14 APRIL 2011

THE NATIONAL CURRICULUM REVIEW

SUBMISSION OF EVIDENCE

GATSBY

SUMMARY

1 The National Curriculum review will receive many detailed submissions regarding what biology, physics and chemistry subject content should feature in the new Science curriculum and at which Key Stage. Gatsby considers such decisions regarding content are best informed by subject specialist organisations such as the science professional bodies within SCORE[1], and as such we do not address them in our response.

2 Instead we focus this response on one key issue: practical work in school science. Since the introduction of the National Curriculum there has been a steady erosion of the teaching of practical skills. This is a cause of significant concern to industry and higher education institutions. Reversing this trend would also increase the engagement of young people in science and lead to greater participation in science post-16.

3 The National Curriculum review is an opportunity to re-examine the role of practical work. In particular, the review must ensure that the Science Curriculum sets high expectations of attainment in the laboratory skills that employers and higher education value. To this end, we recommend that:-

- The National Curriculum review team should provide an impact assessment to show explicitly how any changes to the National Curriculum for Science will support and actively encourage better practical work in schools.
- The review must ensure that the National Curriculum allows sufficient time and space for teachers to undertake a much wider range of practical activities with their students than is currently the case.
- The Science National Curriculum should state explicitly the laboratory skills that students are expected to develop at each Key Stage. If the Programme(s) of Study for Science identify separate requirements for biology, chemistry and physics it will be essential that each of these include explicit statements relating to laboratory skills.
- The review must consider how the requirements of the National Curriculum regarding practical work at Key Stage 4 can be translated into assessment objectives across the range of science GCSEs. It is unacceptable that the assessment of laboratory skills has been reduced to the point where a GCSE student who is unable to, for example, use a microscope or heat measured volumes of liquid without breaking test tubes is still able to achieve maximum marks for their practical work as long as they can write about how they should have done it.
- The review should involve higher education and employers in a much more meaningful way than has been the case in previous National Curriculum reviews. Included within these discussions should be a focus on ensuring that employer and HE requirements for laboratory skills are met, something we believe has been wholly absent from previous reviews.
- The review should set out a timetable of work to show how any changes at Key Stage 4 can be trialled and evaluated before they are included in public examinations.

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[1] The SCORE partnership comprises the ASE, Institute of Physics, Royal Society, Royal Society of Chemistry and Society of Biology. It receives core funding from Gatsby and the DFE.

ABOUT GATSBY

4 Gatsby is a Trust set up in 1967 by David Sainsbury (now Lord Sainsbury of Turville) to realise his charitable objectives. We focus our support on a limited number of areas:

- Plant science research
- Neuroscience research
- Science and engineering education
- Economic development in Africa
- Public policy research and advice
- The Arts

INTRODUCTION

5 The subject content – the concepts and ideas – that appears in the Science National Curriculum is relatively uncontentious and has remained reasonably stable over time. This situation is not unique to England: the similarities in the content of different countries' curricula are much more notable than the differences.

6 However, the National Curriculum expectations relating to practical skills seem to have been in constant flux and have never been expressed in a form that has allowed teachers to provide high quality experiences for their students. Numerous reports and select committee inquiries over the last decade have highlighted that practical work has become more formulaic and limited in terms of the range of activities undertaken in schools.

7 Industry and higher education (HE) also continue to express concerns about the practical science skills of young people. Most recently, a Gatsby-commissioned study[2] into the supply of university technicians discovered that many universities recruiting school leavers to apprentice technician roles found that they had to test whether applicants had the necessary practical skills. But higher education lecturers have long voiced concern about the level practical skills possessed by students entering universities[3]. As a result, a number of universities now run remedial laboratory sessions for their first year science students. Trade bodies such as the Association of the British Pharmaceutical Industry (ABPI) also report concerns about core practical skills, with some candidates even lacking ability in basic lab activities such as the use of balances and pipettes.

8 One role of school science education should be to equip young people with the practical skills and modes of behaviour that underpin the work of apprentices, technicians, scientists and engineers in industry. At present it is failing to do this.

9 We believe it is essential to use the current National Curriculum review as an opportunity to re-examine the role of practical work in science and ensure that the Science Curriculum sets high expectations of attainment in the laboratory skills that employers and HE value.

Recommendation 1: The National Curriculum review team should provide an impact assessment to show explicitly how any changes to the National Curriculum for Science will support and actively encourage better practical work in schools.

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[2] *Technicians under the microscope: a study of the skills and training of university laboratory and engineering workshop technicians*, PA Lewis and H Gospel (2011)

[3] For example, *Survey of Deans of Science, Save British Science* (2003)

PRACTICAL WORK IN SCIENCE: A DEFINITION

10 One of the issues hindering discussion of the role of practical work in science education is a lack of precision about what is meant by practical work. Following the definition used by SCORE and others, we define practical work to be:

Activity in which students manipulate and observe real objects and materials to increase their knowledge and understanding of the natural world, and develop relevant skills.

11 Practical work in primary science education should build on the natural curiosity of children, enabling them to experience and explore the material and natural worlds. This process will continue in secondary schools, but it will be advanced by the development of discipline-specific skills and the use of specialist equipment enabling students to use a more abstract and measured approach. For brevity we refer to these skills as "laboratory skills", although noting that this definition should include the skills that are developed outside of the laboratory through fieldwork.

PURPOSES OF PRACTICAL WORK

12 Based on the definition above, there are a number of reasons why teachers would undertake practical work during a science lesson. The learning aims of practical work include:

- enhancing the learning of scientific concepts and explanations
- enhancing an understanding of scientific processes
- developing laboratory skills

13 We examine below each of these learning aims and how the National Curriculum might be used to achieve them.

14 In addition to these learning aims, surveys of student attitudes to science lessons consistently show the importance of practical work in motivating and inspiring students. There is no doubt that, as well as helping students to understand science, effective practical work can be a powerful motivational tool that can help to increase participation in the sciences post-16.

15 While the National Curriculum should not attempt to specify how practical work should be used to motivate students, by constraining the type of practical work that is undertaken through unwieldy assessment or an overemphasis on the recall of scientific facts, the National Curriculum can erect significant barriers to teachers making use of the full range of practical activities in the classroom.

16 We welcome Government intentions to create space in the Curriculum that would provide more opportunity for teachers to exercise their professional judgement about the types of activity and learning that will benefit their students. From discussions with teachers we believe that this freedom could, in principle, lead to a renaissance of practical work within the Science Curriculum.

Recommendation 2: The review must ensure that the National Curriculum allows sufficient time and space for teachers to undertake a much wider range of practical activities with their students than is currently the case.

LEARNING AIMS FOR PRACTICAL SCIENCE

Enhancing the learning of science concepts and explanations

17 Practical work is important in showing things to learners, ensuring that they have seen what they ought to have seen, as well as giving them an experience or feeling of a phenomenon, particularly an abstract one such as inertia.

18 Much of the practical work that takes place in schools will be intended to help bridge the conceptual gap from the world learners see around them to the more abstract representations used by scientists.

19 But while we would expect much of science to be learnt through the medium of practical work, we do not believe that it would be appropriate to try and dictate this through an over-prescribed, statutory National Curriculum. How and when practical work is used to teach scientific content is a decision that is best left to teachers.

Developing understanding of the processes of science

20 There is widespread agreement that one aim of science education should be to enable students to understand the processes of science. This understanding enables students to appreciate the differences between the knowledge claims made in science and those made by the humanities.

21 Science education should also provide a foundation on which learners can build an understanding of how to evaluate the scientific issues they will face in their adult lives; this relies on students developing an understanding of the empirical underpinning of science and the interplay between theory and experiment.

22 The current National Curriculum at Key Stage 4 states that pupils should be taught:

- how scientific data can be collected and analysed
- how interpretation of data, using creative thought, provides evidence to test ideas and develop theories
- how explanations of many phenomena can be developed using scientific theories, models and ideas
- that there are some questions that science cannot currently answer, and some that science cannot address.

23 This is a useful *overview* of what should be taught. However, the lack of detail, which is carried through into GCSE criteria, has resulted in considerable uncertainty about what it is that should actually be taught and assessed. In particular, because the National Curriculum has subsumed the development of laboratory skills within the development of an understanding of the processes of science, there is insufficient attention paid to the assessment of laboratory skills. This theme is expanded below.

24 The National Curriculum should be explicit about the procedural knowledge that students need to acquire, stating, for example, that students should be able to:

- distinguish between a prediction, an hypothesis and a theory
- identify different types of variable and how one might investigate the relationships between them
- understand the technical use of measurement terms such as 'accuracy', 'precision' and 'error'
- appreciate features of different experimental techniques such as sampling, repeating measurements and randomised controls

25 In a similar way to that for science concepts and explanations, much of students' understanding of scientific processes should be developed through the use of practical work.

Developing laboratory skills

26 Laboratory skills can only be developed through practical work. Students must be given opportunities to develop their manipulative skills through the use of apparatus and by following protocols.

27 Currently the Key Stage 4 programme of study relevant to laboratory skills states pupils should be taught to:

- plan to test a scientific idea, answer a scientific question, or solve a scientific problem
- collect data from primary or secondary sources, including using ICT sources and tools
- work accurately and safely, individually and with others, when collecting first-hand data
- evaluate methods of collection of data and consider their validity and reliability as evidence

28 This set of statements leads to a position where laboratory skills are seen as a relatively insignificant element of an investigation. In particular, there is insufficient emphasis on accurate measurement and observation – precisely the skills that employers so value in apprentices and technicians.

29 As well as insufficient emphasis on the actual undertaking of practical work, these statements exclude a whole range of practical activities that students should be completing, such as performing a dissection, carrying out a titration or building an electric motor.

30 The National Curriculum must be much more explicit about the laboratory skills that science education seeks to develop. The following example, from Quebec, is indicative of how this might be achieved:

> *Elementary school*
>
> Students become familiar with the use of observational instruments (magnifying glass, binoculars) and simple measuring instruments (ruler, eyedropper, graduated cylinder, balance, thermometer, chronometer).
>
> *Secondary school*
>
> Safely using laboratory materials and equipment
>
> - Uses laboratory materials and equipment safely (e.g. allows hotplate to cool, uses beaker tongs)
> - Handles chemicals safely (e.g. uses a spatula and pipette filler)
>
> Separating mixtures
>
> - Separates heterogeneous mixtures using sedimentation and decantation
> - Separates heterogeneous mixtures using filtration
> - Separates different aqueous solutions using evaporation or distillation
>
> Designing and creating an environment
>
> - Uses environmental design and construction techniques that respect the characteristics of the habitat (e.g. terrarium, aquarium, composting medium)
>
> Using measuring instruments
>
> - Adopts the appropriate position for reading an instrument
> - Measures the mass of a substance using a balance
> - Measures the volume of a liquid using the appropriate graduated cylinder

- Measures the volume of an insoluble solid using water displacement
- Measures temperature using a graduated thermometer
- Uses measuring instruments appropriately (e.g. ammeter, volumetric flask)

Using observational instruments

- Uses observational instruments appropriately (e.g. magnifying glass, binoculars, microscope)

Preparing solutions

- Prepares an aqueous solution of a specific concentration given a solid solute
- Prepares an aqueous solution of a specific concentration given a concentrated aqueous solution

Collecting samples

- Collects samples appropriately (e.g. sterilizes the container, uses a spatula, refrigerates the sample)

31 The current review consultation document suggests that the Programme(s) of Study could be specified through separate requirements for biology, chemistry and physics. We assume that, in moving to separate requirements for the three sciences, the intention would not be to remove requirements relating to Experimental and Investigative Science, but rather to integrate this element within the requirements for each of biology, chemistry and physics.

32 This approach offers some advantages. Laboratory skills could be more effectively contextualised within each of the scientific disciplines; one could, for example, be more explicit about the expectations for fieldwork in biology, while emphasising issues concerned with measurement in physics. This approach could also ensure that laboratory skills are more closely aligned to the content areas where the skills are required.

33 Overall we would support identifying separate requirements for biology, chemistry and physics from Key Stage 3 onwards, provided that each included explicit statements relating to laboratory skills. It is worth noting however, that this approach would result in a certain amount of duplication of content. For example the requirements for chemistry, physics and biology would all need to include statements about students learning to make accurate observations and working safely.

Recommendation 3: The Science National Curriculum should state explicitly the laboratory skills that students are expected to develop at each Key Stage. If the Programme(s) of Study for Science identify separate requirements for biology, chemistry and physics it will be essential that each of these include explicit statements relating to laboratory skills.

34 As well as being more explicit about the laboratory skills that students need to develop, the assessment of laboratory skills needs to be strengthened. With the removal of national tests at the end of Year 9, the secondary Science Curriculum is increasingly being driven by the assessment requirements of GCSE. Any review of the National Curriculum needs to take full cognisance of how the content at Key Stage 4 will be re-interpreted through GCSE specifications and, in particular, how practical work will be assessed within science GCSEs.

ASSESSMENT ARRANGEMENTS

35 One of the most significant impacts of the National Curriculum has been to specify that laboratory skills should be developed through students' own investigative work. We suggest this has had a very significant and detrimental impact on the scope and breadth of practical skills that are explicitly developed and assessed.

36 The Science GCSEs developed following the introduction of the National Curriculum used investigations as the basis of coursework in science. Initially the expectation was that investigations would be undertaken and assessed in the course of normal science lessons, building on existing practice with GCSE where students' practical skills were often assessed internally.

37 Two significant trends soon emerged:

- Schools realised that they could maximise student performance by concentrating on a few tried and trusted investigations that required limited laboratory skills. All across the country students were investigating how the length of a wire affects its resistance and the factors affecting the rate of reaction between an acid and marble chips.
- Students were encouraged to complete the write up of the investigation outside the classroom, writing about the planning, analysis and evaluation of the investigation at great length. Thus the focus of the assessment switched from the practical activity to the written.

38 The introduction of controlled assessments for the Science GCSEs beginning in 2011 have taken the devising of investigations out of the hands of teachers but have not addressed the issue of assessing how well students actually carry out the practical work. In some of the sample mark schemes we have examined there are no marks associated with how well the practical procedures are carried out.

39 It is unclear how controlled assessments will affect the range and quantity of non-assessed practical work undertaken. But what is clear is that we have moved a long way from the position prior to the introduction of the National Curriculum where students' ability to use apparatus safely and accurately was assessed directly by teachers or via a practical exam.

40 The assessment of laboratory skills has been reduced to the point where a student unable to, say, use a microscope, set up an electric circuit, or heat measured volumes of liquid without breaking test tubes is still able to achieve maximum marks for their practical work as long as they can describe how they *should* have done it. Currently, assessed practical work in schools seems akin to assessing students' ability to write a recipe without ever expecting them to prepare and taste the food.

41 Assessment of practical work is not straightforward, but unless we can devise assessment arrangements that better recognise the skills that industry and HE are looking for, we will continue to let young people down.

Recommendation 4: The review must consider how the requirements of the National Curriculum regarding practical work at Key Stage 4 can be translated into assessment objectives across the range of science GCSEs.

THE HEALTH OF PRACTICAL WORK IN SCHOOLS

42 In the light of longstanding concerns about the health of practical work, Gatsby has recently embarked on a significant piece of work that will seek to:

- establish an accurate picture of the current health of practical science in UK secondary schools and make international comparisons where feasible
- unpick the current enablers and barriers to effective practical work that affect schools at a local level
- identify the likely impact on practical work of the upcoming education policy changes, including the changes to the National Curriculum, funding mechanisms, Local Authority involvement and initial teacher education
- make pragmatic recommendations on the action needed to ensure high-quality practical work occupies a central and sustained role in all secondary schools.

43 Over the next year or so, we plan to consult with universities and employers on the laboratory skills the Science Curriculum must develop to meet their needs. We would be happy to share early results with the review team in order to help inform the development of the elements of the programme of study related to laboratory skills.

Recommendation 5: The review should involve higher education and employers in a much more meaningful way than has been the case in previous National Curriculum reviews. Included within these discussions should be a focus on ensuring that employer and HE requirements for laboratory skills are met, something we believe has been wholly absent from previous reviews.

44 We have also initiated discussions with the Awarding Organisations to explore how laboratory skills could be assessed reliably while ensuring validity. Our hope is that by working with the Awarding Organisations and the science professional bodies, (especially the Institute of Physics, Royal Society of Chemistry and Society of Biology), we can develop clear criteria for the assessment of practical work that could be included within the GCSE specifications to be introduced following changes to the National Curriculum.

45 Gatsby would also be interested in supporting the piloting of these approaches prior to their introduction in schools as we have seen far too many well-intentioned changes to the Curriculum and assessment fail when they come up against the realities of the school laboratory.

Recommendation 6: The review should set out a timetable of work to show how any changes at Key Stage 4 can be trialled and evaluated before they are included in public examinations.

CONCLUSION

46 There is strong support for the prominence of practical work within the Science National Curriculum. We hope that as a result of the review, teachers, parents and learners will have a much clearer understanding of the expectations they should have with regard to practical work and the development of laboratory skills.

47 There is a vital role for the National Curriculum in specifying the laboratory skills that students need to develop during their science education, including those which meet the needs of industry and higher education. This has not been sufficiently emphasised through various iterations of the National Curriculum.

48 Gatsby has long supported the role of practical work in schools. We stand willing to assist the review team in any efforts to create a Science National Curriculum in which a key aim is the development of laboratory skills that properly meet the needs of learners, employers and higher education.