To DAPS or to IAPS: That is the question

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Abstract
This article reviews how practical work, including practical skills, is currently summatively assessed in school science in a number of countries and makes comparisons with how other subjects, such as music and geography, summatively assess skills. Whilst practical skills in school science are clearly valued as being of importance, there is a lack of clarity as to what these skills actually are and how they might, most effectively, be validly assessed. Countries vary greatly in the extent to which they employ in school science what we term 'Direct Assessment of Practical Skills' (DAPS) or 'Indirect Assessment of Practical Skills' (IAPS). Each of these approaches has advantages and disadvantages but we conclude that too great a reliance on IAPS reduces the likelihood that practical work will be taught and learnt as well as it might be.

Introduction

Despite the widespread acknowledgement of the importance of summative assessment of practical work, surprisingly little has been written about what constitutes good summative assessment of practical work. This chapter reviews how school science practical work is currently summatively assessed in a number of countries and makes comparisons with how a number of other school subjects with a practical component are summatively assessed. Finally, in the light of these sources of evidence, some recommendations are made as to how school science practical work might better be summatively assessed.

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. The term 'practical skills' is used here to mean those skills the mastery of which increases a student's competence to undertake science learning activities where they are involved in manipulating and/or observing real objects and materials, as opposed, for example, to modelling this on a computer. The development of practical skills (such as the ability to focus a microscope, find the end point of a titration or use a voltmeter) is therefore one aim of practical work.

Research in the area of practical work in school science (Abrahams & Millar, 2008; Abrahams & Reiss, 2012) and in the assessment of science education more broadly (Bernholt, Neumann & Netwing, 2012) all describes the significant influence of the curriculum and, in particular, its associated summative assessment on the practical work that teachers opt to do with their students. Certainly, in England, with reference

to external examinations such as General Certificates of Secondary Education (GCSEs), normally taken when a student is aged 16 after two years of study, and Advanced levels (A-levels), at aged 18 after two years of study, it has been recognised (e.g. Donnelly et al., 1996) that it is summative assessment that, to a large extent, drives what is taught, to the point that teachers' preferences for using different types of practical work are routinely influenced by their considerations of curriculum targets and methods of summative assessment (Abrahams & Saglam, 2010). Nott and Wellington (1999) suggest that:

> …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)

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)

The Assessment and Performance Unit in the UK showed that even minor changes in the questions posed of students could lead to very large effects on their attainment (Welford et al., 1985). Indeed, 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. As Gott and Duggan (2002) argue, practical skills therefore include procedural understanding and certain process skills, in addition to specific skills of observation and manipulation*, but little if any* conceptual understanding. Examples of practical skills with little, if any, conceptual understanding – 'naked' practical skills – include, for example, the ability to use a voltmeter or a burette, or to focus a microscope. Likewise, examples of non-scientific naked practical skills include riding a bicycle, walking on stilts, swimming and writing with a pen.

Practical skills, in science as in other subjects, can be assessed, we argue, in two ways: (i) Direct Assessment of Practical Skills (DAPS) and (ii) Indirect Assessment of Practical Skills (IAPS). Direct Assessment of Practical Skills (DAPS) refers to any form of assessment that requires learners, 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.

In contrast, Indirect Assessment of Practical Skills (IAPS) refers 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 undertake. An example would be when a student writes up an account of the reaction between hydrochloric acid and calcium carbonate chips in such a way that the marker could 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.

Welford, Harlen and Schofield (1985) in a report on the testing of practical skills in science for ages 11, 13 and 15 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). In contrast, practical skills are, in some cases, better assessed directly rather than indirectly. For example, whilst a conceptual understanding of the effect of temperature and other factors on the structures of edible materials might well be assessed by a written task, the most effective means of assessing whether someone can make and bake a cake well is simply to watch them as they make the attempt – and then to taste the product.

An 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 provided by the Driving Test in the UK and a number of other countries. 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).

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 some countries 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 provide 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.

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.

Current assessment of science practical skills in England

Within England, practical work is part of GCSE and A-level science courses but the methods of assessment are currently changing in a way that may have profound consequences. At both of these levels, no DAPS will take place. Indeed, the emphasis on the assessment of practical work has been considerably reduced. The only way in which summative assessment of practical work will take place is as part of the terminal written examinations that students take at the end of their two-year courses. Here, at both GCSE and A-level, 15% of the examination marks will be in relation to practical work.

These changes were introduced because of a widespread acknowledgement that the previous way of assessing practical work was not working very well, particularly at GCSE level. However, there is a worry among many in science and in education that one result of these changes will be to decreases the amount of time that 14-18 year-olds spend undertaking practical work in school science. This would be a great loss. Furthermore, even before these changes, there was already the concern that, due to the dominance of summative assessment at GCSE and A-level, there was limited opportunity for the development of practical skills to take place (Nott & Wellington, 1999; Keiler & Woolnough, 2002).

International analysis of current assessment of practical skills in science

In this international analysis of current assessment of practical skills in science, two countries that will be reviewed are chosen from within the PISA 2009 top ten, namely China and Finland, and two that are closer to England's position of 16thplace, namely France and Scotland. Such focus on high-performing PISA countries is widespread both in England (DfE, 2011) and internationally (Pereyra et al., 2011), in the hope that useful lessons might be learnt for other countries though, of course, there are dangers in naïve policy borrowing. In particular, countries differ greatly, and vary over time, in the importance they attach to such things as school accountability, teacher autonomy and the utility of regular summative assessment and reporting of student attainment.

In China, ranked 1st in science in PISA 2009, the examination of practical work in science is one of the important parts in the unified examination (He, personal communication, 18 August 2012). The unified examination is one that students need to pass in order to graduate from secondary to university level and is roughly 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, personal communication, 18 August 2012).

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 20minute examination, with standardized marking criteria being used 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 direct assessment, the skills being assessed during the practical work are also credited; for example, two 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 (six 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.

In Finland, ranked 2nd 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 carrying out simple scientific experiments clarifying the properties of phenomena (Lavonen, personal communication, 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 skills in both the formative and summative manner, and assessment is by direct assessment of practical skills.

In France, ranked 27th 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. The assessment of practical work in the Baccalauréat Général involves two parts, a written test for 16 marks and a practical test for four marks, making a total of 20 marks (Ministère de la jeunesse, de l'éducationnationale et de la recherché, 2012). The practical test lasts for an hour (Ministère de l'éducationnationale, 2012a). Whilst the students are carrying out the practical work,

two teachers assess four students at a time; 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'éducationnationale, 2012b) to directly assess four specific areas after which students go onto the written part, indirectly assessing their skills.

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.

In Scotland, ranked 17th in science PISA 2009, there is only one awarding body for standard grade (students aged fourteen to sixteen) and higher. 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.

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 requirement is for the teacher to attest that the report is the student's own work and was 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). Whilst the teacher is assessing this objective, the assessment of their skills is indirect because students are not marked on their direct manipulation of objects.

Conclusions of current assessment of science practical skills in a range of countries

What emerges from this international analysis is that the assessment of practical work in science 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 and Finland all make use of a substantial proportion of DAPS compared to countries like England and Scotland in which the assessment of practical skills is based predominantly on IAPS.

Indeed, in China, this distinction between whether their students' practical skills are directly assessed or not manifests itself in the fact that students are able to gain credit for their skills in practical work as a separate mark rather than this being inferred from written examinations. 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 and IAPS 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).

Assessment of practical skills in other subjects within the United Kingdom

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

Geography at GCSE and A-level

In one example for geography on the assessment of practical work, the GCSE specification of the OCR awarding body includes a unit entitled 'Local Geographical Investigation' which is worth 25% of the available marks and 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 they undertake fieldwork that must include collection of primary data, students are only marked on the written report of their investigation (IAPS) rather than directly (DAPS) on their practical skills used in the collection of their data. In OCR GCSE geography, there is a further unit entitled 'Geographical Skills'. In this unit, students are able to apply a selection of skills to a range of known and unknown scenarios and they are assessed on their competence in these skills via a written question paper (IAPS) that carries 25% of the marks for the qualification.

Another awarding body, Edexcel, also includes in their specifications a fieldwork investigation; again, this is a written assignment (IAPS) of 2000 words, worth 25% of the available marks (FSC, 2009) rather than DAPS. Whilst an understanding of these skills is currently assessed, again indirectly, 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.

In A-level geography, practical skills constitute between 25 to 45% of the available marks at AS and A2 (Ofqual, 2011) 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 (2011) states that these skills can be assessed indirectly through the use of extended prose (IAPS). 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 using IAPS.

Music Qualifications

The assessment of music is an example of a school subject in which practical skills are clearly identified and in which the assessment is made using 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.

The Associated Board of the Royal Schools of Music (ABRSM), a leading and long-established 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.

The origins of these practical performance tests go back to the nineteenth century. Over the years, the music community has reached agreement on which particular

pieces, when played appropriately, are indicative of which grades. It is generally felt that this agreement either eliminates, or at least substantially reduces, the likelihood of grade inflation over time (Welch, personal communication, 10 September 2012). The criteria used for the ABRSM assessment are widely considered to be objective (Green, personal communication, 9 September 2012).

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 5 but then must pass at least grade 5 theory after which progression to grade 8 can be without additional theory examinations (Green, personal communication, 9 September 2012). Unlike GCSEs and A-levels, there is no expected age at which these ABRSM examinations are taken: this depends simply on each examinee's competence.

For the ABRSM practical graded examinations, only one examiner is present, a generalist (Green, personal communication, 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 indirect assessment of practical skills for the theory component and then directly assesses them for the practical component.

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. 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.

Conclusion from the assessment of science and non-science subjects in England

Although it is the case in England that the awarding bodies place a lot of emphasis for a number of subjects on the need for students to develop subject-specific skills during the course of their studies, subjects vary in the importance accorded to the direct assessment of these skills. However, what is evident is that in a number of other subjects, including music, modern foreign languages and design and technology, direct assessment of these skills is given much more weight than in science.

Currently practical skills as a term is widely used in school science but is rarely defined with anything like the precision that is typical for 'subject content' knowledge in school science. In particular, school science is frequently less precise than some other school subjects as to exactly what manifestation of skills is expected at each age or level. Furthermore, there are a large number of such skills, making it unfeasible to assess all of them summatively within the limited time available in school science.

If the practical skills that awarding bodies and other assessment organisations want students to achieve throughout their science 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). Therefore, the assessment system should be as explicit about which practical skills candidates should develop in school science as they are about the subject content knowledge that is expected of candidates.

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 some that perform highly in PISA. Furthermore, it is clear that DAPS is more widely used in the assessment of a number of other subjects in England. Indeed, the changes that are currently being implemented to the summative assessment of school science for 14-18 year-olds will take England even further away from what is done in a number of high-performing jurisdictions. It is important that those involved in determining how school science practical work is assessed learn lessons from how it assessed in other countries and from how other subjects assess practical skills.

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