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# Improving the assessment of practical work in school science

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## Executive Summary

1. This report reviews how practical work in science is currently assessed in England by the three main awarding bodies (AQA, Edexcel and OCR) for GCSE, A level and for certain other qualifications. Comparisons are also made with the way in which practical work is assessed across a range of other subjects within England, including design and technology, geography and music, as well as how it is assessed in science in other countries, including those that perform well in PISA assessments.
2. We used a variety of literary sources, including academic articles, awarding body specifications and other grey literature, to review how practical work is assessed and we discuss current perceived shortcomings. Case studies involving university departments and an employer are drawn on to evaluate how practical work is assessed and what expectations about it are held by those working in employment and higher education.
3. Whilst practical skills in science are clearly valued and often referred to within the literature, including awarding bodies' specifications, as being of central importance, there is a lack of clarity as to what these skills actually are and how they might, most effectively, be validly assessed.
4. There is variation between awarding bodies in their approach to assessing practical work in science and, in particular, whether practical work should be assessed directly or indirectly.
5. Practical skills can be assessed by the Direct Assessment of Practical Skills (DAPS), for example when a teacher observes and assesses a student carrying out a titration, or the Indirect Assessment of Practical Skills (IAPS), for example when a teacher assesses a report written by a student who has undertaken a titration.
6. There is a greater use of DAPS in science in some high performing PISA countries, such as China and Finland, than in England.
7. In England, the assessment of practical skills in other subjects, such as via Associated Board for the Royal School of Music (ABRSM) examinations and modern foreign languages GCSEs, generally makes greater use of DAPS than do science qualifications.
8. Awarding bodies should be as explicit as to which practical skills candidates should develop as they are about the subject content knowledge that is expected of candidates.
9. Science specifications should be more precise than they generally are at present as to those practical skills needed for different qualifications (e.g. GCSE and A level) and for different grades / levels within such qualifications.

10. Those involved in determining how school science practical work is assessed in England should learn lessons from how it is assessed in other countries and from how other subjects in England assess skills.
11. Awarding bodies and others should consider carefully the optimum balance between the direct and the indirect assessment of practical work in science.
12. Given that employers value skills such as team working, it may sometimes be appropriate, as in the assessment of drama, to use practical work in science to assess students' collaborative as well as individual skills.
13. Greater use of teachers should be made in the summative assessment of their students' practical work, accompanied by a robust moderation procedure.

## Work Package 1: Current assessment of practical work in England

1. In England practical work is often seen as central both to the appeal and effectiveness of science education and to the development of practical skills that will be of use in Higher Education and/or the workplace. Indeed, The House of Commons Science and Technology Committee (2002) reported that:

In our view, practical work, including fieldwork, is a vital part of science education. It helps students to develop their understanding of science, appreciate that science is based on evidence and acquire hands-on skills that are essential if students are to progress in science.

(para. 40)

2. By 'practical skills' we mean those skills the mastery of which increases a student's competence to undertake any type of science learning activity in which they are involved in manipulating and/or observing real objects and materials.
3. In a report on the testing of practical skills in science for ages 11, 13 and 15, Welford, Harlen and Schofield (1985) suggested, that "the assessment of practical skills may be possible from pupils' reports or write-ups – provided that they have actually carried out the practical or investigation prior to putting pen to paper" (p. 51). However, it is our opinion that practical skills are, in some cases, best assessed directly. For example, whilst a conceptual understanding of the topology of knots and manifolds might well be assessed by a written task the most effective means of assessing whether a student is competent in tying their shoe laces is, we would argue, to watch them as they attempt to tie them.
4. As such, we feel that a useful distinction can be made between what we refer to as direct assessment of practical skills (DAPS) and indirect assessment of skills (IAPS)<sup>1</sup>. The former, DAPS, refers to any form of assessment that requires students, through the manipulation of real objects, to *directly* demonstrate a specific or generic skill in a manner that can be used to determine their level of competence in that skill. An example of this would be if a student was assessed on their skill in using an ammeter and this was determined by requiring them to manipulate a real ammeter and use it within a circuit to take readings and for these readings to need to be within an acceptable range for the student to be credited.
5. In contrast, IAPS relates to any form of assessment in which a student's level of competency, again in terms of a specific or generic skill, is *inferred* from their data and/or reports of the practical work that they undertook; for example, when a student writes up an account of the reaction between hydrochloric acid and calcium carbonate chips in a way that the marker would not be certain if the student is faithfully writing what they have just done or simply remembering what they have previously done or been told about this reaction.

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<sup>1</sup> A glossary of key terms is provided in Appendix 1.

6. A common example of the use of both DAPS and IAPS to assess practical skill and conceptual understanding respectively, and one that we consider provides a useful analogy, is the UK Driving Test. In this example not only does the candidate have to demonstrate a sufficient level of competency in terms of practical driving skills out on the road (DAPS) but they must also pass an on-line test to assess their understanding of how to drive a car safely and competently (IAPS). Table 1 shows a comparison between DAPS and IAPS.

Table 1: A comparison of DAPS, the Direct Assessment of Practical Skills, and IAPS, the Indirect Assessment of Practical Skills

	<b>DAPS</b>	<b>IAPS</b>
<b>What is the principle of the assessment?</b>	A student's competency at the manipulation of real objects is <i>directly</i> determined as they manifest a particular skill	A student's competency at the manipulation of real objects is <i>inferred</i> from their data and/or reports of the practical work they undertook
<b>How is the assessment undertaken?</b>	Observations of students as they undertake a piece of practical work	Marking of student reports written immediately after they undertook a piece of practical work <i>or</i> marking of a written examination paper subsequently taken by students
<b>Advantages</b>	High validity  Encourages teachers to ensure that students gain expertise at the practical skills that will be assessed	More straightforward for those who are undertaking the assessment
<b>Disadvantages</b>	More costly  Requires teachers or others to be trained to undertake the assessment  Has greater moderation requirements	Lower validity  Less likely to raise students' level of practical skills

7. There are many cases when the use of IAPS can provide reliable and valid means of assessment. However, the current dominance of IAPS within summative assessment of practical work in science in England means that the focus has been directed on to what students *know* about practical work and how it should, in principle, be

undertaken rather than on their competency in terms of actually being able to *do* practical work themselves. This does not, we suggest, seem the best way to assess, for example, a student's competency in terms of the practical skills required to make up a buffer solution or use an oscilloscope. Table 2 shows a range of practical assessments, not only from science, and examples from each as well as indicating whether these are DAPS or IAPS.

Table 2: Range of practical assessments currently in use and whether these are DAPS or IAPS

<b>Practical assessment in use</b>	<b>DAPS or IAPS</b>
Report on an investigation – students write their report on an investigation using their own data but their practical skills are not observed or assessed directly	IAPS
Report on an investigation – students write their report on an investigation using data with which they have been provided (typically because of a problem that has prevented the student from obtaining any meaningful data)	IAPS
Written examination – students complete a test paper that includes questions about practical work under examination conditions	IAPS
Practical examination report – students conduct a practical and write up their apparatus, methods, results and evaluations	IAPS
Viva – students are given an oral examination in which they are asked questions about a project they have undertaken	IAPS
Practical examination – teacher (or other examiner) observes students undertaking practical work	DAPS
Practical examination by means of recording – examiner listens to an audio-recording, e.g. of a student singing or playing a musical instrument, or watches a video-recording, e.g. of a rehearsal of a play	DAPS
Practical examination by means of observation of an artefact – examiner views a painting made in Art or a product made in design and technology	DAPS

8. Both DAPS and IAPS have advantages and disadvantages. In deciding when DAPS or IAPS is more appropriate we would recommend that if the intention is to determine students' competencies at undertaking any specific practical tasks, then DAPS is more appropriate. Conversely, if the intention is to determine the understanding of a skill or process, then IAPS would be the preferred option.

*Assessed science practical work at GCSE (AQA, Edexcel and OCR)*

9. Ofqual (2009a) states that students need to be assessed through controlled assessment on their ability to:



Plan practical ways to answer scientific questions and test hypotheses; devise appropriate methods for the collection of numerical and other data; assess and manage risks when carrying out practical work; collect, process, analyse and interpret primary and secondary data including the use of appropriate technology; draw evidence-based conclusions; evaluate methods of data collection and the quality of the resulting data.

10. An analysis of the mark schemes for the controlled assessment of practical work (as well as the Practical Skills Assessment used by AQA) shows that whilst they all contribute a maximum of 25% of the final GCSE marks the method of assessment is primarily by IAPS (Appendices 4 and 5). Whilst DAPS does feature in the assessment – the assessment is made by the teacher and the paperwork is moderated by the awarding body – its role, as can be seen for example within the AQA GCSE science specification, is limited and requires, for a maximum of only six possible marks, that students demonstrate, throughout the course, their competence in the required practical skills. Likewise Edexcel, which requires students to complete a piece of practical work and then write about it under written controlled (IAPS) – with marks being awarded for planning (18 marks), observation (6 marks) and conclusion (24 marks) – includes a small contribution from “a teacher-assessed practical skills mark which is generally given for work over the duration of the course” (SCORE, 2009, p.3).
11. Whilst OCR Gateway<sup>2</sup> (2012) also recognises the importance of developing students’ practical skills, the assessment of such skills, as seen in Unit B713: Science Controlled Assessment, is based solely on the use of IAPS (Appendix 3). As with AQA and Edexcel this assessment is focused primarily on assessing students’ *understanding* of practical work rather than their competency in actually *doing* it and requires students to demonstrate in their writing:

scientific *understanding* in making appropriate choices of: equipment, including resolution, and techniques; range and number of data points for the independent variable; number of replicates; control of all other variables, with the aim of collecting accurate data.

(OCR Gateway, 2012, p.125, italics added)

12. As with the other awarding bodies the assessment of practical skills is undertaken by the teacher and subsequently moderated by OCR.
13. Whilst combining the use of IAPS with DAPS enables students to demonstrate not only their understanding of how practical work should be undertaken in terms of the design, collection of results and evaluation of the practical (IAPS) but also their competency in actually using their practical skills (DAPS), there is a marked disparity

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<sup>2</sup> Throughout this report we will draw on examples from the three principal awarding bodies. In such cases our choice is determined partly by an awarding body having a particularly interesting feature and partly by its specifications being presented with particular clarity.

in terms of marks available for these forms of assessment. Indeed, we would suggest that it is this disparity that has brought about the shift (Toplis & Allen, 2012) away from the use of practical work for teaching apparatus handling skills towards an approach that sees its role primarily for the development of knowledge and understanding of substantive concepts that can be assessed effectively and reliably through the use of IAPS.

14. For all three awarding bodies, the controlled assessment involves five steps which have a varying degree of control by the teacher. The first stage entails the student planning how to undertake the background research into an appropriate method for them to use in their investigation and involves *limited control*<sup>3</sup>. The second stage is reporting on the planning of the research and incurs high control as students are required to complete a written test in the presence of a teacher but under examination conditions where they complete the background research, including a hypothesis, list of apparatus, method, risk assessment and the production of an appropriate blank results table, for the data that they aim to collect. Step three is the actual manipulation of the science equipment, where they obtain the data practically, and whilst this is under limited control they are permitted to work in groups if they so choose. It should be emphasized that *no* marks are awarded for the actual manipulation of objects; indeed, there is only one mark given as an observation mark where students may report on a rough finding from the practical. Step four involves processing the primary data, although if the student's data are insufficiently accurate these can be substituted with data provided by the awarding body. Step five involves students analysing the results and then writing an evaluation.
15. SCORE (2009) notes that whilst all awarding bodies use controlled assessment the practical elements of AQA and Edexcel are based on the work of Richard Gott and have a particular focus, within their internal assessment, on the role of evidence in scientific enquiry. This internal assessment refers to the controlled assessment such as an Investigative Skills Assignment (ISA)<sup>4</sup> or Practical Skills Assessment in which the assessment is carried out by the teacher and then moderated by the awarding body.

#### *Current assessed practical work at A level*

16. Within the two years of A level study, practical work at AS level is currently worth 20% of the qualification dropping to 10% at A2 level so that the total contribution of practical work to a full science A level is 15%. In discussing the assessment of A level practical work we have drawn on examples from the three awarding bodies as a means of illustrating generic points. What we write should not be taken as implying that these points apply only to that particular awarding body. If we feel that the

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<sup>3</sup> Limited control means that students "can work unsupervised and outside the classroom. This work will not contribute directly to assessable outcomes" AQA (2012, p.2). Furthermore, teachers can provide limited guidance to students who can also work in groups and access external resources.

<sup>4</sup> At GCSE, an Investigative Skills Assignment (ISA) is a 45 minutes, non-tiered, written test taken under controlled conditions and marked by the school then moderated by AQA (Ofqual, 2009b).

approach of a particular awarding body is atypical then we make this evident in the text.

17. Whilst students following AQA Biology (2012), AQA Chemistry (2012) and AQA Physics (2012) all gain experience of practical work, for example in the first students have the opportunity to use buffers to change or control pH, or to use a water bath as a means of maintaining a stable temperature, they are not directly assessed in terms of specific practical skills through the Practical Skills Assessment.
18. Whilst AQA biology, chemistry and physics all use Practical Skills Assessment alongside ISA, the number of marks available differs depending on the path taken. At A level there are two possible routes and schools are able to choose which route suits their school. The first is a centre-marked route, known as route T, whilst the second is externally marked and is known as route X (AQA Biology 2012; AQA Chemistry, 2012; AQA Physics, 2012). Practical Skills Assessment, “designed to credit candidates for the practical work they undertake naturally as part of the course” (AQA Chemistry, 2012, p. 16), is assessed using DAPS in route T and contributes a maximum of 6 marks towards the total of 50 available marks. The remaining 44 marks are allocated to the ISA and are assessed solely on the basis of IAPS. Details of the marks given can be seen in Appendix 6.
19. The externally marked route X entails an Externally Marked Practical Assignment which carries 50 marks and involves three stages. Stage 1 is where students carry out the practical work following AQA specifications, stage 2 is the processing of the data, where students write up their findings, and stage 3 is the EMPA written test where students answer questions on their own data and questions on additional data related to the topic, analysis and evaluation. Whilst the Externally Marked Practical Assignment, as with the ISA, is assessed solely using IAPS, there is a requirement for what is termed ‘Practical Skills Verification’ which “requires teachers to verify their candidates’ ability to demonstrate safe and skilful practical techniques and make valid and reliable observations” (AQA Physics, 2012, p.44). Whilst the Practical Skills Verification does *not* contribute towards the assessment mark the student can only pass the unit if the teacher verifies that the student has completed the practical task – an example of a very basic DAPS.
20. Whilst there are no additional marks for the Practical Skills Verification, students are required to complete five short practical tasks in order to gain marks for the Externally Marked Practical Assignment. This route therefore allows practical skills to be demonstrated as part of the learning experience but, whilst assessed using DAPS, the assessment does *not* count towards the final qualification as can be seen in Appendix 6.
21. As part of the specifications for OCR Chemistry B Salters (2008) students are assessed by the teacher for practical skills which, at AS, are labelled as “competence – [where students must] carry out practical work competently and safely using a range of techniques” (p.63); at A2, practical work is referred to as “manipulation – [students must] demonstrate safe and skilful practical techniques and processes”

(p.66). These two aspects are each worth 12 out of 60 marks. In order for students to attain the 12 marks, teachers assess their ability at working safely, manipulating equipment and materials, making observations and taking measurements, thus employing a combination of both DAPS and IAPS.

22. If we consider the specification for OCR Advancing Physics A level it can be seen that within the AS course students are required to carry out two short tasks, both assessed using IAPS, and contributing 15% of the total A-level mark, that entail:

*Quality of Measurement (20 marks)*

A report of a measurement or study of a physical relationship, with attention paid to improving the quality of measurement and making valid inferences from data.

*Physics in Use (10 marks)*

A presentation on the use, properties and structure of a material.

(OCR, 2008, p.27, italics in original)

23. The A2 level unit, entitled 'researching physics', which is 15% of the final A level and worth 30 marks, involves the students being assessed using IAPS on the following two tasks:

*Practical Investigation (20 marks)*

A report of an extended investigation of a practical problem related to physics or its applications. The practical investigation should be carried out on any aspect of physics of interest to the candidate.

*Research Briefing (10 marks)*

A short written (max 2000 words) and verbal report based on the individual work of a candidate summarising a topic of physics of his or her own choosing that requires the use and synthesis of ideas from different areas of the subject. Assessment criteria include the ability to defend and explain the ideas under questioning.

(OCR, 2008, p.52, italics in original)

24. Edexcel Biology A level provides an example where there is a different approach to assessment at AS and A2. Both unit 3 practical biology and research skills in AS level and unit 6 practical biology and investigative skills in A2 require students to undertake recommended core practical tasks. However, whilst these core practical tasks are to be experienced by students, they are only assessed through IAPS in the form of examination paper questions which are based on those core practical tasks (Edexcel Biology, 2010). In addition to this, at AS level students are also assessed, in unit 3, on a written research report. However, at A2 level, students write a report on an experimental investigation which they have devised and carried out, alongside this students also complete a synoptic assessment.

### Current assessed practical work in other subjects

25. Practical work is not confined to science alone. Indeed, there are a number of other subjects where practical work is assessed including geography, music, design and technology and modern foreign languages. These subjects provide an insight not only into the way in which other subjects assess practical work but also into the emphasis that they place on the use of DAPS and IAPS in their summative assessment.

#### *Geography at GCSE*

26. In the OCR specification, the unit 'Local Geographical Investigation', worth 25% of the available marks, involves students completing a 2000 word assessment under controlled assessment conditions; they choose one task related to either retail areas or settlements and land-use (OCR, 2012). Whilst the fieldwork they do for the controlled assessment must include collection of primary data, students are only marked on the written report of their investigation rather than directly on their practical skills as they collect the data. Edexcel A and Edexcel B also involve a fieldwork investigation; again, this is a written assignment of 2000 words, worth 25% of the available marks (FSC, 2009) rather than a direct assessment of their practical skills.
27. Looking, for example, at OCR GCSE geography, there is a unit entitled 'Geographical Skills'. In this unit, students are able to apply a selection of skills, listed in Appendix 7, to a range of known and unknown scenarios and they are assessed on their competence in these skills through IAPS, via a written question paper that carries 25% of the marks for the qualification. Whilst students are not given prior information for this unit, it is expected that they will gain the skills required for the examination paper from the three other units ('Extreme Environments', 'The Global Citizen' and 'Similarities and Differences in Settlement and Population'). OCR (2012) states that these:

skills are fundamental to the study and practice of geography ... [and] ... provide a basis for further study and research in a range of subjects as well as being core skills for the world of work. Learning these skills in the context of the three themes will stimulate candidates to 'think geographically'. It will also provide them with opportunities to apply the skills in a wide range of different situations.

(p.25)

28. Whilst an understanding of these skills is currently assessed using IAPS, such an approach does not assess a student's competency in actually applying those practical skills as they would, for example, on a field trip. We return again to the example of the UK Driving Test. Whilst a candidate may be able to explain how to drive a car safely and competently (IAPS), they might not actually be able to pass the practical (DAPS) component of the driving test.

### *Geography at A level*

29. In A level geography, practical skills constitute between 25 to 45% of the available marks at AS and A2 (Ofqual, 2011a) and these skills are assessed in Assessment Objective 3: “Select and use a variety of methods, skills and techniques (including the use of new technologies) to investigate questions and issues, reach conclusions and communicate findings” (ibid, p.7). Whilst the specifics as to which skills are to be assessed is determined by the awarding body, Ofqual (2011a) states that these skills can be assessed indirectly through the use of extended prose. Certainly, in line with GCSE geography, the AQA A level specification (AQA, 2011) also includes a unit on Geographical Skills which contributes 30% of the AS level assessment (if carried forward to A2 it is worth 15% of the total A level qualification) and involves a written examination assessing “structured skills and generic fieldwork questions” (p.4). The skills assessed here include: “investigative, cartographic, graphical, ICT and statistical skills” (ibid, p.5) which are all assessed through a secondary assessment (IAPS).
30. Fieldwork skills are not assessed within GCSE or A level but fieldwork is expected to be undertaken in order that students are able to apply their knowledge gained from it in examinations. Indeed, within the geography community, the best approach to the assessment of fieldwork is still up for debate (Lambert, pers. comm., 30 August 2012).

### *Design and Technology at GCSE*

31. In the OCR GCSE design and technology, students carry out internally assessed practical work that constitutes 60% of the available marks, the remaining 40% being assessed through two written examinations, both worth 20% (OCR, 2008). The skills that are assessed within the internal assessment are development of designing skills, demonstrating good making skills and critical evaluation skills. These skills are assessed within the centre using the OCR marking criteria. The marks are moderated by OCR, for which purpose products that are made and portfolios are sent either through the post or electronically for e-moderation, where digital evidence can be used.
32. The latest specifications, published in 2012, have some changes. In particular, OCR requires candidates to research, design and subsequently model a functional prototype (worth 30% of the available marks) and then design and manufacture a complete product (worth another 30% of the available marks) (OCR, 2012). It remains the case that for AQA, Edexcel and OCR, 60% of the available marks result from the assessment of practical work with the remaining 40% coming from written examinations.

### *Design and Technology at A level*

33. In A level design and technology, between 40% and 60% of the marks are awarded for practical work, with Ofqual (2011b) stating that skills to be assessed are:

communicating ideas and information, planning, designing, making and evaluating. For AQA Design and Technology (2012), 50% of the available A level marks are assessed through practical work. The assessment of this is by IAPS and is based on a written (or electronic) design folder that provides details of a product designed and manufactured by the student.

### *Music at GCSE*

34. The assessment of music is an example of a school subject in which practical skills are clearly identified and in which the assessment involves DAPS. For example, in OCR (2010) GCSE Music, Unit B351: Integrated Tasks involves a performance worth 15% of the available marks, Unit B352: Practical Portfolio involves a group performance worth 15% and Unit B353: Creative task is performed and worth 5%. This work is audio-recorded by the teacher at the school following specified guidelines and is then marked externally.

### *Music – The Associated Board of the Royal Schools of Music*

35. The Associated Board of the Royal Schools of Music (ABRSM), a leading authority on musical assessment, uses a similar approach to the assessment of GCSE music by the Awarding Bodies, in which practical skills, demonstrated and assessed through practical performance, along with theory tests are used to grade students' musical competency. According to ABRSM (2012), their examinations "aim to give students opportunities to acquire the knowledge, skills and understanding to perform music with accuracy, technical fluency and musical awareness". Students are assessed on accuracy, continuity, fluency, tonal awareness and musical character and a sense of performance. These areas can be seen in more detail in Appendix 8.
36. The origins of these practical performance tests go back to the nineteenth century. Over the years, the music community has reached agreement on, for example, which particular pieces, when played appropriately, are indicative of which grades. It is generally felt that this agreement either eliminates or substantially reduces the likelihood of grade inflation over time (Welch, pers. comm., 10 September 2012). The criteria used for the ABRSM assessment are widely considered to be objective (Green, pers. comm., 9 September 2012).
37. In order to pass a grade in such music examinations, students must balance "the various qualities in the playing, using the skill that comes from training and experience" (ABRSM, 2012). Students need to pass only the practical elements for grades 1 to 4; students can progress up to grade 5 without theory but then must pass at least grade 5 theory after which progression to grade 8 can be without additional theory examinations (Green, pers. comm., 9 September 2012).
38. For the ABRSM practical graded examinations, only one examiner is present, a generalist (Green, pers. comm., 9 September 2012). Practical graded examinations have 150 marks available, with 100 marks denoting a Pass, 120 a Merit and 130 a Distinction. It is possible to appeal on the grounds of unfairness or misconduct by the

examiners but not on purely academic grounds. If the appeal is upheld the result can be re-examination, review of results or another procedure to benefit the candidate. The length of the examination ranges from 12 minutes for Grade 1 to 30 minutes for Grade 8 and involves performance of set pieces, scales and arpeggios, a sight-reading test and an aural test; these are all assessed to provide the final mark. Indeed, ABRSM's "exams aim to give students opportunities to acquire the knowledge, skills and understanding to perform music with accuracy, technical fluency and musical awareness" (ABRSM, 2012). For the ABRSM theory-graded examinations, a total of 100 marks are available with 66 denoting a Pass, 80 a Merit and 90 a Distinction. The theory examination takes 90 minutes for grades 1, 2 and 3, 120 minutes for grades 4 and 5, and increases to 180 minutes for grades 6 to 8. The theory examinations are supervised by an invigilator and sent to ABRSM for marking. The ABRSM assessment for gaining grades thus entails IAPS for the theory component and DAPS for the practical component.

#### *Music at diploma level*

39. Beyond grade 8 there are three levels of diploma and in these examinations, where possible, two examiners are present for each examination, otherwise one examiner is present and the documentation and recorded evidence will be sent to ABRSM to ensure standard quality assurance on procedures (Green, pers. comm., 9 September 2012). Also, at the discretion of ABRSM, a third person may be present for monitoring procedures and the maintenance of standards. One of the two examiners is a specialist in the discipline of the examinee, the other is a generalist and both are fully trained by ABRSM. Each examiner marks the examinee independently and then their combined judgment of the discipline and the attainments within a broader musical setting qualify for the final mark (or, in the case of one examiner, ABRSM will confirm the marks). In addition to the examiners being in the room where the examinee is performing, the performance aspects of the examination are audio-recorded for moderation and monitoring purposes.

#### *Modern foreign languages at GCSE*

40. The assessment of modern foreign languages at GCSE, as exemplified by OCR's (2009) GCSEs in French, German and Spanish, involves assessment of a student's competency in four 'skill' areas – listening, speaking, reading and writing. Modern foreign languages are another example of a school subject in which practical skills are clearly identified and in which DAPS plays an important part in the assessment regime. Whilst we refer here to 'skill' areas, because we believe these to be such, the OCR (2009) specifications do not in fact use the word 'skills'. The speaking area, worth 30% of the available marks, is assessed by the teacher using a controlled assessment procedure, although there are clear requirements for the audio-recording of students' speech for external moderation purposes. The remaining areas, that contribute 70% of the available marks, are marked externally, although the assessment of writing is also undertaken as a controlled assessment.



41. The assessment of the speaking area involves three areas: communication; quality of language; and pronunciation and intonation. In order to gain full marks in communication, a student “responds fully to all tasks/questions, including open-ended ones. Uses relevant information to develop and justify individual ideas and points of view. Produces information spontaneously without being cued” (OCR, 2009, p.50). In quality of language, a student gains full marks when they show “confident and accurate use of a wide variety of clause types, vocabulary and structures, including verb structures and tenses. Very fluent, coherent and consistent” (OCR, 2009, p.51). Finally, within the third area of pronunciation and intonation, full marks are given when a student is “very accurate for a non-target language speaker though there may be some minor slips” (OCR, 2009, p.51).

### **Current assessed practical work in other qualifications**

#### *The International Baccalaureate Diploma*

42. The International Baccalaureate Diploma, and here we use chemistry as an example, “emphasises the importance of practical chemistry as an investigation” (Ofqual, 2012, p.23). It assesses practical work by students “conducting a series of investigations together with a project using generic criteria. This requires higher-order skills to design, conclude and evaluate findings. Candidates are expected to complete 60 hours of practical activities and project work which contributes 24 per cent of the final score” (ibid, p.23). This approach, where students are conducting the practical work and being assessed on these practical work skills, entails the use of DAPS.

#### *BTEC*

43. Another approach to assessing practical work can be seen in the BTEC level 1 and level 2 qualification in science set by Edexcel. Edexcel states that it is essential for aspiring scientists to have practical skills such as:

- carrying out theoretical and practical research
- working in a pilot scale department
- carrying out quality control tests on chemical, biological or physical samples during the stages of the manufacture of products
- calibrating audiological, optical or medical equipment to ensure accuracy of readings when testing hearing
- growing cultures in a laboratory
- testing waste products
- ensuring food products are not harmful
- ensuring water is safe to drink
- testing and drawing conclusions from forensic science evidence.

(Edexcel, 2012, p.73)

44. This qualification involves a Scientific Skills unit which is externally assessed through the use of a written, paper-based examination. The assessment of practical work in the BTEC is therefore essentially limited to IAPS with no use of DAPS to assess any of the above listed practical skills.

#### *Level 3 Extended Project*

45. The Level 3 Extended Project for 14 to 19 year olds, as exemplified by Edexcel (2008), is where students are able to carry out an in-depth study in one of the four areas: a dissertation, an investigation, a performance or an artefact. The dissertation is between 5000 and 6000 words in length and involves students referring to secondary sources whilst the investigation is between 4000 and 5000 words in length and involves carrying out a practical project and collecting primary data. The performance and artefact areas must also include written evidence to accompany the project of between 1500 and 3000 words in length. The assessment of the four areas is by the teacher within the centre and externally moderated by Edexcel. The project is assessed as shown in Appendix 9.

#### *IGCSEs*

46. The science IGCSEs, as awarded by the University of Cambridge International Examinations (2012), assess practical work. The qualification for combined science IGCSE involves three areas, one of which is a practical assessment worth 20% of the available marks. The practical assessment involves coursework, a practical test (1 hour 30 minutes) or an alternative to practical paper (1 hour). The syllabus states that for assessment objective C 'Experimental skills and investigations' (University of Cambridge International Examinations, 2012, p.9):

Students should be able to

use techniques, apparatus and materials (including the following of a sequence of instructions where appropriate)  
make and record observations, measurements and estimates  
interpret and evaluate experimental observations and data  
plan investigations and/or evaluate methods, and suggest possible improvements (including the selection of techniques, apparatus and materials).

(University of Cambridge International Examinations, 2012, p.9)

47. They explain that:

Scientific subjects are, by their nature, experimental. It is therefore important that an assessment of a student's knowledge and understanding of Science should contain a component relating to practical work and experimental skills (as identified by assessment objective C). To accommodate, within IGCSE, differing circumstances – such as the availability of resources – CIE provides three different means of assessing assessment objective C objective: School-based assessment, a formal Practical Test and an Alternative to Practical Paper.

48. The School-based assessment of practical assesses four skill areas:

C1 Using and organising techniques, apparatus and materials

C2 Observing, measuring and recording

C3 Handling experimental observations and data

C4 Planning, carrying out and evaluating investigations

(University of Cambridge International Examinations, 2012, p.44)

49. The four skills are of equal weight (6 marks) and assessment must be based on practical work that the students carry out throughout the course. For moderation purposes, teachers must make sure they have evidence of two assessments for each skill with information on the tasks and how marks were awarded, along with a student's written work for C2, C3 and C4 (University of Cambridge International Examinations, 2012). For Skill C1, students gain all 6 marks if they follow:

written, diagrammatic or oral instructions to perform an experiment involving a series of practical operations where there may be a need to modify or adjust one step in the light of the effect of a previous step. ... Uses familiar apparatus, materials and techniques safely, correctly and methodically.

(University of Cambridge International Examinations, 2012, p.45)

50. For skill C2, "Makes relevant observations, measurements or estimates to a degree of accuracy appropriate to the instruments or techniques used. Records results in an appropriate manner given no format" (ibid, p.46) is awarded 6 marks. In skill C3, 6 marks are awarded when:

Processes results in an appropriate manner given no format. Deals appropriately with anomalous or inconsistent results. Recognises and comments on possible sources of experimental error. Expresses conclusions as generalisations or patterns where appropriate.

(University of Cambridge International Examinations, 2012, p.46)

51. Finally for C4, students gain 6 marks when the following criteria are met:

Analyses a practical problem systematically and produces a logical plan for an investigation. In a given situation, recognises that there are a number of variables and attempts to control them. Evaluates chosen procedures, suggests/implements modifications where appropriate and shows a systematic approach in dealing with unexpected results.

(University of Cambridge International Examinations, 2012, p.47)

52. An interesting aspect is how each skill area is assessed:

Skill C1 may not generate a written product from the candidates. It will often be assessed by watching the candidates carrying out practical work.

Skills C2, C3 and C4 will usually generate a written product from the candidates. This product will provide evidence for moderation.

(University of Cambridge International Examinations, 2012, p.48)

53. Therefore, C1 is often assessed through DAPS, while skills C2, C3 and C4 are usually assessed through IAPS.
54. Alternatively, schools may choose paper 5 which is a “Practical test (1 hour 30 minutes) – with questions covering experimental and observational skills” (University of Cambridge International Examinations, 2012, p.10). For this practical test, students are supervised by a teacher and, according to the examiner’s report from the University of Cambridge International Examinations (2010):

Candidates had opportunity to show their practical ability as all three questions were readily accessible. The overall standard of achievement was very satisfactory. There were a few very high scores. Supervisors played their part in preparing the examination and providing a set of results. Supervisors’ results are very important, enabling the Examiners to have before them a reliable set of results against which candidates’ responses can be compared.

(p.38)

55. Whilst there is a practical test this is not assessed using DAPS; rather it is the students’ written responses to questions about the results (either given to them by their teacher or those which they obtained) that are assessed, an example of IAPS.
56. The alternative to paper 4 and paper 5 is paper 6 which is an “Alternative to Practical (1 hour) – a written paper designed to test familiarity with laboratory based procedures” (University of Cambridge International Examinations, 2012, p.10). This examines students’ familiarity with laboratory practical procedures, an example of IAPS. Details of the questions set by the awarding body can be seen in Appendix 10.

#### *The CREST award*

57. The CREST award is based on a project approach within STEM subjects. It claims to link the “personal passions of students to curriculum-based learning” (British Science Association, 2008) and is endorsed by UCAS. Students are given the opportunity to “investigate, design or make, research a subject, or design a science communication project” (British Science Association, 2008). Assessment of CREST awards is based on students’ project work and profile forms. The profile form ensures students address each award (bronze, silver and gold) criterion sequentially. The initial assessment is carried out by the teacher who, when satisfied with the work, contacts the local coordinator to assess the project. The student will present their work through a

poster or a presentation to the local coordinator, who then signs profile forms off (British Science Association, 2008). It is stated that:

Students should be able to explain what they did and why, have presented their data in an appropriate way and drawn logical conclusions. They should understand how their results fit in with their background knowledge and research. Projects with an industrial mentor should explore the wider applications of the project work.

(British Science Association, 2008)

58. The bronze award is assessed internally by the teacher whereas the silver and gold awards must be assessed externally by a local coordinator; for moderation purposes, teachers may be asked to produce samples of project reports and students' profile forms to the British Science Association. The assessment guidelines state:

The assessment process is a combination of a review of the student's Profile Form and interaction with the student.

Assessors confirm through questioning students that the project is the student's own work and that they clearly understand the processes they have used. With team projects assessors establish what contribution each student has made to the project to ensure they have each contributed a fair share to all parts of the process.

To achieve a CREST Award, students must demonstrate that they have satisfactorily answered the questions on the relevant Profile Form. The questions differ according to the level of the Award and for Science and Technology projects. Assessors should look for answers to the majority of the questions posed.

(British Science Association, 2008)

59. Whilst the assessment involves confirmation of students' knowledge through questioning, it is the assessment of the profile form that achieves the bronze, silver or gold CREST award, an example of IAPS. According to an evaluation of the impact of the CREST award by Grant (2007), for students at Key Stage 4, "silver awards can be used as an alternative means of accrediting work for students who may have good practical skills but tend to underperform in examinations" (p. 50).
60. What has emerged from this analysis is that practical work is clearly considered by awarding bodies and others to be an important part of teaching and learning, not only in science but also across a range of other subjects. Indeed, Woodley (2009) suggests that most UK science teachers also believe that practical work is a key component with school science education in England. However, that said, whilst many awarding bodies talk frequently about practical work and practical skills with regards to a range of subjects, very few of these subjects – notable exceptions being music and modern foreign languages – assess these practical skills to any great extent in terms of DAPS.

61. Thus, although it is the case that the awarding bodies place a lot of emphasis on the need for students to gain experience of undertaking practical work during the course of their studies, few of the skills so developed, other than in music and modern foreign languages, form a direct and substantial part of any summative assessment in England (see Appendix 11). Whilst awarding bodies place an emphasis on students experiencing practical work, there is the concern that, due to the dominance of summative assessment at GCSE and A level, there is limited opportunity for such experience and development of practical skills to take place (Nott & Wellington, 1999; Donnelly, 2000; Keiler & Woolnough, 2002).

## Work Package 2: Broad review of practical work outside England

62. In this broad review of practical work outside the UK, the countries that will be reviewed are chosen from within the PISA 2009 tables for science. We focus on a sample of countries within the top ten, namely China, Finland, Singapore, New Zealand, and Australia, and two that are closer to England's position in 16<sup>th</sup>, namely France and Scotland.
63. In China, ranked 1<sup>st</sup> in science in PISA 2009, the examination of practical work in science is one of the important parts in the unified examination (He, pers. comm., 18 August 2012). The unified examination is one that students must pass in order to graduate from secondary to university level and is approximately equivalent to somewhere between GCSE and A level in the UK. The requirements of the practical examination state that it must be: "checking students' skills and procedures of conducting practical work; checking students' abilities of scientifically selecting and using instruments; checking students' responsibility of keeping used instruments unbroken, tidy, and well-placed afterwards" (He, pers. comm., 18 August 2012).
64. The actual assessment of students' performance in conducting practical work is based on teacher reports where a teacher directly observes and assesses between two to four students in a twenty minute examination, with standardized marking criterion throughout the process (ibid). During the practical, students also complete a report showing their records, analysis and evaluation of the process. As the requirements imply a need for a DAPS approach, the skills being assessed during the practical work are also credited; for example, 2 marks may be given for correctly adjusting the balance before weighing an item. A total of 10 marks are available and this assessment of practical work is independent of the assessment of written examinations. The marks will be put on a student's transcript in the form of pass (6 marks or above) or fail for practical work for biology / chemistry / physics respectively, rather than being aggregated with the marks of the written examinations or even classified within an overarching science award. Indeed, separate to the practical examination there is a written examination with a total of 100 marks available. Assessment of the students' practical skills is only carried out during practical work.
65. In Finland, ranked 2<sup>nd</sup> in science in PISA 2009, students are assessed through both formative assessment during the course and summative assessment at the end of it. The national level curriculum (FNBE, 2004) recommends that students should learn versatile science process skills, like formulation of questions, making observations and measurements, formulating simple models for use in explaining phenomena, and, moreover, carry out simple scientific experiments clarifying the properties of phenomena (Lavonen, pers. comm., 29 August 2012). However, according to PISA 2006 school questionnaire data, students mainly perform a science investigation according to instructions given and rarely plan simple experiments, agree on tasks and the allocation of tasks, and set objectives or goals together with other students (Lavonen & Laaksonen, 2009). In Finland teachers are independently responsible for

assessing learning of these competence skills in both the formative and summative manner, and assessment is by DAPS.

66. In Singapore, ranked 4<sup>th</sup> in science PISA 2009, 15 year-olds study at least one separate science subject (biology, chemistry or physics) where they undertake practical work in preparation for the O level science practical assessment (Lee, pers. comm., 1 September 2012). O level science practical assessment comprises three skill sets with seven key aims:

Skill 1 – Performing and Observing. (Candidates are required to demonstrate their ability to perform an experiment using familiar apparatus, materials and techniques safely and methodically and to make relevant and accurate observations and measurements, recording results in an appropriate manner.)

Skill 2 – Analysing. (Candidates are required to process results, identify and comment on a key source of error and to draw conclusions which are consistent with obtained results.)

Skill 3 – Planning. (Candidates are required to analyse a practical problem and produce an appropriate procedure for an investigation.)

67. The intention of science practical assessment for O levels is:

Strengthen the teaching and learning of science as an inquiry  
Greater emphasis on scientific processes and mastery of practical skills  
Emphasis on active learning, not just passively following procedures  
Give teachers greater flexibility in managing students' experiences  
Expose students to a wider range of experiments and investigations  
Bridging theory and practical  
Increasing assessment literacy in teachers.

(Lee, pers. comm., 1 September 2012)

68. Practical work has always been part of the Singapore-Cambridge General Certificate Advanced Level; however, the assessment has shifted from a summative to a more formative approach. According to Hoe and Tiam (n.d.), the assessment of practical work in Singapore pre-2004 was reliant on a one-off summative assessment that did not allow for a “comprehensive assessment of experimental and investigative skills” (p.1) and this led to a driving force to change towards a more formative assessment of practical work where, since 2004, there has been a greater emphasis on process skills whilst the planning skills are still part of a separate written examination.
69. Three skill areas are assessed “MMO: Manipulation, Measurement and Observation, PDO: Presentation of Data and Observation and ACE: Analysis, Conclusions and Evaluation” (ibid, p.4). Students, whilst carrying out the practical tasks, are assessed on these three skill areas by the teacher, there are “2 combined skill tasks (of 1 h 15 min duration) to be assessed within a specified window period once in each academic year of the 2-year A level course” (ibid, p.4), an instance of DAPS.



70. The assessed tasks are only distributed to schools within a certain period prior to the assessment; therefore, teachers teach all the “required practical skills and prepare their students well for the practical tasks” (ibid, p.4). According to Hoe and Tiam (n.d.), benefits of such an approach for teachers include helping them to understand the skills required for the examination and providing opportunities for professional development through internal moderation sessions. Furthermore, a survey of students’ views showed that they felt the approach “assessed their practical skills more accurately as the assessment was continuous and gave them more opportunities to demonstrate their capabilities as compared to a one-off practical examination” (ibid, p.4).
71. In New Zealand, ranked 7<sup>th</sup> in PISA 2009, practical work in science is viewed as important with school examination criteria being developed with the involvement of teachers and input from the tertiary sector (Walsh, 1999). Similar to the IB Diploma in England, “the New Zealand NCEA” (Ofqual, 2012, p.23) science courses provide opportunities for practical research projects to be integrated into them (Cowie, pers. comm., 18 September 2012). For example, in chemistry a standard is available where students can use an analytic technique to “carry out open-ended investigation which allows students to design and carry out their own experiments in support of a research project” (ibid, p.38).
72. The assessment used nationally is internal but externally moderated. This approach has been commented on by Ofqual (2012) as being demanding in terms of the type of assessment but educationally beneficial as teachers are assessing what students know and can do directly (DAPS) as opposed to an examiner making inferences made by an awarding body via a written examination paper (IAPS). However, the reality is that assessment is principally undertaken by teachers marking the reports of the investigations that their students write (Cowie, pers. comm., 18 September 2012).
73. Australia, ranked 10<sup>th</sup> in science in PISA 2009, is an example of a country where examinations are determined at state level; in each of the six states assessment of practical work is different. In Queensland and the Australian Capital Territory, school-based examinations take place but in the other five states and the Northern Territory state-based external examinations are used (Dawson, pers. comm., 31 August 2012).
74. Practical work is assessed for students in Year 12 throughout Australian schools and is usually worth from 10% to 30% of the total marks (Dawson, pers. comm., 24 June 2012). One example which is aimed at high attaining students is ‘The International Competitions and Assessments for Schools (ICAS) Science’ which assesses skills in the following scientific areas: “Interpreting data, including observing, measuring and interpreting diagrams, tables and graphs; Applying data, including inferring, predicting and concluding; and Higher order skills, including investigating, reasoning and problem solving” (Educational Assessment Australia, 2012). However, ICAS is a multiple choice test and does not directly assess practical skills in science. Whilst the test does include items about interpreting data and understanding experimental

design (for example, identifying a suitable control), the competency of the students' skills are only inferred on the basis that students with a higher level of competency in these should do better as a result (Connolly, pers. comm., 20 August 2012).

75. Another assessment program in Australia is the Essential Secondary Science Assessment which is an online interactive multimedia assessment which “mandates the teaching of science in contexts that assist students to see the relevance of science and to make meaning of scientific knowledge, understanding, skills, values and attitudes” (New South Wales Government Education and Communities, 2012). Because the test is assessed in an online format, students' skills are assessed by IAPS.
76. The Australian Curriculum Assessment and Reporting Authority (ACARA), which is the equivalent of the previous QCDA in England, runs a national sample test in science literacy for eleven to twelve year olds (Connolly, pers. comm., 20 August 2012). This is called the National Assessment Program – Science Literacy and enables teachers to assess their students in comparison to the national proficiency levels, so as to allow them to track the effectiveness of their teaching and the abilities of their students (ACARA, 2009). The tests assess three key strands:

Strand A: formulating or identifying investigable questions and hypotheses, planning investigations and collecting evidence.

Strand B: interpreting evidence and drawing conclusions from their own or others' data, critiquing the trustworthiness of evidence and claims made by others, and communicating findings.

Strand C: using science understandings for describing and explaining natural phenomena, and for interpreting reports about phenomena.

(ACARA, 2009, p.3)

77. The assessment of these three key strands involves two parts: an “objective assessment, with 37 multiple-choice and open-ended questions” and “a practical task from the Living Things concept area requiring students to carry out an investigation in groups of three and then respond individually to a set of questions about the investigation” (ACARA, 2009, p.7). Whilst the objective assessment is an instance of IAPS, students' examination papers being marked by the teacher, the practical task assessment entails teachers assessing students as they carry out the investigation and so is an instance of DAPS.

78. In France, ranked 27<sup>th</sup> in science PISA 2009, the Baccalauréat Général, for ages 15 and above, integrates science subjects so that biology, chemistry, geology and physics are in one specification. According to Ofqual (2012):

The *baccalauréat général* lists required practicals with techniques and skills to be acquired and details of how the necessary skills can be developed and then assessed. This practical assessment (which may be in chemistry and / or physics) contributes up to 20 per cent of the total chemistry–physics score.

(Italics in original, p.144)

79. The assessment of practical work in the Baccalauréat Général involves two parts, a written test for 16 marks and a practical test for 4 marks, making a total of 20 marks (Ministère de la jeunesse, de l'éducation nationale et de la recherche, 2012). The practical test lasts for an hour (Ministère de l'éducation nationale, 2012a). Whilst the students are carrying out the practical work, two teachers assess four students at a time (DAPS); however, the teachers do not examine their own students but those of their colleagues. The practical work that is assessed annually is randomly selected from a prepared list of possible activities which the students have been prepared for during the course. Teachers use a "grille d'évaluation" (observation grid) (Ministère de l'éducation nationale, 2012b) which looks at four specific areas as seen in Table 3. After this, students go onto the written part, the IAPS component.

Table 3: Observation grid (adapted from Ministère de l'éducation nationale, 2012b)

1. Understand how and why to manipulate (about 1 to 3 marks)
2. Use of techniques (about half of the total marks)
3. Use of methods to represent the experimental data (about a quarter of the total marks)
4. Apply an explanatory approach (about 2 to 3 marks)

80. The first area, Understand how and why to manipulate, assesses students' approaches to the experiment through observation and preparation, such as their justification for their choice of equipment or method that is linked to their hypothesis. The second area, Use of techniques, assesses students' abilities at using the equipment correctly, such as setting up a microscope or protocols for handling equipment as well as the use of simulation software. The third area, Use of methods to represent the experimental data, assesses students at their ability to select and use the information to record using, for example, drawings and tables in a suitable way. The fourth area, Apply an explanatory approach, assesses students' ability in argumentation and understanding of the experiment, understanding the problems in the experiment, commenting on results and evaluating them.

81. In Scotland, ranked 17<sup>th</sup> in science PISA 2009, there is only one awarding body for standard grade and higher. The standard grade is for students aged fourteen to sixteen and grading is awarded from grade 7 to grade 1 – the highest. In the specification for standard grade in biology, chemistry and physics by the Scottish Qualifications Authority (2008), students are assessed on the practical work as an internal assessment worth 20% of their final grade. It is known as the Internal Assessment of Practical Abilities and focuses on two areas: "Carrying out Techniques" and "Designing and Carrying out Investigations" (p.6). The first, carrying out techniques, relates to fieldwork and laboratory work. The grade that a student attains here is determined by their ability to carry out ten clearly specified practical techniques throughout the two years of the standard grade course. The physics techniques assessed in the standard grade qualification in physics can be seen in Appendix 12.

82. In the Higher courses, for students aged 17 in Scotland, the assessment for practical work is within Outcome 3. This is in the form of evidence, where the requirements for:

Outcome 3 requires the teacher/lecturer to attest that the report is the individual work of the candidate derived from the active participation in an experiment involving the candidate in:

- planning the experiment
- deciding how it is to be managed
- identifying and obtaining the necessary resources, some of which must be unfamiliar
- carrying out the experiment
- evaluating all stages of the experiment, including the initial analysis of the situation and planning and organising experimental procedures.

(Scottish Qualifications Authority, 2008, p.30)

83. Outcome 3 is the same for the higher qualification in biology, chemistry and physics. Whilst the teacher is assessing this objective, the assessment comes from IAPS as opposed to DAPS because students are not marked on their direct manipulation of objects; this can be seen in Appendix 13 which shows the example for chemistry.

84. In conclusion, what has emerged from this international analysis is that the assessment of practical work appears to differ markedly in those countries that we have looked at in terms of the proportion of DAPS and IAPS that they use to assess practical skills. In particular, amongst those countries that performed well in terms of their science PISA results, China, Singapore, New Zealand and Finland all make use of a substantial proportion of DAPS, compared to countries like Australia, England and Scotland in which the assessment of practical skills is based predominantly on IAPS.

85. Indeed, in China, this distinction between DAPS and IAPS manifests itself in the fact that students are able to gain credit for their skills in practical work as a separate mark that indicates their competences first hand rather than having to be inferred from examinations (IAPS). Interestingly, according to Ofqual (2012) which looked at chemistry qualifications in Australia, China, France, Finland and New Zealand, despite these differences in the proportion of DAPS used in these countries, all share a similar appreciation of the “importance of practical work and the acquisition of skills of carrying out, recording, analysing and concluding” (p.138).

86. However, despite the widespread view as to the importance of practical skills what has emerged is that in many cases the term ‘practical skills’ is used as a catch-all phrase without an explicit statement of precisely whilst these skills are.

### Work Package 3: A synthesis of research on the assessment of science practical work

87. Recent research in the area of practical work (Abrahams & Millar, 2008; Abrahams & Reiss, 2012) and in the assessment of science education more broadly (Bernholt, Neumann & Netwing, 2012) all describe the significant influence of the curriculum and, in particular, its associated assessment on the practical work that teachers opt to do. In England, at GCSE and A level, it has long been recognised (Donnelly *et al.*, 1996; Pollard *et al.*, 2000; ARG, 2001) that, to a very considerable extent, it is assessment that drives what is taught, to the extent that teachers' preferences for using different types of practical work are routinely influenced by their considerations of curriculum targets and methods of assessment (Abrahams & Saglam, 2010).

88. In order for assessment to be effective, it is necessary to know what it is that is being assessed, be that conceptual understanding, procedural understanding, process skills or practical skills. In order to assess these areas, it is necessary to understand the meanings of these terms. According to Gott and Duggan (2002):

By conceptual understanding we mean a knowledge base of substantive concepts such as the laws of motion, solubility or respiration which are underpinned by scientific facts. By procedural understanding we mean 'the thinking behind the doing' of science and include concepts such as deciding how many measurements to take, over what range and with what sample, how to interpret the pattern in the resulting data and how to evaluate the whole task.

(p.186)

89. Process skills are "generalisable, transferable from one context to another and readily applicable in any context" (Hodson, 1994, p.159). However, the term 'practical skills', whilst often referred to in the literature on practical work (cf. Bennett & Kennedy, 2001; Hofstein & Lunetta 2004; SCORE, 2009), is rarely explicitly defined. Whilst practical skills clearly include an individual's competency in the manipulation of a particular piece of apparatus/equipment there are a large number of such skills, making it unfeasible to assess all of them within the limited time available in school science. Furthermore, different industrial employers, as well as university departments, will have very different perspectives on which practical skills they consider important. This helps to explain why, despite the development of a range of practical skills in school science, the Confederation of British Industry (2011) was still able to claim that 23% of employers felt that the lack of practical experience and lab skills (possibly only those skills appropriate to their specific industry) was a barrier to recruitment of STEM-skilled staff.

90. In order to explain how these terms relate in the context of science practical work, consider a case in which a teacher, when teaching electricity, wants to use a practical task to demonstrate the conservation of current in a parallel circuit. The procedural understanding in this case would entail knowing how to set up a working parallel

circuit and be able to operate and read with sufficient accuracy an ammeter in order to obtain the readings intended by the teacher. The conceptual understanding would be to know that the data obtained from the ammeter readings can be understood in terms of the scientific idea that the flow of electric charge is conserved in a parallel circuit. The process skills would refer to the ability to follow the instructions provided by the teacher and understand the generic issues relating to fair tests and measurement errors.

91. The role of assessment of practical work in science lessons (formerly known as Sc1) has been commented on (Donnelly, 2000) as being primarily used for assessment towards specific examinations rather than for the skills it may provide:

... it appears that Sc1 is most commonly used for purposes of assessment, and more rarely taught, either for the sake of the skills it is intended to promote or as a vehicle for the teaching of scientific content. (There is perhaps an ambiguity here, with teachers indicating that they very often use Sc1 for assessment purposes, rather than that they very often undertake assessment of Sc1.)

(p.28)

92. One particular problem with the current system is the limited amount of any direct assessment of practical skills. As Donnelly *et al.* (1996) have argued, as teachers teach to the assessment the limited amount of direct assessment of practical skills means that there is less inclination amongst teachers to devote time and effort to developing students' practical skills. Indeed, whilst Dillon and Manning (2010) talk generally about pedagogy in their claim that it is the "assessment tail that wags the pedagogy dog" (p.18), Nott and Wellington (1999) relate this specifically to science education when they state:

The skills and processes of investigations are not taught, but experienced, and the conduct of investigations is about summative marks for GCSEs rather than formative assessment to become a competent scientist. In that both pupils and teachers see them as more about getting marks than learning some science, the assessment tail is definitely wagging the science dog.

(p.17)

93. This claim is exemplified in practice by a comment made by a teacher and reported by Abrahams (2005):

When we do investigations I'm perfectly honest with the kids. I'll say to them that, as a piece of science, I think this is garbage, in terms of getting coursework marks it's superb. So we'll just play the game, we'll spend two or three weeks playing the game, getting some good marks, and then we can move on and do some science again. That's intellectual honesty.

(p.136)

94. In a study by Bennett and Kennedy (2001), they reported on “the inadequacies in the current model of assessment of practical skills and abilities, with written examinations questions on practical work examining only a very limited range of abilities” (p.108). Indeed, changes in the way practical work is used in schools has meant, as Toplis and Allen (2012) discuss, that there has been:

a shift in England and Wales since the 1960’s [sic] away from practical work for teaching apparatus handling skills and towards augmentation of knowledge and understanding of substantive concepts, and 21st century UK school science has little to do with the formal assessment of these skills.

(p.5)

95. We believe that as practice in school is led by assessment pressure, if there is a desire for teachers to re-focus some of the time spent in doing practical work on developing useful practical skills for further study and employment, then it is essential that such skills are formally included in the *summative* assessment process. Shifting the assessment of practical work back towards a more equitable balance between practical skills and augmentation of knowledge and understanding of substantive concepts is important at a time when The Campaign for Science and Engineering (2011) notes that the UK must do more to ensure that students have the necessary science practical skills to enter the workplace.

96. Gatsby have carried out investigations into the views of Higher Education Institutions and Employers on the assessment of practical skills. According to Gatsby (2012), STEM employers felt that practical skills are important within their establishments. Their understanding of ‘practical skills’ was “broad ... a significant proportion included dexterity, hand skills and lab work within their definition” (Gatsby, 2012, p.3). It appears very likely that different employers value different types of practical skills, so that getting a consensus amongst employers, however desirable, might be very difficult.

97. Because different employers require different practical skills, the one area where there might be a consensus would be with regards to generic skills. Indeed, Gatsby (2012) found that:

Analysing and interpreting data to provide good evidence, and taking and recording measurements with accuracy and precision were identified as skills that were essential for school leavers recruited into science staff roles and being of most value to an organisation.

98. Furthermore, Gatsby (2012) found that 46% of surveyed employers stated they used a practical test at interview to assess practical skills and knowledge alongside the application form. Even if these new recruits are not tested on their practical skills at interview, 95% of employers provide them with practical skills training (Gatsby, 2012). That study also found that employers felt that the ability to “apply practical

skills to new situations”, such as manipulation of equipment and experience of new techniques relevant to employment, would be a useful additional to A level courses to help students in employment upon leaving school.

99. A further report on a small scale study exploring university staff views on laboratory skills in new undergraduates within the Russell Group Universities in England also concluded that students were commencing university lacking not only in practical skills but also the confidence to carry out practical work within a laboratory (Grant, 2011). Indeed, both Grant (2011) and Gatsby (2012) found that practical skills had declined over the last five years and that a factor in the lack of practical skills was the “limited exposure to practical work at school” (Grant, 2011, p.2).

100. Grant and Jenkins (2011) discussed how Higher Education Institutions were making provisions for students to develop their practical skills both prior to taking up courses and within their first year of undergraduate study. The ways included:

- Focusing on skills development in first year practical courses;
- Changes to course structures including pre-labs and project work;
- Training for teachers and demonstrators;
- Assessment methods during practical classes;
- Outreach and links with schools.

(Grant & Jenkins, 2011, p.3)

101. These findings were similar to another study by Grant (2011) which found that university staff at Russell Group Universities had adapted their lab-based teaching in order to better prepare their students by the end of the first year. The changes were:

- Simplifying first year lab courses by providing more step-by-step instructions, removing complex experiments or allowing more time;
- Increasing the focus and/or time spent on basic skills;
- Increasing the levels of support through more staff time or demonstrators;
- Introducing online pre-labs

(Grant, 2011, p. 2)

102. One conclusion that can be drawn from these reports is the ever growing need to ensure that students gain not only experience of practical skills in schools but also the confidence within a laboratory situation so that they are better prepared for employment and higher education. Indeed, while it is clearly impossible to teach the full range of practical skills that every employer and higher education institution desires, enabling school students to gain experience of a reasonable number of core practical skills will certainly benefit them far more than having no such experience.



## Work Package 4: Case Studies

### *Case Study 1: Chemistry*

*Dr Maple*

*Role: Undergraduate practical course coordinator, Northern University*

103. The Chemistry department at York starts with the assumption that students will arrive to begin their undergraduate degree not only with a wide range of practical skills but that within those skills there will be a wide range of competencies. This has become even more pronounced as the department recruits students from overseas and from countries in which, Dr Maple reported, there is little if any practical work in their equivalent of A level study. The focus of the department has therefore been to start from basics and, as such, the first year laboratory sessions have been designed to develop the practical skills that are considered essential in order to successfully complete the chemistry degree as well as providing a sound foundation for either future research or work in industry. As such, Dr Maple felt that any practical skills that A level students had already developed would make little, if any, difference to the way in which they progressed through their degree programme.
104. The approach adopted in the chemistry department for assessing practical skills was a mixture of both DAPS and IAPS. Dr Maple felt that whilst it was essential to include DAPS as a means of directly assessing a student's competency with a particular skill it was also necessary to recognise – if only for pragmatic reasons – that with 100+ students in a lab it was important to ensure that the DAPS was relatively quick and easy to assess and could be done fairly and reliably by non-academic members of the department (most labs are staffed by PhD student demonstrators). The assessment approach that has been created therefore requires students to develop a skill, for example the ability to purify a substance, and, in this case, for this to be assessed quickly and effectively by the lab demonstrators using the electrical conductivity of the substance. A range of possible conductivity results are provided for the demonstrators – along with marks for each value – with the highest level of competency being assigned to students whose sample has the same conductivity as that produced by the academic when trialling the experiment. IAPS is also used to assess practical work and this is done by requiring students to keep a record of their laboratory activities. The ability to write up a practical task, record and analyse data etc. can then also be assessed periodically.
105. In terms of UK students with A levels in chemistry Dr Maple felt that a transcript of A level marks – including a separate mark for practical work – would only be useful if this was coupled with a requirement that A level chemistry assessed, using DAPS as well as IAPS, competency in those same core practical skills that the department currently developed in Year 1. However, that said, Dr Maple emphasised that with the growing number of international students who, as mentioned earlier, often had little experience of practical work it would be highly unlikely that the department would move away from assuming a 'no practical skills' starting point. As such, the main advantage of developing and assessing such skills was that it gave the students

confidence in the laboratory and this, Dr Maple claimed, was the most important characteristic in terms of doing well in the laboratory. It was, after all, impossible to develop every practical skill that would be used as an undergraduate and certainly as a graduate but confidence, coupled with the generic ability of being able to follow a set of instructions (a recipe), was likely to mean that the student would successfully be able to master new skills – taught by following a written procedure – as and when presented to them.

### *Case Study 2: Electronics*

*Dr Redwood*

*Role: Undergraduate practical course coordinator, Northern University*

106. Dr Redwood pointed out that most of the students entering this degree did not have an Electronics A level, but rather a mixture of A levels including (but not restricted to) Mathematics, Computer Science, Physics and Chemistry. Because of this, experience had shown that most of them lacked the basic subject-specific practical skills needed to successfully complete their degree. As such, the starting assumption was that students would enter the department with no subject-specific practical skills – such as the ability to solder and use a range of electronic testing devices, such as an oscilloscope, and, as a consequence, the first year of the degree had been designed to develop and assess these practical skills. The most useful skill that Dr Redwood felt that students could bring from their study at A level was that of being able to follow basic recipe-style instructions so that they could engage with the material that had been developed within the department to develop their subject-specific practical skills.
107. Whilst the department assesses practical work using both DAPS and IAPS, time constraints mean that the role of DAPS is very minor. Indeed, whilst Dr Redwood did use a 1-5 scale to assess a practical skill competency in, for example, soldering, with marks so awarded contributing (along with IAPS marks) to the total mark for that practical task, most of the assessment marks would be derived from using IAPS from marking the students' written reports in lab books. Lab books are taken in twice a year and assessed in terms of (i) how far the student got with a particular task and (ii) whether it did what it was designed to do e.g. in the case of a task that involved constructing a circuit, did the circuit perform as it was designed to do – lights lit up in a particular order – as then it could be inferred that the soldering had been carried out successfully and the student was assumed to have reached a certain level of competency. Whilst Dr Redwood felt that it was feasible for laboratory demonstrators to assess using IAPS, he considered it unreliable for more than one person to assess using DAPS and so he alone undertook to do this. As such, due to large class sizes and a relatively short amount of time for such individual assessment, this assessment entailed taking no more than a quick cursory glance at the solder. Dr Redwood mentioned that the department had previously tried to assess practical skills using DAPS in the form of a practical examination but had found that problems with equipment and/or failure of testing kit made such means of assessment unreliable as well as unfairly penalising early errors in the practical task that introduced a 'knock-on' cumulative effect.

108. The main improvement, suggested by Dr Redwood, would be for electronics A level to have a practical component that assessed students' abilities in certain subject-specific skills and for these assessment marks to be recorded separately, as on a degree-like transcript. Yet, however advantageous this might be, the fact that very few of their students took A level electronics coupled with the fact that the department was a recruiting, rather than a selecting, one meant, Dr Redwood felt, that, realistically speaking, that they would always need to start from the lowest common denominator. That would entail assuming that students had very few, if any, relevant subject-specific skills.

*Case Study 3: Physics*

*Dr Lime*

*Role: Undergraduate laboratory coordinator, Northern University*

109. The Physics department at York assumes no competency with practical skills amongst students commencing their undergraduate degree. Dr Lime reports that there appears to have a steady decline in the development of practical skills in schools – if the students he sees in the laboratory are representative of A level physics students nationally – and there is no longer an expectation that, for example, students will have even the most basic subject-specific skills, such as being able to use an ammeter and voltmeter. Dr Lime reported that what is still expected is that students will possess basic generic skills such as being able to plot graphs, deal with significant figures and have an understanding of error.

110. The department has developed an introductory programme for developing certain specific practical skills – such as how to use an oscilloscope – and each of these skills is allocated two weeks of laboratory time. DAPS is not used in the assessment process because it is considered to be overly expensive, time consuming and difficult to timetable given the large size of student laboratory groups. As such, all assessment involves IAPS in the form of written laboratory reports with the assessment being weighted equally between (i) the quality of the data, (ii) the quality of the written work and (iii) the method/introduction and discussion.

111. What Dr Lime would like to see in terms of A level physics would be the introduction of some kind of assessment of basic subject-specific skills along the lines of a 'can do' test. These would be both useful as well as developing student confidence in the area of practical work – something they currently lack, he felt.

112. In terms of current A level grades Dr Lime did not feel that there was any strong positive correlation between grade and competency at practical skills. He saw no advantage to assessing practical skills separately because, as a recruiting department, they do not have the luxury of being able to reject students simply because they lack competency in terms of basic subject-specific skills. Indeed, the degree had been restructured to incorporate time for developing these skills for just this reason (as well as recruiting overseas students some of whom had very little practical laboratory experience) and this was unlikely to change. As such, the

department makes no attempt to test school leavers on arrival for specific practical skills but assumes that they will have to be taught everything from scratch.

*Case Study 4: Physics*

*Dr Sycamore*

*Role: Senior Lecturer and i/c undergraduate admissions, Southern University*

113. Dr Sycamore felt strongly that student arrive to study physics at Southern University after having done their A levels having little interest in practical work or understanding of its purpose in physics:

I think they are never motivated by experiments. Experiments are something they have to do in order to get onto a course teaching them general relativity. No-one is motivated by experiments and I think part of the problem there, I think, is that it is never taught to them in a way that makes them realise the importance of experiments, I suspect. The teachers say, do this experiment, this is how we understand forces work, but they never really teach hypothesis testing, which is really the core thing for the first year course. So the way that I run the course is that the emphasis is very little on learning the physics but much, much more on hypothesis testing, distinguishing one model from another and, very, very importantly, understanding uncertainties. I quite often teach that knowing your uncertainty on a measurement quantity is almost far more important than the central value that you obtain.

114. Because of variations between schools and colleges, the department assumes very little expertise in dealing with laboratory equipment: “Rulers and thermometers yes but that is about it really. I don’t necessarily assume that they’ve done it. I certainly assume that they haven’t used an oscilloscope or Vernier scales before. Some of them might but not very many at all”.

115. Dr Sycamore welcomed the idea of his department being provided with more data on how students had performed in practical work at GCSE and A level but cautioned that, on its own, this would not solve much:

At the moment what happens is, I mean, well for GCSEs we don’t get any sub-divided information we just get the raw, or final, grade, whereas for A level we sometimes get the module mark which may or may not include the practical elements that they did. That could be broken down. So if we wanted that information I think what I would need is some unification of how that information is presented by the examining boards, right. At the moment what happens is that they all do it in slightly different ways and call them slightly different things and it is very difficult to compare them so I would unify that amongst the boards. I would unify how it is presented on the UCAS forms because that is the key repository where we get that information from, so if that can be unified in some way and it should be possible in some way at

least for A levels. It might be different for the IB, it might be different for everything else but at least for A levels it should be possible to manage that.

*Case Study 5: Electronic Engineering and Computer Science*

*Dr Ash*

*Role: Senior Deputy Dean and Director of Admissions for Electronic Engineering and Computer Science, Southern University*

116. Dr Ash felt that in computer science what was needed was not specific practical skills but more generic capabilities:

OK, so I am wondering what you mean by practical skills. So, there are some different things. One interesting thing is, with computer science anyway, they don't actually need to be able to programme, it's not necessary that they know particular programming language like Java or C or Pascal or whatever, they don't actually need to be able to programme. What we are more interested in is inquisitive and logical minds so mathematical, sort of the analytic mind where they can take a problem and say 'Oh I can do it this way or that way', so that is kind of more what we look for rather than practical 'I can do programming – I know this language'. So the practical skills, if this is what you mean by practical skills, would be more around the logical thinking, the problem solving, the analytic thinking – that is the kind of thing.

117. Indeed, Dr Ash referred to specific practical skills, in whatever science, as "tool skills". While he saw a place for these in pre-university science courses he was much more interested in the more generic, process skills. At the same time he admitted that he didn't know the sort of practical work that students undertook at A level.

118. Dr Ash felt that it would indeed be valuable to have, for students taking science courses in schools and colleges, a transcript providing information about their relative performance in theory and practical work "but it would need to come with some sort of simple description of what the actual practical work was".

*Case Study 6: Government employer (GE)*

*Dr Beech – Resource manager; Dr Oak – Head of plant science; Dr Elm – Team Leader in the food and environmental science research group*

119. Whilst GE employs mainly graduates and postgraduates it also recruits to a growing apprenticeship programme that has A levels and their equivalents (NVQ level 3) as entry qualifications and which leads to a position as a junior lab technician. In terms of competency with practical skills Dr Oak reported that GE has "a pretty low expectation of those skills" that both prospective apprentices (and graduates) will have on entry and has developed its own training programme. The full range of practical skills that GE considers an apprentice needs to function as a safe and effective junior laboratory technician are listed in Appendix 2. As can be seen, these

include core generic practical skills that GE deems essential for all apprentices to master as well as a range of more subject-specific practical skills for those taking either a biology- or chemistry-orientated apprenticeship.

120. The practical skills that the training is designed to develop are assessed by the Team Manager using DAPS which is considered to be both desirable and feasible given that the current group contains only 21 apprentices.
121. In terms of in-house practical skill training, Dr Elm reported that they use a process in which the trainee is assessed on the basis of the material they produce, e.g. the purity or pH of a given product. This assessment is linked with the International Organization for Standardization (ISO) that monitors standards within GE and ensures that Standard Operating Procedures (SOPs) are adhered to and are undertaken at an acceptably high level of competency. Whilst these are assessed internally external moderators visit GE and can randomly request that trainees repeat SOPs on which they have been assessed in order to check that they can reproduce the same level of competency with a particular skill when being assessed by an external moderator. For example, the trainee would be expected to produce the same level of purity or pH as they had produced under internal assessment. Internal assessors are therefore required by GE to be totally honest about their assessment so as to ensure that external moderation does not lead to claims about lenient marking which might threaten the ISO accreditation of the organisation.
122. Dr Oak suggested that if these core practical skills could be taught and assessed in school in the same manner as they were assessed by the GE this would be a useful change to the current A levels that, Dr Beech thought, were a very poor reflection of practical ability.

### *Conclusion*

123. What these case studies have shown is the extent to which science departments in two leading universities and a large government employer have come to expect those entering their degree or training programmes to do so with the bare minimum of specific practical skills. None of those interviewed in the six case studies considered that current GCSEs or A levels provided any explicit evidence for a person's level of competency in practical work in general or, perhaps more importantly, for any subject-specific practical skills. Indeed, to a large extent, both universities and the government employer assume a 'no practical skills' starting position and have implemented their own in-house training programme. In some cases, whilst practical skills are developed through repeated use in regular laboratory sessions, the assessment of these skills remains predominantly by IAPS due to pressures of time, financial cost and problems with the reliability of equipment. In other cases assessment of practical skills involves a mixture of DAPS and IAPS. Interestingly, it is in the Government employer that DAPS features most strongly. When DAPS is used, assessment is often based on the candidate's ability to produce some product, a property of which can be measured, or be able to use a particular piece of equipment to do something that can also be measured, for

example measuring the conductivity of a solution that has been produced or reading the output values from an unknown test device using an oscilloscope.

124. One common concern was that students or apprentices currently arrive with a wide variety of academic backgrounds and it was not envisaged that this would change in either the short or medium term. As competency in specific practical skills was not part of any current (or planned) entry requirement it would remain essential to start the development of any practical skills training from the point of 'the lowest common denominator', i.e. the least competent member of the group, as to do otherwise would be impracticable and unfair.
125. One conclusion we draw from these case studies is that at GCSE and A level, the greater use of DAPS for the assessment of practical work in science might depend upon having external moderators – as with the ISO – with the authority to alter a centre's marking if its internal assessment did not reflect the 'real' level of its students' practical skills. A second conclusion is that it would be beneficial if A levels, in particular, were more explicit about the practical skills, specific and generic, that students were expected to become competent at and if there was harmony across the awarding bodies as to these skills.

## Discussion and Recommendations

126. There is a need to clarify what the term 'practical skills' is used to mean. Currently, practical skills as a term is widely used but it is rarely defined with anything like the precision that is typical for 'subject content' knowledge. If the practical skills that awarding bodies want students to achieve throughout their course are not clearly defined, and then assessed, the problem which Nott and Wellington (1999) discuss can lead to the assessment being merely a process in which students learn how to gain high marks for summative examinations as opposed to being taught about and having opportunities to develop their practical skills:

The skills and processes of investigations are not taught but experienced, and the conduct of investigations is about summative marks for GCSEs rather than formative assessment to become a competent scientist.

(p.17)

127. **Recommendation 1:** Awarding bodies should be as explicit as to which practical skills candidates should develop as they are about the subject content knowledge that is expected of candidates.

128. Science is frequently less precise than some other subjects as to exactly what manifestation of skills is expected at what level. Precision as to the practical skills that need to be developed at each level is an area of assessment that, in particular, music qualifications have been able to develop effectively. Within the ABRSM grade system in the Aural test, as an example, grade 1 students must sing "as 'echoes' three phases played by the examiner" (ABRSM, 2011a, p.1); by grade 4 students must sing "five notes from score in free time" (ABRSM, 2011b, p.1) and by grade 8 students must sing "the *lower* part of a two-part phrase from score, with the upper part played by the examiner" (ABRSM, 2011c, p.1, italics in original). Such precision aids both candidates and their teachers since effective assessment requires a clear understanding of what it is to be assessed.

129. **Recommendation 2:** Science specifications should be more precise than they generally are at present as to those skills needed for different qualifications (e.g. GCSE and A level) and for different grades / levels within such qualifications.

130. Awarding bodies need to state explicitly what it is they intend to assess and in doing so differentiate between DAPS and IAPS in the assessment to ensure that assessment can be undertaken successfully.

131. **Recommendation 3:** If the intention is to determine students' competencies at undertaking any specific practical tasks, then DAPS is more appropriate. Conversely, if the intention is to determine the understanding of a skill or process, then IAPS is more appropriate.



132. The comparison of the ways in which school science is assessed in other countries shows that England uses DAPS less than a number of other countries, including several that perform highly in PISA. Furthermore, it is clear that DAPDS is more widely used in the assessment of a number of other subjects in England.
133. **Recommendation 4:** Those involved in determining how school science practical work is assessed in England could learn lessons from how it assessed in other countries and from how other subjects in England assess practical skills.
134. Whilst DAPS does not necessarily require teachers to undertake the assessment, a recent report from the Nuffield Foundation on the assessment of primary science has called for a greater role for teachers in the assessment process (Harlen *et al.*, 2012). We believe, given the numbers of students involved and the potential higher costs of employing more DAPS, teachers should be directly involved in the direct assessment of practical work.
135. **Recommendation 5:** Greater use of teachers should be made in the summative assessment of their students' practical work, accompanied by a robust moderation procedure.

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## Appendix 1: **Glossary of terminology**

*Direct Assessment of Practical Skills (DAPS):* Where students' skills are assessed either in the presence of the person who is awarding marks (e.g. when observing the manipulation of objects in science) or when a record is made (e.g. an audio-tape recording when assessing oral skills in modern foreign languages) and sent to the person who is awarding marks.

*Formative assessment:* Assessment *for* learning, where students are given feedback from the teacher during the teaching they receive in order to progress as opposed to being given a final assessment of their learning.

*Indirect Assessment of Practical Skills (IAPS):* Where students' skills are *inferred* in a written examination or some other secondary source of assessment.

*Internal assessment:* Assessment carried out in the centre (school/college), marked by the teacher and moderated by the awarding body. This is the coursework within a qualification. Within science qualifications, 'internal assessment' generally refers to practical work assessment.

*Investigative Skills Assignment (ISA):* The ISAs are 45-minute, non-tiered written tests, taken under controlled conditions. Each ISA is set by AQA, marked by the teacher/centre using marking guidance provided by AQA, and moderated by AQA.

*Process skills:* Generic skills such as, in science, observation, measurement, sorting/classifying, planning, predicting, experimenting and communication.

*Practical skills:* Skills necessary for undertaking a non-written task, e.g. performing a titration, reading an oscilloscope, playing an arpeggio, ordering a meal in a foreign language.

*Summative assessment:* Assessment *of* the learning, where the marks are for a terminal test or examination.



Appendix 2: **The practical skills that one government employer considers a junior laboratory technician requires**

<b>Core skills for all apprentices</b>	
Health and Safety	Knowledge of COSHH
	Use of PPE
	Use of fume hood
	Fire safety
	Spill safety
Quality Assurance	Understanding and Following SOP's
	Completing lab books and results sheets
	Understanding and working to basic requirements of ISO 17025
	Understanding and working to basic requirements of GLP
Core laboratory skills	Use of standard laboratory glassware eg (measuring cylinder, volumetric flasks)
	Use of bench top balance
	Use of analytical balance
	Use of pipettes (e.g. positive displacement, air displacement, electronic, glass)
	Calibration and use of a pH meter
	Use of centrifuge
	Use of a bench top shaker
	Use and maintenance of dish washers
	Use of spectrophotometers
	Making up standard solutions; appropriate storage and disposal
	Use and maintenance of fridges and freezers
	Use of a laminar flow cabinet
Sampling	Preparation of paperwork and dispatch of samples for analysis (internally and externally)
	Maintenance of sample storage and disposal systems
	Maintenance of reference material storage and disposal systems
	Sample checking, logging and tracking
Electronic Systems	Use of e-procurement for ordering consumables
	Accessing SOP's on workbench
	Use of Nautilus LIMS (for sample logging and tracking)
	Use of excel spreadsheets
	Use of Word

<b>Biology Specific Skills</b>	
Laboratory skills	
microbiology	Media preparation
	Aseptic technique
	Agar spread plate and pour plate
	Inoculating broths and subbing

	Colony counting
Microscopy	Use of microscopes
	Sample and slide preparation e.g. Gram stain
Serology	ELISA, sample preparation and testing
Molecular biology	DNA extraction,
	PCR and gel electrophoresis
	Taqman
Biological assays	Sap inoculation, bait testing and growing on
Results	Interpretation of results to show patterns and trends with possible conclusions

<b>Chemistry Specific Skills</b>	
Laboratory skills	Preparation of calibration standards through the performance of a serial dilution
	Hand washing glassware
	Acid cleaning plasticware/glassware
	Use of Legacy LIMS
sample prep	Performance of simple liquid extraction methods
	Sample preparation / homogenisation
ecotoxicology	Use of thermometers, thermohygrometers and Tinytag dataloggers
	Determination of soil moisture content
	Use and maintenance of incubators and plant growth chambers
	Preparation of standard laboratory solvents and ecotoxicological media
	Determination of soil maximum water holding capacity
	Use and maintenance of field weather monitoring station
	Use and maintenance of field automated water sampling stations
	Maintenance of aquatic ecotoxicological cultures (e.g. <i>Daphnid</i> , green algae, chironomid)
	Maintenance of study sample soil moisture contents

### Appendix 3: OCR Gateway (2012, p. 120)

#### **Part 1 – Research and collecting secondary data**

Part 1 requires candidates to plan and carry out research. The Part 1 stimulus material introduces the task and provides guidance for the research. The research may be conducted either in class or as a homework exercise. The information collected is required for Parts 2 and 3.

#### **Part 2 – Planning and collecting primary data**

Part 2 requires candidates to plan and carry out an investigation to collect primary data to test a hypothesis stated in the Part 2 stimulus material. Collecting the data, as well as an assessed skill, will help candidates in Part 3 of the task by:

- enhancing their awareness of the practical techniques involved
- focusing on the quality of the data collected
- making them aware of the risks and necessary safety precautions.

#### **Part 3 – Analysis and evaluation**

Part 3 requires candidates to process and analyse the results from their research (Part 1) and their primary data (Part 2). They will also be required to evaluate their data and the methods used to collect it, and draw and justify a conclusion. Candidates will be guided by questions in an answer booklet.

Appendix 4: Practical work in the 2006-2011 GCSE science specifications (taken from SCORE (2009))

Specification		OCR 21st century	OCR Gateway	AQA	Edexcel
Core	Total % internal assessment	33%	33%	25%	40%
	Assessment tasks	20% Case study (May not be practically-based) 13.3% Data analysis task. Based on primary data; collection of the data is not assessed	Science in the News (Not practically-based) Can-do practical tasks <b>OR</b> Research task, Data analysis, Practical skills	ISAs Written tasks based on a practical done by the student <b>PLUS</b> Practical skills assessment	3 written tasks based on practical work <b>PLUS</b> Teacher-assessed practical skills mark
Additional science	Total % internal assessment	33%	33%	25%	40%
	Assessment tasks	A complete investigation	Research task, Data analysis, Practical skills	As above	As above
Additional Applied science	Total % internal assessment	50%	Not offered by this awarding body	60%	Not offered by this awarding body
	Assessment tasks	16.7% work-related report (not practically-based) 21% practically-based suitability test 12% standard procedures		20% Science in the workplace (portfolio) 40% Using Scientific skills (portfolio)	

Appendix 5: Practical work from 2011 in GCSE science specifications (taken from AQA, Edexcel and OCR websites)

Specification		OCR 21st century	OCR Gateway	AQA	Edexcel
Core	<b>Total % internal assessment</b>	25%	25%	25%	25%
	<b>Assessment tasks</b>	A practical investigation	3 parts: Part 1, Research and collecting secondary data, requires candidates to plan and carry out research; Part 2, Planning and collecting primary data, requires candidates to plan and carry out an investigation to collect primary data to test a hypothesis stated in the Part 2 stimulus material; Part 3, Analysis and evaluation, requires candidates to process and analyse the results from their research (Part 1) and their primary data (Part 2).	Investigative Skills Assignment (ISA) – 2 written assessments; one involves answering a number of questions relating to the students' data, the other involves questions on a given set of data, plus one or two lessons for practical work and data processing.	3 parts: Part A, Planning, includes choosing equipment, controls needed for the task, evidence/ observations and range, identification and management of risk; Part B, Observations, includes primary and secondary evidence collection and recording; Part C, Conclusions, includes processing and presentation of evidence, quality of evidence, conclusions based on evidence, evaluation of method, evaluation of conclusion.
Additional science	<b>Total % internal assessment</b>	25%	25%	25%	25%
	<b>Assessment tasks</b>	A practical investigation	3 parts: Research and collecting secondary data; Planning and collecting primary data; Analysis and evaluation	As above	As above
Applied	<b>Total % internal assessment</b>	Not offered by this	Not offered by this awarding body	60%	Not offered by this awarding body

	<b>Assessment tasks</b>	awarding body		A Controlled Assessment based on two assignments chosen from those supplied by AQA each year: 1. Investigating the work of scientists and how they use science 2. How scientists use evidence to solve problems	
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Appendix 6: Available marks for AQA AS and A2 Sciences (taken from AQA Biology, 2012; AQA Chemistry, 2012; and AQA Physics, 2012)

		Route T: Teacher Assessed – percentage of marks		Route X: Externally Marked – percentage of total marks	
		Practical Skills Assessment	ISA	Practical Skills Verification	Externally Marked Practical Assignment
Unit 3 – Internal Assessment Investigative and practical skills in AS	Biology	12	88	-	100
	Chemistry	24	76	-	100
	Physics	18	82	-	100
Unit 6 – Internal Assessment Investigative and practical skills in A2	Biology	12	88	-	100
	Chemistry	24	76	-	100
	Physics	18	82	-	100

Note: Differences between the marks awarded to the three sciences for units 3 and 6 is a feature of the AQA mark allocation scheme

## Appendix 7: Skills assessed in the Geographical skills unit (taken from OCR, 2012)

1. There will be a compulsory Ordnance Survey (OS) question which will require candidates to know about:

- OS maps at scales of 1:25 000 and 1:50 000
- 4-figure and 6-figure grid references
- symbols
- height, gradient, aspect
- distance, direction, area
- physical and human features of the landscape.

2. Candidates should be able to:

- annotate maps and diagrams
- draw maps and diagrams
- extract, interpret and analyse information from the following maps and diagrams.

3. Candidates should be able to:

- Analyse written articles from a variety of sources for understanding, interpretation and recognition of bias
- Use databases, to obtain data including census and meteorological data
- Make decisions based on analysis of evidence and geographical concepts
- Use the internet to find information
- Formulate and justify an argument
- Use ICT to present and analyse data
- Draw and justify conclusions
- Use spreadsheets to collate and analyse data
- Communicate to a variety of audiences and in a variety of styles
- Use Geographic Information Systems (GIS) to locate, layer and analyse sets of data
- Interpret tables of data
- Use satellite images to obtain information
- Carry out surveys and interviews
- Understand and interpret percentages
- Devise and carry out questionnaires
- Understand and interpret proportions
- Interpret and annotate ground, oblique and aerial photographs
- Understand, calculate and interpret averages (mean) and ranges
- Interpret, draw and annotate diagrams and sketches
- Understand, carry out and interpret sampling - systematic, random and stratified
- Use overlays
- Produce and interpret field sketches
- Interpret cartoons.



## Appendix 8: **ABRSM (2012)**

### **Accuracy, continuity and fluency**

Accuracy encompasses the technical control and co-ordination required to produce correct rhythm, including continuity of performance; convincing tempo, including consistency of the chosen speeds; clearly audible observance of performing directions; and accurate pitch, including well-centred intonation where appropriate. Slips from basically secure intonation are not as serious as an inability to centre the pitch precisely, which causes a loss of tonality.

### **Tonal awareness**

Tonal awareness covers the way an instrument is used and includes situations where a poor instrument may be skilfully managed. It encompasses the ability: to produce focused and consistent tone where required; to control and contrast dynamics and attack as appropriate to the musical context; and to grade musical tone into phrases. Pedalling for pianists and vibrato for string players are extra tonal refinements that are welcomed at all stages but not expected until Grade 5.

### **Musical character and a sense of performance**

Musical character arises from the imaginative application of technical skills in ways that will most vividly convey the mood of the piece to the listener. A sense of performance encompasses the degree of engagement with the music, including the level of commitment and conviction evident in the playing or singing.

Candidates will also be assessed on their abilities:

- to perform the prescribed technical exercises for the grade (e.g. scales and arpeggios) with fluency, accuracy, evenness and musical shape
- to respond to prescribed aural tests accurately, promptly and with musical perception
- to perform a short piece of unfamiliar music with accuracy, control, continuity and attention to expressive detail

Not all of the assessment objectives will necessarily be met in order for candidate to pass. A sense of musical character in performance, for example, is not required for a Pass to be awarded and is more appropriately identified with higher levels of attainment. Weakness in some of the assessment objectives may be balanced by better performance in others. The mark awarded will depend in practice on the extent to which the candidate has met the assessment objectives overall.

Appendix 9: **Extended Project assessment objectives and weighting (taken from Edexcel, 2008)**

<b>Assessment objective</b>	<b>Marks available</b>	<b>Weighting</b>
<p style="text-align: center;"><b>AO1 Manage</b></p> <p>Identify, design, plan and carry out a project, applying a range of skills, strategies and methods to achieve objectives.</p>	9	17%
<p style="text-align: center;"><b>AO2 Use resources</b></p> <p>Research, critically select, organise and use information, and select and use a range of resources. Analyse data, apply relevantly and demonstrate understanding of any links, connections and complexities of the topic.</p>	12	22%
<p style="text-align: center;"><b>AO3 Develop and realise</b></p> <p>Select and use a range of skills, including, where appropriate, new technologies and problem solving, to take decisions critically and achieve planned outcomes.</p>	24	44%
<p style="text-align: center;"><b>AO4 Review</b></p> <p>Evaluate all aspects of the extended project, including outcomes in relation to stated objectives and own learning and performance. Select and use a range of communication skills and media to present evidenced project outcomes and conclusions in an appropriate format.</p>	9	17%
<b>Total</b>	<b>54</b>	<b>100%</b>

## Appendix 10: University of Cambridge International Examinations (2012, p.54)

Questions may be set requesting candidates to:

- describe in simple terms how they would carry out practical procedures
- explain and/or comment critically on described procedures or points of practical detail
- follow instructions for drawing diagrams
- draw, complete and/or label diagrams of apparatus
- take readings from their own diagrams, drawn as instructed, and/or from printed diagrams including:
  - reading a scale with appropriate precision/accuracy with consistent use of significant figures and with appropriate units
  - interpolating between scale divisions,
  - taking repeat measurements to obtain an average value
- process data as required, complete tables of data
- present data graphically, using suitable axes and scales (appropriately labelled) and plotting the points accurately
- take readings from a graph by interpolation and extrapolation
- determine a gradient, intercept or intersection on a graph
- draw and report a conclusion or result clearly
- identify and/or select, with reasons, items of apparatus to be used for carrying out practical procedures
- explain, suggest and/or comment critically on precautions taken and/or possible improvements to techniques and procedures
- describe, from memory, tests for gases and ions, and/or draw conclusions from such tests

Appendix 11: Summative assessments in awards showing an *average* percentage across award bodies (AQA, Edexcel, OCR)\* given for DAPS and IAPS in practical work assessment

Subject/level	Proportion of marks awarded in percentage of the qualification accounted for by practical work	Proportion of practical work assessment accounted for by DAPS	Proportion of practical work assessment accounted for by IAPS	Teacher assessed Y/N	Externally moderated Y/N
GCSE Biology	25%	15%	85%	Y	Y – IAPS only
GCSE Chemistry	25%	15%	85%	Y	Y – IAPS only
GCSE Physics	25%	15%	85%	Y	Y – IAPS only
GCSE Music	60%	67%	33%	Y	Y – Both (Recording Sent)
GCSE Geography	25%	0%	100%	Y	Y – IAPS only
GCSE Design and Technology	50%	50%	50%	Y	Y – Both DAPS and IAPS. Final product demonstrates skills and photographs of students demonstrating skills
GCSE Modern Foreign Languages	30%	100%	0%	Y	Y - DAPS. Students oral presentation is recorded and sent to be moderated
BTEC	25%	0%	100%	N	Y – IAPS only. This is assessed through a paper examination only
AS Biology	20%	12%	88%	Y	Y – IAPS only
AS Chemistry	20%	24%	76%	Y	Y – IAPS only
AS Physics	20%	18%	82%	Y	Y – IAPS only
AS Geography	30%	0%	100%	N	Y – IAPS only. This is assessed through a paper examination only

AS Design and Technology	50%	45%	55%	Y	Y – Both DAPS and IAPS. Final product demonstrates skills and photographs of students demonstrating skills
A2 Biology	10%	12%	88%	Y	Y – IAPS only
A2 Chemistry	10%	24%	76%	Y	Y – IAPS only
A2 Physics	10%	18%	82%	Y	Y – IAPS only
A2 Geography	15%	0%	100%	N	Y – IAPS only. This is assessed through a paper examination only
A2 Design and Technology	25%	31%	69%	Y	Y – Both DAPS and IAPS. Final product demonstrates skills and photographs of students demonstrating skills
IB Chemistry	24%	13%	87%	Y	Y – samples of students work for both DAPS and IAPS are sent to be moderated
IB Geography	20%	0%	100%	Y	Y – IAPS only

\*N.B: BTEC is specific and only delivered by Edexcel. The IB in chemistry and geography are specific and delivered by the International Baccalaureate. The BTEC, IB chemistry and IB geography are not averages here.

Appendix 12: **Physics techniques for the standard grade qualification in physics (taken from Scottish Qualifications Authority, 2008, pp.137-140)**

Technique	Specification	Criteria for assessment
<p>The candidate is able to:</p> <p>1. measure the speed of a moving object</p>	<p>The candidate uses a light-gate to measure the instantaneous speed of an object as it moves down a slope. A length of card is fixed to the object. The length of the card is measured by the candidate. The object is released from a reference line on the slope so that it passes through the light-gate which is positioned at a second reference point on the slope. The time for the card to pass through the light-gate is measured electronically. The instantaneous speed of the object at the second reference point is calculated by the candidate.</p>	<p>The candidate produces written results and arrives at a value of the instantaneous speed within + or – 10% of the teacher’s measurement.</p>
<p>2. measure the approximate focal length in order to select a particular convex lens from a box containing five different lenses</p>	<p>The candidate is presented with a box containing five unmarked converging lenses covering a range of focal lengths from 50 mm to 500 mm. The candidate is asked to identify by measurement a lens of specified focal length.</p>	<p>The candidate correctly measures the focal length and selects a lens of specified focal length.</p>
<p>3. measure the angle of incidence and the angle of refraction of a ray of light going from plastic or glass into air</p>	<p>The candidate is provided with a ray-box, a protractor and a plastic or glass semi-circular block. The candidate sets up a ray-box on a sheet of paper and directs a non-divergent ray of light at the curved surface of the semi-circular block and emerges from the plane surface. The direction of the incident ray and the position of the glass block are previously drawn on the sheet of paper by the teacher. The candidate draws the normal and the direction of the refracted ray on the sheet of paper. The angle of incidence and the angle of refraction are then measured from the sheet of paper using the protractor.</p>	<p>The candidate draws the normal, measures the angle of incidence and the angle of refraction and records values which are within + or – 2 degrees of the teacher’s measurements.</p>
<p>4. detect an open or a short circuit in an electric circuit</p>	<p>The candidate is supplied with three circuit boards each with three similar lamps in lampholders and connected in series. Each circuit board has a different fault. One has an open-circuited lead, another has an open-circuited lamp, and the other a short-circuited lampholder.</p>	<p>The candidate correctly identifies the fault on each board and its location.</p>
<p>5. measure</p>	<p>The candidate is presented with an assembled series</p>	<p>The candidate</p>

<p>current in and voltage across an electrical component</p>	<p>circuit comprising a d.c. supply, resistor and a lamp. The circuit components are on mounts with terminals. The candidate is given a suitable d.c. ammeter and voltmeter (or multimeter).</p>	<p>measures the current in the circuit, and the voltage across either the resistor or the lamp and arrives at values within <math>\pm 5\%</math> of those measured by the teacher.</p>
<p>6. connect an oscilloscope to an a.c. supply and measure the peak voltage</p>	<p>The candidate is given the following apparatus: signal generator, oscilloscope, calculator, connecting leads.</p> <p>The oscilloscope is set by the teacher as follows:</p> <ul style="list-style-type: none"> <li>• brightness and focus correctly adjusted;</li> <li>• X-shift and Y-shift centred;</li> <li>• X-gain minimum, Y-gain minimum amplification;</li> <li>• stability adjusted for 1 kHz;</li> <li>• input;</li> <li>• Sync — internal, Trig-auto;</li> <li>• time-base on lowest setting.</li> </ul> <p>The signal generator is set as follows:</p> <ul style="list-style-type: none"> <li>• frequency at 1 kHz;</li> <li>• voltage such as to give a wave-form that is just discernible when the oscilloscope is set as described above.</li> </ul> <p>The oscilloscope and signal generator have been switched on previously, but are not connected to each other.</p> <p>The candidate must not adjust the signal generator, but will require to adjust the time-base and the Y-gain controls, and use the Y-gain calibration scale to calculate the voltage.</p> <p>Different candidates are asked to measure different voltages.</p>	<p>The candidate must adjust the time-base and Y-gain controls, measure the peak voltage and arrive at a value within <math>\pm 5\%</math> of that measured by the teacher.</p>
<p>7. set up and adjust a voltage divider circuit to produce a specified voltage</p>	<p>The candidate is given a low voltage supply eg cell, battery; a suitable linear potentiometer and a suitable d.c. voltmeter or multimeter. The components are supplied on mounts with terminals. No connections are made between any of the components.</p> <p>The candidate is not provided with a circuit diagram.</p>	<p>The circuit must be correctly assembled as a voltage divider circuit and the voltmeter must read 1.0 V <math>\pm 0.1</math> V.</p>

<p>8. wire up correctly a mixed series and parallel circuit, given the circuit diagram</p>	<p>The candidate is supplied with 2 cells, 2 lamps, a resistor, a suitable d.c. ammeter or multimeter, a switch, connecting leads and a circuit diagram. The components are presented with no connections made between them. The components are on mounts with 4 mm sockets.</p> <p>The circuit diagram shows the two cells, the switch, the resistor, all in series, and in series with these components is a parallel arrangement of the two lamps. The value of the resistor is such that the lamps will light.</p>	<p>The circuit must be set up as shown in the diagram presented to the candidate and, when switched on, allow the current to be measured</p>
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Appendix 13: Performance criteria and suggested item to aid professional judgement in Objective 3 of the higher chemistry qualification (taken from Scottish Qualifications Authority, 2008, pp.114-155)

Performance Criteria	Suggested items to aid professional judgement
(a) The information is collected by active participation in the experiment	The candidate should be involved in planning, organising and completing the experiment.
(b) The experimental procedures are described accurately	<p>A clear statement of the aim or objective.            A few brief concise sentences as appropriate:                a labelled diagram or brief description of apparatus, instruments used                how the measurements were taken or observations made                comments on safety</p> <p>There is no need for a detailed description. The use of the impersonal passive voice is to be encouraged as an example of good practice but this is not mandatory for meeting the Performance Criteria.</p>
(c) Relevant measurements and observations are recorded in an appropriate format	<p>Readings or observations (raw data) should be recorded using the following, as appropriate:</p> <ul style="list-style-type: none"> <li>• a table with correct headings and appropriate units</li> <li>• a table with readings/observations entered correctly.</li> <li>• a statement of results</li> </ul>
(d) Recorded experimental information is analysed and presented in an appropriate format  <b>Unit D069 12 Energy Matters and Unit D071 12 Chemical Reactions only</b>	<p>Readings or observations (raw data) should be analysed/presented using the following, as appropriate:</p> <ul style="list-style-type: none"> <li>• a table with suitable headings and units</li> <li>• a table with ascending or descending independent variable</li> <li>• a table showing appropriate computations</li> <li>• a correct calculation</li> <li>• a graph with independent and dependent variables plotted on appropriate axes</li> <li>• a graph with suitable scales and axes labelled with quantities and units</li> <li>• a graph with data correctly plotted with a line or curve of best fit</li> </ul> <p>For a tabular presentation this may be an extension of the table used for Performance Criteria (c).</p>
(e) Conclusions drawn are valid	<p>Conclusions should use evidence from the experiment and relate back to the aim of the experiment. At least one of the following should be included:</p> <ul style="list-style-type: none"> <li>• the overall pattern to readings</li> <li>• the trends in analysed information or results</li> </ul>

	<ul style="list-style-type: none"><li>• the connection between variables</li><li>• an analysis of the observations</li><li>• the findings from completed calculations</li></ul> <p>Conclusions should also include evaluation of the experimental procedures and could make reference to one of the following:</p> <ul style="list-style-type: none"><li>• effectiveness of procedures</li><li>• control of variables</li><li>• limitations of equipment</li><li>• possible improvements</li><li>• possible sources of error</li></ul>
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