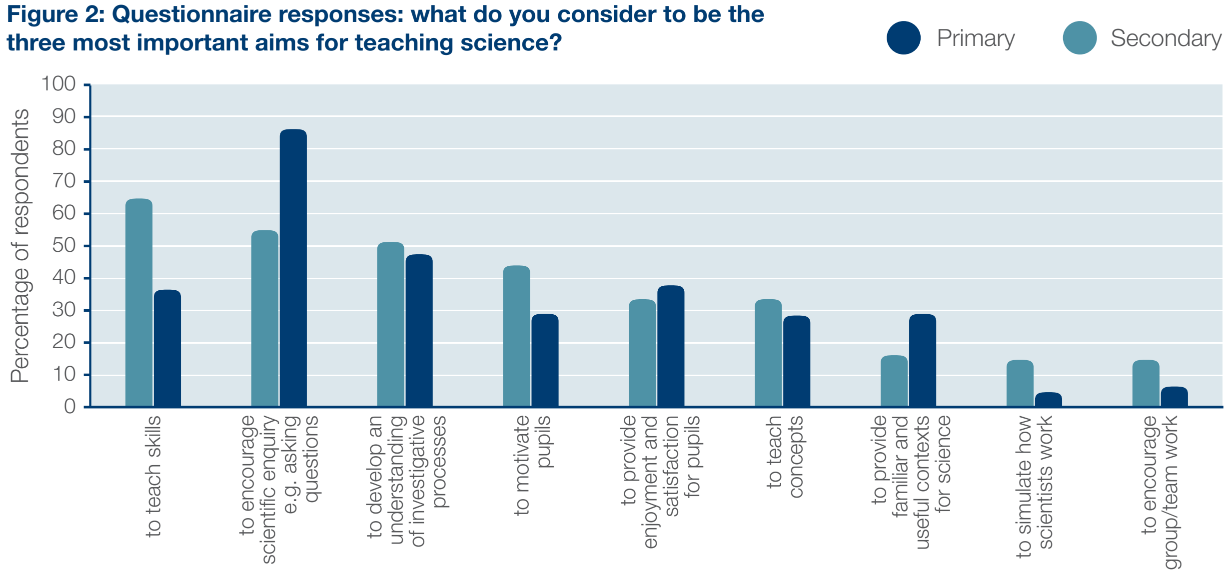
3.2.1 THE PURPOSES OF PRACTICAL WORK IN SCIENCE

The research review identified that there are a range of purposes for practical science; indeed there are several purposes for science education as a whole (e.g. science as general education as well as training for future career paths). Evidence is presented of the highly positive attitude that teachers and pupils have to practical science, though the evidence of pupil attitudes is equivocal and would benefit from further enquiry. Teachers’ and other stakeholders’ positive attitudes are borne out by the individual respondents who, in answer to the question ‘How important is practical work in science education?’ agreed it is vital – as one head of science put it: *‘science without practical is like swimming without water’*.

3.2.2 DIFFERENCES BETWEEN PRIMARY AND SECONDARY PHASES

The survey respondents were offered a list of nine different purposes for practical science and asked to choose the most important three. Within this constraint, primary teachers had clear priorities – developing scientific enquiry (85.9%) and almost half also chose the closely related ‘understanding investigative processes’.

Figure 2: Questionnaire responses: what do you consider to be the three most important aims for teaching science?



The major difference from secondary is the role of ‘teaching skills’ (about one third in primary and two thirds in secondary).

A further interesting difference between the two phases is the reverse importance each gives to pupil motivation and pupil enjoyment. Primary teachers are twice as likely to consider familiar and useful contexts, while secondary teachers slightly more likely to choose the development of concepts. A minority of both chose learning about how scientists work and promoting group work (Figure 2).

The individual respondents mirrored this order of importance of the secondary respondents quite closely, and between them added a few more: safety and risk management, creativity, the experience of phenomena and the ‘messiness’ of the material world and to encourage continuation in the study of science and the choice of science-related careers (Table 2).

3.2.3 CONCLUSIONS

In conclusion, there seems to be a broad consensus for the range and priorities of purposes for practical science, though it is of concern that only 30% included concept development as one of their top three reasons for practical work. The following sections explore how the actual practice in schools might not match this range of purposes and practices.

KEY FINDINGS

2. The importance of practical work in science is widely accepted and it is acknowledged that good quality practical work promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding.

3.3 WHAT IS THE IMPACT OF GOOD PRACTICE AND EFFECTIVE PEDAGOGY?

It is very clear that practical work in itself does not automatically improve learning in science rather it must be fully integrated as a major element of effective pedagogy in science.

Table 2: Submitted evidence: how important is practical work in science education?

	Open respondents % (n=30)
Teach skills	70
Motivate pupils	60
Understand investigation processes	47
Encourage enquiry	37
Teach concepts	37
Provide pupil enjoyment	33
Show how science works	23
Link practical to theory	23
Provide science contexts	20
Encourage creativity	13
Encourage group work	7

The literature review has much to report on this area, quoting in summary from the most recent extensive published review of teaching and learning in school science:

> *When well planned and effectively implemented, science education laboratory and simulation experiences situate students’ learning in varying levels of inquiry requiring students to be both mentally and physically engaged in ways that are not possible in other science education experiences ...Social learning theory makes clear the importance of prompting group work in the laboratory so that meaningful conceptually focused dialogue takes place between students as well as between the teacher and the students.* (Lunetta *et al*. 2007, p.405).

The literature review also highlights sources of research into good practices, in particular the way to make the links between ‘hands-on’ and ‘brains-on experiences’(e.g. Millar 2004 p.12)), and the considerable literature (e.g. Rocard *et al.* 2007, p.8, Pollen 2007, Abrahams and Millar 2008) on the effectiveness of enquiry learning. As a contrast there are also reports of how practice often falls short, and in particular the evidence of pupil’s difficulties which result (Keys 1998).

3.3.1 FROM THE LEARNER'S PERSPECTIVE

The review emphasises the importance of pupils' ownership of their practical science for their motivation and learning. Quotations from an extensive student-run survey of views, carried out during Science Year (Cerini *et al.* 2003), suggest how students are well-aware of which kinds of activities promote learning. Many researchers have emphasised the need to make the purposes of practical work more explicit to learners (e.g. Millar 2004, Abrahams and Millar 2008, Sere 2001) and have stressed the teachers' aims for practical work are often found to be rather limited:

> *The teachers' focus in these lessons was predominantly on developing students' substantive scientific knowledge, rather than on developing understanding of scientific enquiry procedures. Practical work was generally effective in getting students to do what was intended with physical objects, but much less effective in getting them to use the scientific ideas to guide their actions and reflect upon the data they collect. There was little evidence that the cognitive challenge of linking observables to ideas is recognised by those who design practical activities for science lessons.* (Abrahams and Millar 2008, in a study of 25 'typical' science lessons).

Such responses reinforce the finding from the current survey that only 30% of respondents considered the development of concepts to be in the top three purposes of practical work. However further exploration of these responses would be desirable in order to clarify the way in which the 'development of concepts' has been interpreted.

The strong influence of Constructivism on the development of good practice in science pedagogy is illustrated by the comment in Lunetta *et al.* (2007):

> *Learners construct knowledge by solving genuine, meaningful problems.*

There is research on the importance of putting learners in situations where they experience the uncertainties of the real world and how scientists (and science) deal with this. The recent GCSE 'Science for the Twenty First Century' is an example of a course which has tackled this. The review of the research concludes:

> *Given what we know about learning in science (Bybee 2000, Bransford et al. 2000), we are in a position to identify which activities, practical or otherwise, are likely to engage students and help them to develop an understanding of what science is and how science works.*

3.3.2 TEACHERS' CONFIDENCE

In the questionnaires, respondents were not asked directly about their teaching methods but were asked to indicate how confident they were in undertaking practical work in science and why. Over 60% of both primary and secondary teachers said they were confident and a further third were fairly confident. The main reasons given for this were experience (including experience gained e.g. as a scientist, prior to becoming a teacher), knowing the subject and having enthusiasm for it, and having time to practice in school or to attend courses and conferences.

It is clear from the individual responses to this item, that practical work in science is well-embedded in the professional life of teachers of science and that there is an almost universal expectation that a teacher will develop expertise in this, in time. However this still leaves open the question of why confidence is so high when other evidence questions the quality and range of practical work that is undertaken.

3.3.3 THE VALUE OF GROUP WORK

Other ways in which practical work influences pedagogy also came through in both the questionnaire responses and discussions. In particular the value of group work in practical science is important in the context of employers' perceptions of the need for better team-working and other 'soft' skills. Teachers sometimes behave as if the reason pupils work in groups is that there is insufficient equipment for them to work individually. It could be useful to pay more explicit attention to the encouragement of interpersonal skills through working in groups alongside developing speaking and listening skills through discussion in science around the practical activities. It is likely that this would also strengthen the connections between 'hands-on' and 'brains-on' experiences and the pupils' sense of ownership.

3.3.4 CONCLUSIONS

In conclusion, it is a matter for debate as to whether the levels of confidence, self-recorded in the surveys, are above or below expectations of good practice but it is noteworthy that these levels are similar in primary and secondary. One could conclude from this, that confidence as a teacher of science is not determined simply by how much science one knows. What is clear from the respondents, however, is the degree to which practical work is considered to be fundamental and prevalent to their teaching of science.

This very clear and positive finding must be built on in taking forward a strategy as is the strong view that confidence in practical work, for both teachers and students, is gained by doing it. From this it may be possible, for example, to develop a learning package for teachers' CPD, to promote good practice. The promotion of this, during the early years of a teacher's career, could help to 'fast-track' the gaining of experience, seen as essential by most respondents to the survey.

KEY FINDINGS

3. There is a strong commitment to high quality practical work in science among teachers, technicians, and other stakeholders alike.
4. There is a wide range of good practical work in science taking place across the UK but there are indications that the situation could be improved by extending good practice and focussing on the quality, rather than just the quantity, of practical work.
5. Effective pedagogy is at the heart of improving the quality of practical work in science. When well planned and effectively implemented, practical work stimulates and engages students' learning at varying levels of inquiry challenging them both mentally and physically in ways that are not possible through other science education experiences.
6. Many teachers indicated that they felt confident doing practical work but there was a very strong indication that this was because they had been able to gain experience over a period of time.

3.4 ENABLERS AND BARRIERS TO PRACTICAL WORK IN SCIENCE

Research into these issues was covered in the review; individual respondents were asked specifically to identify these and the secondary questionnaire asked several questions which addressed aspects of these issues. The primary phase survey asked only how ASE could offer better support.

3.4.1 ENABLERS

Table 3 shows that there was a wide range of responses from secondary respondents to the open question 'What would improve confidence in teaching practical science?' This range is presumably a reflection of local circumstances, including the experience of the teacher responding. The factors that were referred to most often are not unexpected and reflect other anecdotal evidence.

Other responses included more knowledge, finding suitable ideas e.g. on the Internet, getting feedback from pupils, class size, the curriculum and improved laboratory spaces.

Primary teachers had a similarly wide range of responses and issues that were raised but there were several significant differences that included:

- no expectation of technical support;
- no explicit mention of safety worries;
- more emphasis on CPD, especially for subject knowledge;
- more time on the curriculum for science; less emphasis on literacy and numeracy.

Each of which reflects, in general, the different situation in primary schools compared to secondary.

Table 3: Questionnaire responses: what would improve confidence in teaching practical science? Most frequent responses in rank order.

Rank	Enablers
1	Time (for preparation)
2	Training (especially in non specialism)
3	Pupil behaviour
4	Technical support
5	Money for equipment
6	Health and safety worries overcome
7	Support from colleagues

3.4.2 BARRIERS

Tables 4a and 4b summarise the most frequent responses, in rank order, to the questions; Why does your current practice (of teaching practical science) vary from your ideal? and What would improve the situation? for the secondary questionnaire respondents and the individual respondents, respectively. A small number of respondents indicated that they saw no barriers.

Table 4a: Questionnaire responses: barriers to practical work in science. Most frequent responses from teachers and technicians in rank order.

Rank	Barriers
1	Curriculum content
2	Resources and facilities
3	Time
4	Exams and assessment
6	Pupils' behaviour
7	Teachers' inexperience
8	Technical support
9	Health and safety
10	Class size
11	Lesson length

Table 4b: Submitted evidence: barriers to practical work in science. Individual respondent's most frequent references in rank order.

Rank	Barriers
1	Resources and facilities
2	Teachers' inexperience
3	Health and safety
4	Technical support
5	Exams and assessment
6	Pupils' behaviour
7	Curriculum (content and resources)
8	Time
9	Lack of CPD

The use of simulations instead of hands-on experience, lack of computers, and lack of senior management support were also mentioned but the frequency was less than 10 respondents in each case. All the above seem predicated on the assumption that these are barriers to more practical work. Four respondents thought there was too much practical work.

In contrast to the vast majority of the evidence, there are striking differences in the way in which barriers to practical work are perceived by the questionnaire respondents who are mainly in the classroom and the individual respondents to the call for evidence, who are largely outside the classroom or school. This is perhaps a consequence of good intentions e.g. of a new curriculum not being implemented satisfactorily, possibly because schools are not recognising, or remedying the inexperience of teachers both when teaching a new course, or teaching outside their subject specialism.

3.4.3 RESOURCES: EQUIPMENT AND FACILITIES

The literature report is limited but notes that there is an increased use of 'out of classroom' settings, including fieldwork (Rickinson 2004). On the inadequacy of provision it refers to the work of CLEAPSS and the Royal Society of Chemistry (RSC), both of whom have responded forcefully on this in their own right. Almost all of the 21 organisations who responded raised this as a barrier, as did three of the six individuals, often with much helpful detail (e.g. Peter Borrows). Concerns were expressed that Project Faraday (a laboratory design project), and the Building Schools for the Future programme, have not been sufficiently well-informed by science teachers' needs. Secondary questionnaire responses identified this as significant constraint, second in importance only to curriculum content, and many referred to the lack of available laboratories.

There were a number of suggestions as to how this barrier could be overcome, from the respondents, including:

- increasing the funding and ring-fencing it for science resources;
- match independent schools' funding;
- extend Project Faraday laboratory design project, to include equipment and CPD for science staff.

A number of the institutional respondents referred to resources they produce to provide support to teachers in practical science (e.g. IOP website www.practicalphysics.org and the resources of the Association for the study of Animal Behaviour).

3.4.4 SAFETY AND TECHNICAL SUPPORT

The literature review reports that evidence to the House of Lords inquiry into *Science teaching in schools* indicates curriculum developers, such as the Nuffield Foundation, provide practical ideas with new specifications, but this is not common elsewhere and teachers often struggle to find the time to develop practical activities for a changed syllabus. One author who responded gave details of the constraints which operate in publishing practical resources. For example authors may only be available to write when they have no easy access to laboratory facilities; CLEAPSS offers a service to vet the safety of activities, at proof stage – it would be more useful if it had a developmental role. Caution over safety matters can lead to vagueness in providing practical details (paradoxically), making more work for the teacher or technician in school.

Secondary questionnaire responses considering what needs to improve, highlight this with the highest number wanting more preparation time for practical work and asking for more technician support to improve their practical science. This is exacerbated by concerns about health and safety though several respondents acknowledge that these fears may be ill-founded. CLEAPSS has researched the perception of increased proscription of certain activities (e.g. involving chemicals and blood sampling), and found that these are almost insignificant, but that teachers often have misconceptions. What is of greater concern to teachers is whether pupils' behaviour will make procedures unsafe. This was the second most common barrier mentioned in the questionnaire responses and was also noted by about a third of the institutions as an issue of classroom management.

3.4.5 CURRICULUM AND ASSESSMENT

The research reports on the evidence of the Science Learning Centres, CLEAPSS and NESTA (from Science Year) of the damaging effect of 'teaching to the test'. In the literature review, Dillon summarises this as:

> *There are growing concerns that the amount and quality of practical work carried out in schools have both suffered as a result of the impact of the national tests in science. This is the key finding in this review.*

Though there is not much research evidence quoted, the concern is certainly apparent from other aspects of this enquiry. It was the second most common constraint named in the secondary questionnaire responses. Significantly, it was exceeded only by the constraints of the curriculum, where many respondents referred to the recent changes at KS4 as substantially reducing the opportunities for practical work. There appear to be at least two reasons for this; unfamiliarity with the new specifications and the different intentions of a course such as 'Science for the Twenty First Century' often characterised as requiring discussion to the exclusion of hands-on experiences. The organisations responding also expressed concerns about the assessment emphasis; they were less critical of the curriculum but several with industrial links thought that recent changes could reduce the opportunity to develop practical skills.

3.4.6 TIME

The questionnaires asked the approximate percentage of time spent on practical work at different stages of secondary school (Figure 3). They were also asked if this had changed 'in recent years' (Figure 4).

Figure 3: Amount of time spent on practical work in science

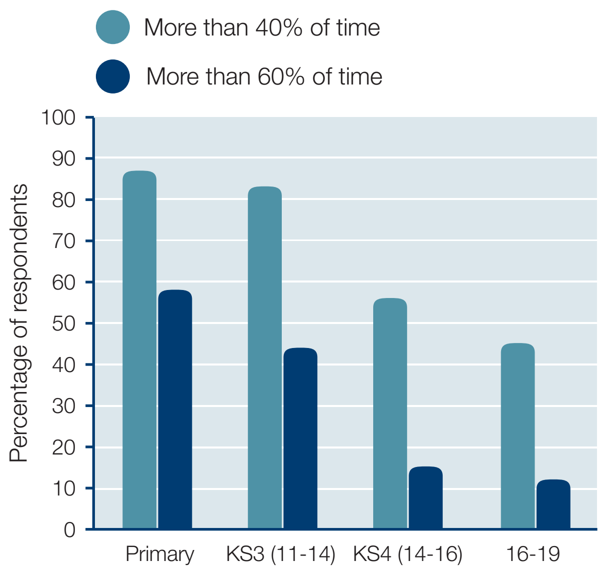
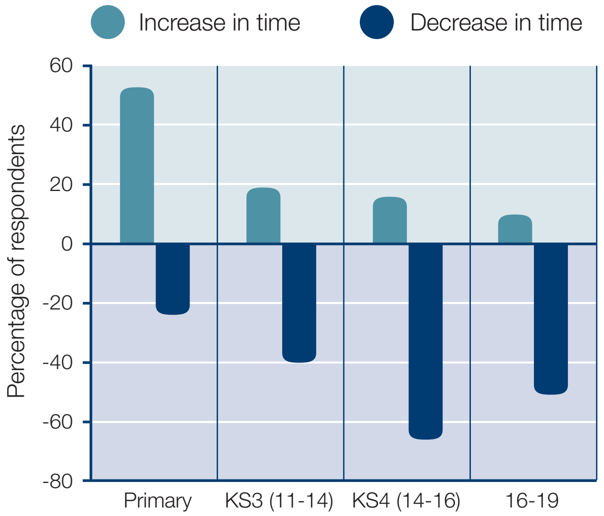


Figure 4: Recent changes in time spent on practical work



It is notable that the incidence of practical work in science is perceived by teachers to be very substantial, which matches the importance they give it. Over half of primary respondents have seen an increase in the time devoted to practical in recent years, though in only 18% of responses was this a significant increase. Despite the high percentage of secondary teachers who have experienced a fall in the time for practical recently, the mean time spent on practical science in secondary schools appears to be between one third and a half of all lesson time. Note that these responses may be misleading due to individual interpretation of not only the question but also what is considered to be 'practical work'.

3.4.7 TEACHER EXPERTISE

Half of the organisations responding highlighted the issue of non-specialist teachers, confident in their own area but uncertain in their practical competence outside this. The problem is considered to be more serious in the physical sciences and this could have a knock-on effect of reducing the number of pupils who enjoy these subjects, so reducing the pool of expertise further. About 2% of secondary teachers mentioned that this was reducing their confidence.

It has however been noted that, the IOP and RSC have been tackling this with projects funded by the TDA and the Gatsby Charitable Foundation which enhance the training of PGCE students or offer additional support and training to science teachers who are non-specialists in Chemistry and Physics. The evaluation of the Physics Enhancement Programme (PEP) found that NQTs particularly valued the mentoring support in their preparation of practical physics activities. This is also a feature of the new Science Additional Specialism Programme (SASP) courses for teachers who are developing their second specialism.

Respondents to the primary questionnaire, when asked about what would improve their confidence were notably positive. It was often difficult to separate out what had made them confident, from what was required to improve this. The reason could be that the sample responding was quite small, and appeared to be unrepresentative in terms of experience in science. Many said they had science backgrounds, had been secondary teachers or were ASTs, tutors and advisers. There were however about 10% who mentioned aspects of knowledge and understanding of science. The main areas mentioned were physical science and science skills.

3.4.8 TRAINING AND PROFESSIONAL DEVELOPMENT

The primary survey showed a substantial appetite for CPD in all forms – courses, conferences, working with colleagues etc. This is borne out by the response to the question, 'When did you last undertake some primary science CPD?' with 41% saying 'this term' and a further 34% 'this year'. Secondary teachers were asked specifically about CPD in practical science. Only 21% said they had had any in the last year and over 40% of respondents could not remember ever having received CPD in practical science. This is a very significant finding as many secondary teachers listed CPD as a priority to overcoming barriers to good practical science. Most of these emphasised that the training and CPD should be practically based and quite specific – related for example to areas of subject inexperience or to new course requirements.

There is also seen to be a need for technician and HLTA training and a better career structure for technicians. The research report identified a number of priority areas for CPD, including the range, purposes and assessment of practical science, how to relate practical experiences to the learning of scientific theories, and identifying sources of continuing support such as online resources. The organisation respondents had proposals for improving the provision of CPD, such as increased funding, ring-fenced funding, the targeting of the early years of teaching by a scheme such as the IOP's Physics Enhancement Programme, and the requirement for CPD to be part of registration with the GTC (for which ASE's CSciTeach already provides a model).

3.4.9 CONCLUSIONS

Based on the evidence gained during this study there is clearly an overall positive attitude towards practical work and there are some good examples but there are also several messages that need to be addressed:

- There is well-documented evidence about the shortcomings of equipment funding, particularly in secondary schools; the need is to ensure that those who make decisions in these matters are well-informed.
- There are currently no serious threats to practical science from health and safety requirements, but the situation needs to be kept under review. Locally, in some secondary schools, pupils' behaviour and a lack of technical expertise may result in significant reductions in practical science.
- The current assessment demands are damaging practical science.
- Many teachers believe that the new GCSE courses have significantly reduced the amount of practical science in KS4. This is likely to be due to a lack of experience and/or understanding of the aims of the changes to the KS4 science curriculum.
- Although many teachers are dissatisfied with the amount of time and resources for practical science and some have experienced falls in provision, the time devoted to it is still substantial.
- Mentoring of inexperienced teachers can build confidence in practical science.
- Opportunities for training and professional development, particularly for secondary teachers and for technicians, are inadequate.

KEY FINDINGS

7. There is well-documented evidence of the shortcomings of equipment funding and replacement of laboratories which require continued monitoring and should be addressed as part of wider strategy and improvement in facilities.
8. Although there are currently no serious threats to practical science from health and safety requirements, there is a negative impact resulting from perceptions as to the restriction imposed by health and safety concerns, particularly regarding field trips. This latter situation needs to be addressed and kept under review as new legislation, pupils' behaviour and a lack of technical support can result in significant reductions in practical work in science.
9. Although many teachers expressed dissatisfaction with the amount of time and resources for practical work in science and reported falls in provision, the time devoted to it is still substantial, with 80% indicating they spent more than 40% of lesson time at KS3 doing practical work, though only 56% and 45% reporting that they spent more than 40% of time at KS4 and KS5 respectively.
10. There was concern expressed that teachers did not necessarily feel confident in carrying out practical work outside their specialist discipline. The importance of mentoring of inexperienced teachers was noted as a way of building confidence.
11. Subject-specific professional development, or rather the lack of it, has been highlighted in other reports. More specifically the questionnaire responses indicated that, although 21% of teachers engaged in CPD specifically related to practical work in the last year, over 40% indicated they could not remember 'ever' receiving CPD on practical work. Opportunities for training and professional development for teachers and for technicians, to support practical work, need to be improved and teachers and technicians engaged with these.

3.5 OPPORTUNITIES FOR THE DEVELOPMENT OF PRACTICAL WORK IN SCIENCE

In this review, it is important to look forward as well as to take stock of the current situation. The research report included a review of 'research at the cutting edge', much of which is being carried out across Europe and in the US. It is not clear how appropriate the findings might be, to apply in the UK, though the motivations are common – to improve attainment and to increase the numbers studying science in higher education. Details of the areas of research are mainly under the general heading of 'enquiry science' and follow up many of the issues discussed above.

3.5.1 ICT

Information and Communication Technology (ICT), has the potential to impact on practical science in a number of ways. These include sensors for ease of data collection, computational data analysis tools, computer simulations to present science concepts and the Internet for information, including data, concepts and contexts for science. The evidence in the research report is, broadly speaking, that it has so far promised more than it has delivered (Lunetta *et al.* 2007) and that there is some excess of supply over demand (London Challenge 2007).

Individual respondents were asked specifically their views on the use of ICT in investigations and enquiry. Of the half who addressed this question, almost all insisted that it should supplement not replace hands-on experience. There was widest support for the data analysis capability, because of its facility and also that its use could show what scientists do. A few considered its value in experimental design, and for gathering data from the Internet (though there was a concern that the data and the designs would not be 'real and messy'). Only one respondent (a teacher) considered these were an essential part of science education.

Simulations were considered to have a role in developing understanding, through presenting ideas clearly and attractively. Those showing dangerous situations and those allowing pupils' inputs were considered particularly valuable. There was a concern that pupils might not be taught that simulations could not provide evidence.

The responses to the question 'what would improve the situation in practical work?' appear to validate the findings in other research that demand for ICT is not as great as might be generally expected.

3.5.2 CURRICULUM AND ASSESSMENT DEVELOPMENTS

Secondary questionnaire respondents were generally critical of recent and forthcoming changes in the science curriculum and its assessment. Many considered that the GCSE changes of 2006 had been detrimental to practical science. Only one of the 643 respondents showed the confidence to write:

> *Over time I will develop my GCSE course to include more practical work especially for illustrative purposes (i.e. to support theory being taught).*

A handful of others expected there to be better practical activities available through published resources. Plans to improve the curriculum in Scotland (A Curriculum for Excellence) and England (at KS3) evoked no positive expectations from respondents; many considering that assessment is the key to improving the situation. A number of primary phase respondents felt that more help was needed in good assessment practice and the Primary National Strategy should include science, since it is a core subject.

Individual respondents offered help with some of these issues. OCR made the important point that if practical science is not assessed this would put at risk the provision of facilities. However, they conclude:

> *Assessment of practical skills in the sciences is currently narrow in scope and repetitive and probably has an unhelpful influence on the way in which practical work in used in teaching.*

They propose:

> *Moving assessment of practical skills into free-standing qualifications in practical competence may be a way of improving.....*

Respondents from industry-linked organisations have suggestions to improve the resourcing of the newer applied courses and diplomas. Other organisations drew attention to the wide range of practical resources and courses which they currently provide. Several teachers who made individual responses offered to test new practical activities.

3.5.3 CONCLUSIONS

The roles of ICT within practical work in science were explored. The majority of respondents feel it should supplement and not replace hands-on activity. Indeed, this research found a low level of expectation that developments of ICT would improve practical work in science.

As was discussed in Section 3.4.6, 66% of the respondents to the questionnaire indicated that the amount of practical work at KS4 had been reduced in recent years. This finding is supported by the critical comments relating to the impact of the GCSE changes in 2006, and their impact on practical work in science.

There is a striking lack of expectation by teachers that future developments, from educational research, ICT provision or new courses, will improve the position of practical work in science. This indicates a need for both dissemination of the work that has been done, and an improved infrastructure for training and professional development of teachers and technicians.

KEY FINDINGS

12. The use of ICT is a vexed question that exposes inherent tensions. There is, however, an underlying consensus that ICT should supplement and enhance practical work not replace it. How this is to be done is not well understood and many respondents to the questionnaire did not see ICT as a way of improving practical work.
13. Current assessment demands are damaging and restricting practical science; 66% of the respondents to the questionnaire indicated that the amount of practical work at KS4 had been reduced in recent years. Lack of experience and/or understanding of the aims of the new GCSE courses appear to have adversely affected the amount of practical work at KS4 in a considerable number of schools.

The three sources of evidence and some provisional conclusions were presented to a wide range of stakeholders with an interest in practical science, at a meeting at the Royal Society on 16 April 2008. The attendees are listed in Appendix 3 and others contributed comments on the evidence via email. It should be noted that the results of the Primary Survey were not available at that time, but it was agreed that the report and strategy should include practical science in Primary Schools.

Based on their deliberations on the evidence available, this stakeholder group highlighted particular issues that need to be clarified and given further consideration. The following extracts from these discussions emphasise those aspects that were felt to require particular attention. The group then suggested possible elements that should contribute to an overall strategy.

4.1 IDENTIFIED ISSUES

4.1.1 DEFINITIONS AND PURPOSES

In relation to the definition and purposes for practical work in science it was felt that:

- There is a tension between the use of primary and secondary data. In particular it was argued that promoting the role of analysis of secondary data as part of practical work should not come at the expense of generating primary data – there is a place for both and the issue is less where the data come from rather what is done with it. In generating primary data students experience more of the messiness and dead-ends that require them to be creative, problem-solve and deeply understand what they are doing than might be required when given cleaned-up secondary data.
- There are inherent risks in using *simulated data*, highlighted by the fact that an increasing number of students appeared to be having difficulty discerning the difference between real and simulated data.
- There appears to be little explicit evidence as to how practical work helps students to progress in science. It was noted that there are some ongoing studies which might better elucidate the situation.

4.1.2 GOOD PRACTICE

The stakeholders reiterated again that it was the quality, not simply quantity, of practical work that is the important message that should be promoted. They drew particular attention to:

- The indication that questionnaire respondents appear to think that any reduction of time spent on practical is bad for the pupil's science education, but they may have been doing the same thing over and over again, and are probably now doing a greater variety of activity.
- The fact that good practice includes: consideration of purposes, pupil ownership, classroom management, learning from the successes of out of school activities including science clubs.

4.1.3 TEACHERS' CONFIDENCE AND PROFESSIONAL DEVELOPMENT

While the stakeholders' group accepted the importance of teachers' confidence in teaching practical work it advised caution as to the interpretation of the survey findings. The questionnaire results on levels of confidence can be read in a positive way (almost all are confident or fairly confident) or negative (why are 1/3 only 'fairly confident'?). SCORE might consider whether it would aim for 100% of science teachers to be very confident. Furthermore, those teachers expressing confidence in practical work may be staying within their comfort zone and may not actually be practicing a high quality of practical work. The arguably high levels of confidence might also explain the relatively low levels of CPD in practical work – if a teacher feels confident they are unlikely to be seeking CPD.

4.1.4 USE AND AVAILABILITY OF RESOURCES

Having the right resources available at the appropriate time is an obvious pre-requisite for high quality practical work but the stakeholder discussions gave additional insights into the issue:

- Resources might be available but may not be being used to their full potential. For example, there is some evidence that the systematic use of data logging across science departments is much lower than it could be given the situations where the collection of continuous data would be of benefit.
- Much work is taking place on the design of laboratories but it is arguable how well the work is driven by the needs of teachers and technicians. The starting point should be on 'how do schools spaces support practical work?' as a minimum requirement laboratories should:
  - have enough space;
  - have gas electricity and water points in sufficient quantity to allow flexibility of use;
  - be 'future proofed' as far as possible.
- Resource/guidance/schemes of work that teachers use are very influential but it was reported that commercially published schemes are unlikely to promote practical work which requires any equipment/technician support/time that the average school is unlikely to have because this would affect their marketability. In contrast curriculum development projects, which are less dependent on achieving market share, can often explore new ground and introduce a wider range of practical work.

4.1.5 SAFETY AND TECHNICAL SUPPORT

Concern was expressed that, despite general agreement of all stakeholders on the importance of good technical support, much needs to be done to ensure that:

- school science technicians are given a stronger profile as experts in their own area and not treated simply as general support staff;
- specific training needs and career structure are provided for technical staff;
- there should be adequate technical staff to meet the needs of the school science department.

Safety issues are too often seen in a negative light but it was pointed out the new legislation such as REACH (Health and Safety) legislation could act as a driver for need of improved CPD for both teachers and technicians.

4.1.6 IMPACT OF ASSESSMENT PRESSURES

The impact of assessment is well documented but it was noted that:

- The emphasis on controlled assessment in some qualifications means practical tasks are set by awarding bodies and therefore need to be deliverable within a 30 – 60 minute slot, be 100% reliable, deliver results for every student in that group, be prepared quickly by technician and use equipment available in every school in the country. OCR A level students have to do 3 tasks in a year at a minimum and while there is scope for more, the priority is always on the prescribed tasks.
- Assessing group work might help in classroom management and support progression into such university courses as engineering where assessed group project work is the norm.

4.2 RECOMMENDATIONS FOR FURTHER WORK

The stakeholder group, in response to a request to consider ways in which some of the issues might be addressed, outlined several elements that might be included in a strategic framework.

4.2.1 PRODUCE A TEACHER AND TECHNICIAN GUIDE

This should include a definition of practical work in science, the key messages about nature, purposes and good practice in practical science. It could include an agreed list of experiments that all children should carry out and a list of demonstrations that all children should see. This has implications for the resourcing of departments and professional development. Given the current position of practical work, there is no requirement, for example, that all children should ever see Brownian motion. There would have to be debate about what should be in and what should be out, not to mention whether or not such an idea is desirable.

4.2.2 PROMOTE GOOD PRACTICE

This could be by use of case studies etc, and would include considerations of:

- time for preparation;
- use of laboratory space;
- development of a teacher's expertise;
- leadership within science departments and school decision-making;
- financial aspects;
- outside support from university departments, industry and science institutes.

4.2.3 DEVELOP A MORE COHERENT, SUSTAINED PROGRAMME OF CPD IN PRACTICAL WORK

Initial teacher trainers rely on schools to deliver practical training to trainees - this could be developed into an induction year practical programme during which NQTs are required to attend regular sessions on practical work during the year, for instance, once a month. Alternatively, elements of the PGCE programme could be devoted to the value of practical work in the classroom. The ITT programme is already crowded, nevertheless such work is being carried out currently at King's College, Birmingham and Leeds (e.g. with support from the IOP's PEP programme and the Gatsby Charitable Foundation). The introduction of a Masters in Teaching and Learning could open opportunities for modules on practical work.

There should also be a link to early years' professional development and accreditation to take advantage of points earned in PGCE programmes, backed by an entitlement to CPD and a choice of offer. It could be a requirement that each year at least one school INSET session be available to the science department to explore the use of the practical work in their teaching. Evenings, weekends and holidays could be explored as possible times to hold INSET sessions, although this may lead to demands for payment. Perhaps practical work should be part of teacher standards so that it would need to be clearly exemplified.

Such a CPD programme would need to engage providers beyond the school, including:

- university department working with their students and with the local teacher community;
- Excellent Teachers could lead the in-school INSET sessions;
- ASTs could lead sessions in collegiate groupings of schools;
- Science Learning Centres could provide courses;
- SSAT schools and support structures could be involved;
- learned societies could be involved.

This work should be under-pinned with necessary training of laboratory technicians and their availability: e.g. an AST running a session on practical work will require significant support from a technician to prepare adequately.

4.2.4 IMPROVE INFORMATION FLOW ABOUT GOOD PRACTICAL SCIENCE

Teachers and trainers need to be able to refer easily to common materials supporting practical work. The existing sources of information could be drawn together into a compendium that is structured so that it relates to current GCE, GCSE, KS3 or primary courses.

4.2.5 INFLUENCE POLICY-MAKERS TO TAKE DECISIONS THAT WOULD SUPPORT PRACTICAL SCIENCE

The stakeholders suggested a range of influencing activities that they thought SCORE could undertake.

a. Ring-fence money for practical work
School science departments differ in their resourcing levels and this affects their ability to equally offer high-quality practical work. A solution might be to ring-fence science department funding (capital and recurrent budgets).

b. Define a maximum class size for practical science
Class size has impacts on behaviour and its management and therefore on practical work in science. There is a statutory requirement in Scotland for a maximum class size of 20 students. However there are consequences of making this statutory, particularly for small schools where a class of 22 then has to be split, and it also restricts flexibility in terms of relating class size to behaviour (the higher ability groups may not need to be in small classes possibly releasing teachers to focus on struggling students).

c. Arrange a meeting between awarding bodies
Given the influence of assessment on practical work, a meeting bringing together all the awarding bodies to discuss mutual ways forward could deliver progress.

d. Require Ofsted to inspect and report on quality of practical science as a routine part of their inspections

4.3 IMPLEMENTING A STRATEGY

In implementing any of these suggestions it was advised that the strategy should work through existing frameworks, and should be piloted in schools. Creating new structures, or introducing significant change, may not be successful in producing a sustained improvement in the use of practical work in science teaching. Working through existing structures and institutions has the advantage of linking to funding that is already in place. It was also suggested that monitoring of impact of the strategy could be done through the ESRC-funded research into longitudinal studies of science education.

SCORE has carefully considered the evidence presented in this report and believes that the findings to date provide support for a strategy which:

a. improves the effectiveness of existing provision through improved dialogue and awareness of initiatives and an agreed definition of what is considered to be practical work in science;

b. embodies a strong communications strategy for dissemination of information including details of support that is available to support practical work and to engage in debate about ways in which practical work in science can be further improved;

c. strengthens support and professional development specifically focused on improving practical work in science thereby building capacity and sustainability;

d. is based on evidence which can better define the problems, support the monitoring and evaluation of the impact of the strategy during its implementation and influence existing and future policy-making.

These four purposes in turn lead to a strategic framework with has five integrated strands of activity which are exemplified below.

5.1 STRAND A: LEADERSHIP AND MANAGEMENT

This strand requires the establishment of a 'management group', convened by SCORE, with a membership that includes SCORE members, representatives of DCSF, DIUS, National Network of Science Learning Centres, Secondary National Strategy, SSAT, CLEAPSS, Gatsby Charitable Foundation and industrial partners.

The remit of the group would be to:

- act as a steering and monitoring group for the practical work in science strategy;
- ensure that existing provision for supporting practical work in science was shared and potential anomalies highlighted and addressed where possible;
- generate and run a series of workshops on specific aspects of practical work in science that could inform future activities;
- provide advice on further developments to support practical work in science.

5.2 STRAND B: COMMUNICATION AND DISSEMINATION

This strand will aim to raise the profile of practical work and to maximise the awareness of the support that is available to support practical work in science. In particular this strand will look to:

- publish a widely supported 'framework' for practical work in science which includes a consensus statement on what constitutes 'practical work in science', aims and purposes for practical work and an outline of the strategy to improve practical work in schools and colleges;
- ensure that information about all resources for practical work in science is widely available and easily accessible e.g. promoting the practicalbiololgy, practicalphysics and practicalchemistry websites in one booklet;
- disseminate resources which exemplify good practice e.g. 'Interactive Practicals' and 'Effective Demonstrations' booklets produced through the Secondary National Strategy;
- promote existing resources and information about good quality resourcing, of equipment, laboratory design and for other settings such as fieldwork;
- produce information on purposes, practices, resource demands and the requirements of health and safety legislation on practical work in science for stakeholders such as TDA, industry, heads, and governors.

5.3 STRAND C: ENSURING FACILITIES AND RESOURCES ARE APPROPRIATE

This strand would seek to bring together the best advice on facilities and resources to support practical work in science.

5.4 STRAND D: DEVELOPING PROFESSIONAL EXPERTISE IN PRACTICAL WORK IN SCIENCE

This strand will develop ways in which the expertise in practical work can be developed principally through existing mechanisms. It is essential that there is some dedicated resource (human and financial) to ensure that the practical work elements are not lost because of other pressures.

The message from the evidence gathered through the survey was very clear that expertise and confidence in practical work requires 'hands-on' experiences for teachers (as well as pupils). Thus there is a need to provide support which, through experienced practitioners, builds 'everyday expertise' in, for example, non-specialists, those teachers in the early parts of their career and those about to embark on teaching a new course. Although initially it is time consuming and resource intensive, there is evidence that the best way of developing expertise in practical science is by doing it under the guidance of a more experienced colleague or tutor. The challenge is to find ways in which such a sharing of expertise can take place.

Several options need to be explored through a combination of existing structures and piloting of more focused mechanisms. The types of provision that might be involved operate at various levels for example:

- in school sessions where departments have a programme for members demonstrating or developing activities on a regular basis, say twice a term plus one training day per year dedicated to practical work;
- developing programmes of work with ASTs, Excellent Teachers, and leading practitioners which incorporate practical work as a priority;
- working with NNSLCs and SNS on 'train the trainer' programmes which require individuals to carry out some training of colleagues back in their own schools and colleges;
- explore the use of time during pre-service training, induction and early years of a career to specifically improve practical work experience and expertise;
- encourage, maybe through subject associations and professional bodies, self-help groups of teachers to engage in practical work development.

5.5 STRAND E: RESEARCH AND EVIDENCE

Although there is a great deal of information available on practical work in science there are still gaps and a need to address questions about existing provision in order to better inform future developments and monitor the impact of any interventions. In particular further consideration needs to be given to the detail required of a wider base-line survey of the current state of practical work in science in schools and colleges. Other areas for further investigation include:

- a survey of the extent of practical work training in ITT courses and ways in which any short-comings might be addressed;
- reviewing evidence on class size and the extent to which it is an inhibitor to successful practical work;
- gathering of more information about successful CPD practical work courses and the impact in the school or college;
- an enquiry into the attitudes of pupils to a range of types of practical work in science, at different stages through their compulsory education;
- investigating the status and career paths of technicians as a result of workforce reform and the impact this has on practical work in science.

6 CONCLUSIONS

The evidence gathered during the preparation of this report and the contributions made by all the stakeholders to the discussions overwhelmingly endorse the view that practical work is an essential element of teaching and learning in science. Furthermore there is widespread acknowledgement of the fact that there are, in all types of school across the UK, many examples of high quality practical work being undertaken in science classes. Thus in many respects there is much to be positive about with regard to the status of practical work in science education.

However, despite such strong support, there is also evidence to support the concerns expressed elsewhere that the amount of time spent on practical work has decreased, the range and variety of experimental and investigative activities has become restricted and that the quality of provision is not consistent across the country or from school to school. A complex interaction of factors has contributed to this situation that includes:

- the perceived and actual constraints resulting from curriculum and assessment requirements;
- unfounded perceptions of health and safety requirements;
- insufficient technical support;
- the lack of opportunities for teachers to engage in professional development specifically focused on using practical work as part of their teaching and importantly the time for teachers to practise new techniques, experiments, demonstrations and investigations.

There is strong agreement that there are actions that can be taken to address the concerns expressed and to improve the effectiveness of practical work. Furthermore there is a broad consensus and willingness from stakeholders to contribute to building on the findings of this report to implement the proposed strategy which it outlines. In particular there is general agreement that:

- to be effective practical work should be a key element in a highly developed set of pedagogical skills and subject expertise;
- the core of practical work lies in the development of laboratory and experimental techniques, investigative procedures and fieldwork activities;
- the core activities should be supplemented by effective and appropriate use of other learning approaches that might include simulations, role play, and group discussions.

Based on this consensus the strategy and its implementation should aim to:

- improve the effectiveness and quality of existing practice in all schools;
- strengthen the provision of professional development for teachers and technicians. Specifically, focusing on developing personal expertise in practical work and building capacity and sustainability to support high quality practical work in all schools;
- provide an evidence base to better define issues relating to improving the effectiveness of practical work in science teaching and learning;
- ensure the dissemination and sharing of good practice both within and between schools.

Without doubt good quality practical experiences engage young people with science. The challenge, reiterated by the findings of this report, is to build on the strengths that exist and ensure that practical work is used even more effectively to engage and inspire yet more young people.

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APPENDIX 1

A) SECONDARY QUESTIONNAIRE RESPONDENTS (N = 1103)

1 Subject specialism

Biology 34.5%, Chemistry 25.6%, Physics 23.5%, Science 14.2%, other 2.2%

2 Position on staff

Main scale teacher 22.5%, Head of Science 15.9%, Post-holder 14.8%, principal/advanced skills/post threshold 12.1%, NQT 4.8%, senior manager 2.8% other (presumed mainly technicians) 27.1%

3 Type of school

Comprehensive 11-18 46%, comprehensive 11-16 16.1%, independent 13.9%, grammar 6.5%, sixth form college 4.1%, other (including FE, Special, Middle) 13.4%, specialist science college 15.7%

4 School location

Urban 32.7%, small town 30.3%, suburban 26.6%, rural 10.5%

England 85.6%, Scotland 10.7%, Wales 2.0%, Northern Ireland 1.8%

B) PRIMARY QUESTIONNAIRE RESPONDENTS (N = 185)

1 Post

58.1% teachers
69.4% science coordinators

2 Position on staff

Main scale	39.4 %
Post threshold	28.7%
Senior management	25.5%
NQT / RQT	6.4%
Other	included ASTs, trainees and HLTAs

3 Age range

82.6% teachers of age 7-11; of remainder only 1 teaching under 5s

4 Location

96.4% working in England; remaining 4 teachers in Scotland

APPENDIX 2

LIST OF INDIVIDUAL RESPONDENTS

Received from organisations:

- British Association for the Advancement of Science
- Institute of Chemical Engineers
- Royal Society of Chemistry
- Royal Meteorological Society
- OCR
- Society for General Microbiology
- British Psychological Society
- AstraZeneca
- ABPI
- British Pharmacological Society
- The Association for the Study of Animal Behaviour
- CLEAPSS
- British Lichen Society
- Scottish Schools Equipment Research Centre
- Science Learning Centre's Secondary Development Group
- @Bristol
- Institute of Food Science & Technology
- British Ecological Society
- Institute of Physics
- Institute of Animal Technology
- Field Studies Council
- School of Education, Durham University

Received from individuals:

- Mike Bell, Science teacher, Hinchingbrooke School, Huntingdon
- Peter Borrows, former Director of CLEAPSS
- Alastair Gittner, Head of Science, Stocksbridge High School
- Dr Tim Freegarde, School of Physics & Astronomy, University of Southampton
- Peter Humphries, ASE
- Helen Harden, teacher and author
- Andy Piggott, Independent Science Consultant

APPENDIX 3

STAKEHOLDER WORKSHOP

Representatives at the stakeholder workshop on 22 August 2007 at the Royal Society

Derek Bell	ASE
Peter Borrows	Consultant
Phil Bunyan	CLEAPSS
Nicola Hannam	Science Council
Martin Hollins	Independent Consultant
Liz Lawrence	ASE
Colin Osborne	Royal Society of Chemistry
Ginny Page	Royal Society
Michael Reiss	Royal Society
Neil Roscoe	Institute of Biology
Daniel Sandford-Smith	Institute of Physics
Clare Thomson	Institute of Physics

Representatives at the stakeholder workshop on 16 April 2008 at the Royal Society

Peter Borrows	Former Director of CLEAPSS
Dariel Burdass	So ciety for General Microbiology
Julian Clarke	National Strategies
Justin Dillon	King's College London
Ian Galloway	Science Learning Centre South East
Kevin Hewison	WJEC
Martin Hollins	Independent Consultant
Steve Jones	Specialist Schools and Academies Trust
Liz Lawrence	ASE, Chair of Primary Science Committee
John Noel	OCR
Malcolm Oakes	Independent Consultant
Alison Redmore	Science Learning Centre East
Michael Reiss	Royal Society
Neil Roscoe	Institute of Biology
Adrian Schmidt	WJEC
Kay Stephenson	CLEAPSS
Clare Thomson	Institute of Physics
Emma Woodley	Royal Society of Chemistry
Fred Young	SSERC

Representatives at the stakeholder workshop on 18 August 2008 at the Royal Society

Derek Bell	ASE
Liz Burns	OCR
Justin Dillon	King's College London
Kate Dunk	Energy Institution
Ian Galloway	Science Learning Centre South East
Martin Hollins	Independent Consultant
Steve Jones	Specialist Schools and Academies Trust
Rosalind Mist	SCORE
Malcolm Oakes	Independent Consultant
Colin Osborne	Royal Society of Chemistry
Ginny Page	Royal Society
Julie Pollard	IChemE
Adrian Schmidt	WJEC
Kay Stephenson	CLEAPSS

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