GCSE practical work in English secondary schools

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ABSTRACT

In England, the GCSE science curriculum has been undergoing major changes, and the new school curriculum was implemented in September 2016. One of the big changes is that the internal assessment of practical work no longer counts towards the final GCSE science grade. It has been established that assessment influences teaching, so non-contribution of practical work to the final grade may dilute the funding for practical work conducted in schools, especially in GCSE lessons. However, the GCSE science exam paper will now include questions on practical work which may allow more lesson time to be devoted to discussion of results and observations of practical work, an area of development identified in previous studies. Discussions provide opportunities for learners to make links between the practical task and the underlying conceptual knowledge, thereby increasing the effectiveness of practical work. This article aims to explore the range of literature available on the effectiveness of science practical work in English secondary schools and consider the possible effects of the removal of internal assessment of practical work from the GCSE curriculum.

KEYWORDS

GCSE Science Curriculum

Practical Work

Assessment

Effectiveness

Scientific Competencies

INTRODUCTION

Practical work is recognised in English schools as an essential part of science education, and learners enjoy it more than any other approach to the teaching and learning of science (Murray & Reiss 2005). Despite this taken-for-granted view and the widespread use of practical work in school science, research findings have questioned the effectiveness of practical work in English schools (Hodson 1991; Osborne 1993; Wellington 1998; Abrahams & Millar 2008).

The GCSE science curriculum for practical work has undergone major changes, particularly in its assessment. This exploratory literature review explores the changes in the aims of practical work in secondary classrooms over the last 50 years and the concerns related to the assessment of practical work. The review will also look into the effectiveness of practical work and will explore the changes that may happen due to the changed curriculum. This review will be of interest to others who have an interest in the effectiveness of science practical work and have concerns about the delivery of practical work under the new curriculum.

A HISTORICAL OVERVIEW OF SCIENCE PRACTICAL WORK IN SECONDARY SCHOOLS

Practical work is considered by most science teachers as a 'part and parcel' of teaching and learning science (Woodley 2009: 49) and is indispensable for 'a traditional science teacher' (Donnelly 1998:589). This taken-for-granted view of practical work indicates that many teachers end up using practical work as the 'basic modus operandi' (Abrahams 2011: 2) for the teaching of science, as they consider it the 'right thing to do' (Millar 2002: 53). Teachers' reasons for doing practical work are influenced by not only by their own beliefs about what the role of a science teacher should be but also by contemporary politics. The political influence can be traced back to the era after the 1850s Great Exhibition, when the rising social and economic importance of science was recognised, following which grants were released for laboratory set-ups in schools. The aim was to increase the uptake of science. The nature of practical work in the UK has seen three major shifts in terms of its aim: the Discovery Approach, that utilised Armstrong's (1903) heuristic approach to enable learners to 'find out instead of being merely told things' (p. 236), was followed by the Process Approach focusing on developing scientific and transferable skills of learners, which in turn gave way to the Scientific Enquiry approach. The National Curriculum, in 1988, established the latter model for scientific enquiry in practical work. It was considered by many as a flawed model (Kelly 1990; Wellington 1994, 1998; Donnelly 1995) due to its rigid approach of 'practical work by order' (Wellington 1998: 4). Assessment of practical work was now introduced in 'Sc1' which referred to scientific enquiry. (Sc1 involves an assessment of a practical science investigation. Key Stage 4 students complete this controlled assessment by carrying out set practical work and then written work about it, worth 25 per cent of the final grade.) Sc1 focused on assessment of four key areas: planning, observation, analysis and evaluation. The assessment of practical skills was mainly through the student write-up of an investigation.

The introduction of the assessment of practical work in the National Curriculum inadvertently altered teachers' aims when using practical work. Teachers were under increasing pressure, as their results impacted how their schools were judged and positioned on league tables (Jeffrey 2002). The monitoring of performance, by senior management, in 'audit society' (Power 1997:, 4), caused teachersto focus only on a few relevant practicals for assessment, which were rehearsed to ensure learners got the best possible marks (Kind & Taber 2005; English & Paes 2015). This focus led to a number of rising concerns about the effectiveness of practical work and the discrepancies in its assessment (Nott & Wellington 1997; Donnelly 2000; Bennett & Kennedy 2001). It is widely recognised that teachers' selection of practical work, chosen pedagogy for practical work (Abrahams & Reiss 2012) and hence the learning environment (Hofstein & Lunetta 2003) are routinely influenced by their concerns about curriculum objectives and assessment measures (Donnelly 2000; Abrahams & Saglam 2010; Bernholt et al. 2012). Political pressure to ensure the integrity of the exam led to the dropping of the Sc1 or POAE (Planning, Obtaining and presenting evidence, Analysing and considering evidence and Evaluating) model in 2006 (English & Paes 2015), and many assessment models have since been trialled, from inclusion of the moderated and unmoderated assessment of skills to testing the understanding of scientific terminology in the lab and in written papers. Till 2015/16, in English Key Stage 4 science, internal assessment of practical work by the teacher was worth 25% of the learner's final GCSE science grade, so practical work was often seen as a means to gain marks. However, since September 2016 a new science GCSE curriculum has been implemented which has dropped the practical mark contribution to the final grade.

NEW CURRICULUM: BUCKLING UNDER INTERNATIONAL PRESSURES?

The Coalition government in 2011, under global competition pressures, had responded to the earlier-mentioned assessment concerns with a major overhaul of the English National Curriculum. The UK's ranking in science, between 2006 and 2012, in international league tables like Programme for International Student Assessment (PISA), had dropped significantly, from 14th to 21st place (OECD 2007, 2014). Politicians like the previous secretary of state for education, Michael Gove, had taken the quantitative data of OECD's PISA result as a valid measure of the effectiveness of a country's education system (Osborne 2014) and rushed into implementing changes in education policy. The focus on international comparisons to inform the decisions for curriculum overhaul is evident in the White Paper (DfE 2010).

The 2015 PISA (OECD 2016) assessment focused on science, and tested learners' competencies in scientific literacy. 'Competencies' refer to not just the conceptual knowledge in science but also to the knowledge needed to obtain reliable data. Learners with these competencies are able to use practical results or observations to justify and explain scientifically the underpinning scientific concepts. To fulfil the demands of the future economic, social and environmental needs and also to equip future citizens with the ability to make informed choices, it is considered essential that learners are given chances to develop these competencies. The emphasis in classrooms then needs to be on promoting learners' higher-order cognitive processes of evaluation, critique and synthesis using the underpinning scientific concepts (Osborne 2014). Future employers would seek individuals with the ability to critically analyse, synthesise and communicate knowledge. To develop these higher-order skills, classrooms should provide learners with chances to participate, using critical reasoning, in the construction and analysis of arguments backed with evidence. These opportunities are potentially available in practical tasks, provided teachers are not sidetracked by internal assessment.

The new GCSE science curriculum, implemented in September 2016 and first assessed in 2018, has removed the internal assessment of practical work in schools. The practical work conducted in lessons will no longer contribute to a candidate's GCSE final grades. However, for GCSE sciences, exam boards have identified certain required practical work within each topic area, in each of the three science subjects. Fifteen per cent of the total mark for each qualification will be for exam questions that specifically draw on the experience and conceptual understanding that learners have gained from doing practical work. Schools are expected to provide a written 'practical science statement' to the exam board vouching for each learner's participation in the required practical tasks and completion of their lab books (OCR 2016:79). Fifteen per cent of the total mark for each qualification will be for exam questions that specifically draw on the experience and conceptual understanding that learners have gained from doing practical work, ie their competencies in scientific literacy. Exam boards recommend all learners to complete at least the required practical tasks to prepare fully for the written examinations as there will be questions that assess practical skills (ibid.).

Teachers' aims in doing practical work underwent significant changes after the introduction of Sc1 assessment (Abrahams & Saglam 2010). It is hence probable that the latest changes in assessment will herald further changes to the purpose and delivery of practical work in schools. This literature review will now explore the effectiveness of practical work and consider possible changes in it due to the removal of internal assessment.

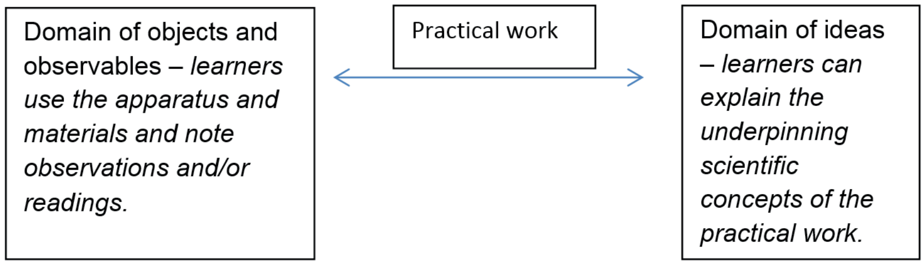

Figure 1: Purpose of practical work: to help learners make the link between the two domains (adapted from Millar et al. 2002)

EFFECTIVENESS OF PRACTICAL WORK

Practical work can develop conceptual understanding, procedural understanding, process skills and practical skills (Hodson 1991; Gott & Duggan 2007). It can also enable learners to make connections between scientific ideas and practical observations. Tiberghien's (2000) model of knowledge identifies two domains of knowledge: the domain of objects and observables and the domain of ideas. For practical work, the domain of objects includes mainly 'hands-on' activities, which the teacher wants the learners to do with the physical resources, followed by observations of the phenomenon. The latter domain includes 'minds-on' activities for facilitating learners to understand the link between the observations and underpinning scientific concept.

Practical work, viewed as a bridge between these domains, is considered effective only if learners achieve competence in both domains and can make links between them (Millar et al. 2002) (Fig. 1). The role of the domain of ideas can vary depending on the type of practical task: for some tasks it may be that minor-learners just have to make observations, while for others it may be that major-learners need to develop learner's understanding of underpinning scientific concepts in order to describe or explain their observations. In the latter tasks, learners need to think along with the 'doing and seeing', ie work not only with their 'hands on' but also with their 'minds on' (Millar 2009:4).

So, to evaluate the effectiveness of practical work it is essential to consider the specific practical task, ie profile the task, in order to identify teacher's expectations from the two domains. The theoretical model (Fig. 2) developed by Millar et al. (1999) is used for profiling

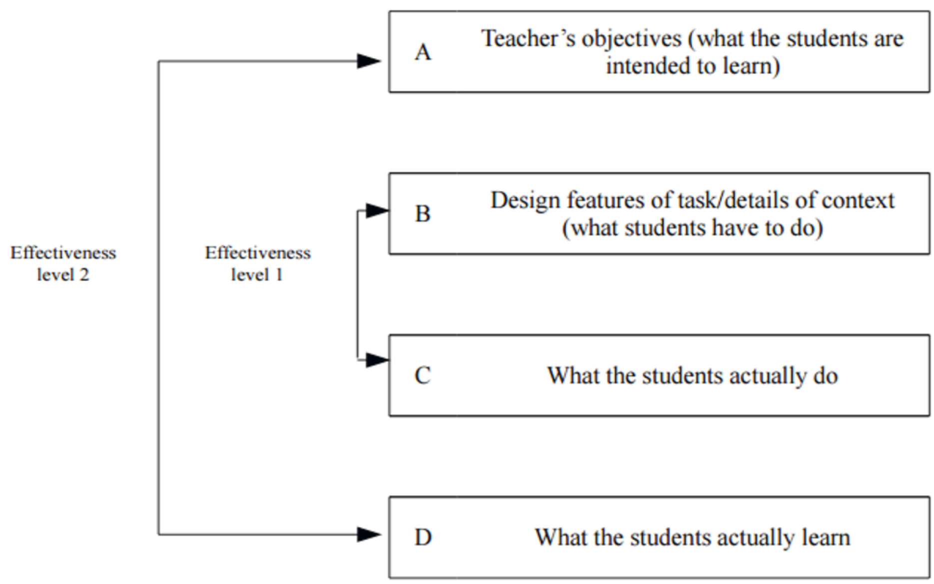

Figure 2: Two-level model of effectiveness (from Millar et al. 1999)

practical task design and for evaluating the effectiveness of a specific practical task.

The effectiveness of a specific practical task is evaluated at two levels. At level 1 the effectiveness refers to the relationship between boxes B and C – whether the learners do what the teacher intended them to do in the specific practical task (Fig. 2), ie the intended and the actual learner activities during a practical task. At level 2, effectiveness refers to the relationship between boxes A and D, and is evaluated in terms of whether the learners learn what the teacher intended them to learn ie the intended and the actual learning outcomes after the specific practical task. Abrahams & Millar (2008) studied the effectiveness of practical tasks in secondary schools by using a 2×2 effectiveness matrix developed by merging the above-mentioned model of effectiveness (Millar et al. 1999) with a model of knowledge (Tiberghien 2000) (Fig. 3).

The 2×2 effectiveness theoretical framework (Fig. 4) makes it possible to consider each of the two levels of effectiveness in terms of these two distinct domains.

Figure 5 shows how the 2×2 matrix model can be applied to evaluate a practical task in which the learners prepare copper sulphate crystals and where the teacher's aim is that learners should develop an understanding of the neutralisation of acids and insoluble bases to form soluble salts.

POSSIBILITY OF IMPROVED EFFECTIVENESS OF PRACTICAL WORK

Practical work in secondary science lessons was found to be generally ineffective in the domain of ideas by Abrahams & Millar (2008). That study focused on practical sessions and found that the learners were often unable to explain their observations with reference

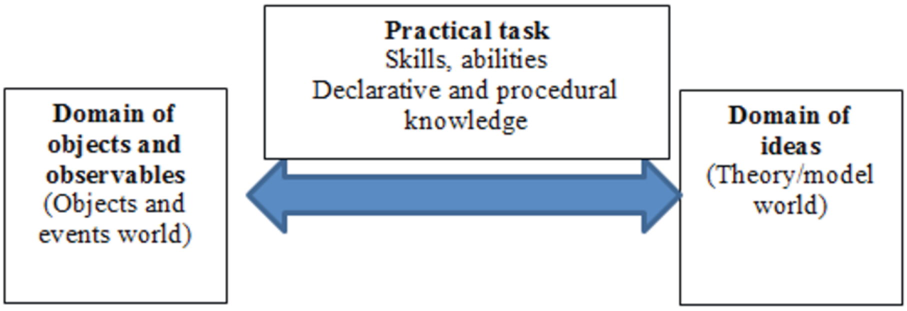

Figure 3: Two-domain model of knowledge (Tiberghien 2000)

Effectiveness of the practical task in achieving the intended outcomes..	In the domain of observables	In the domain of ideas
At level 1: '*doing*' level or What students do during a practical task? A practical task is effective in this level if...	..students set up and operate or use the provided materials and apparatus in the way the teacher had intended then to. ...students generate data in the way the teacher had intended them to.	..students thinks about the method and observations *during* a practical task using the ideas intended them to use.
At level 2: '*learning*' level or What students learn from the practical task? A practical task is effective in this level if...	...students can later recall the practical task method, observations and the key features of the data. ...students can set up and operate or use similar materials and apparatus. ...Can recall the key features of the collected data or observations.	..students can later explain their understanding of their observations or collected data using the scientific concepts or ideas intended by the teacher.

Figure 4: 2x2 effectiveness matrix (adapted from Abrahams & Millar 2008)

Effectiveness of the practical task in achieving the intended outcomes..	In the domain of observables	In the domain of ideas
At level 1: '*doing*' level or What students do during a practical task? A practical task is effective in this level if...	...Students use Bunsen burner safely, add copper (I) oxide slowly till a residue remains, set up water bath and use it safely. ...Students prepare copper sulphate crystals.	...Students are aware that a soluble salts is formed which is indicated by the colour change. ...Students are able to write the correct chemical equation for the reaction. ...Students are aware of the reason for the formation of the black residue. ...Students are aware of the reasons for evaporating the solution and why it shouldn't be heated to dryness.
At level 2: '*learning*' level or What students learn from the practical task? A practical task is effective in this level if...	...Students can later recall the method used to prepare crystals of copper sulphate ...They can recall how they knew when the reaction was complete. ...They can recollect the colour change in the reaction. ...They can recall what they observed when the solution was heated over the water bath. They can recall the appearance of the copper sulphate crystals.	...Students can later explain their understanding of their observations by referring to the neutralisation reactions. ...Students can later explain that a soluble salt was prepared in the reaction. ...Students can later explain that salt solutions can be crystallised to produce solid salts. ...Students can later explain that sulphuric acid is neutralised by the copper (II) oxide to produce copper (II) sulphate and water. ...Students can later predict the products formed from reaction of another acid and base. ...Students can later use the formulae of common ions to deduce the formulae of salts.

Figure 5: indicators of the effectiveness in the preparation of copper sulphate practical

to the underpinning theoretical concepts. There is also, in secondary classrooms, generally a failure to engage learners in tasks involving talking, reading and writing required to build the association between the scientific concept and the observations (Osborne 2015: 19). The opportunity to discuss and evaluate the findings and explore their meaning is often skipped in the rush at the end of a practical task (Hodson 1991; Abrahams & Millar 2008; Abrahams & Reiss, 2012). Further, the discussion about practical results, if any, usually culminates in an 'epistemically meaningless chat' (Osborne & Millar 2017:39) if the teacher has not clearly identified the desired epistemic progress to well-defined learning goals (Golding 2012). This results in learners being unable to differentiate between observations (data) and the conclusion (theory) (Leach et al. 1997). However, in some practical tasks, enhancing the development of scientific conceptual understanding remains weak possibly due to an increase in cognitive overload – the difficulty of simultaneously thinking intellectually (domain of ideas) and applying manipulative skills (Johnstone & Wham, 1982; Tamir, 1991). It is therefore unreasonable to expect a single practical activity to produce durable long-term learning of a scientific idea or concept. Learning about the ideas is likely to happen over a sequence of lessons rather than in a possibly brief practical session. The sequence of lessons would involve planning of various activities, including practical tasks, at appropriate points. To meet the requirements of the new curriculum, teachers might orientate their practice to developing conceptual structures and reasoning rather than focusing on tasks and activities (Duschl & Gitomer 1997). Teachers and hence learners would see the practical work as 'a means to an end and not as an end in itself' (Millar 2010:112).

In the new curriculum, the understanding of practical work will be assessed within written papers. So, learners require competence in both domains of observables as well as ideas. Teachers could now, in the absence of internal assessment pressures, possibly aim to develop higher cognitive skills by providing learners with sufficient time and opportunities for interaction and reflection, a chance for learners to express their interpretation of and beliefs about the meanings of their inquiry (Gunstone & Champagne 1990). This could lead to effective delivery of practical sessions, facilitating learners to 'interact intellectually as well as physically, involving hands-on investigation and minds-on reflection' (Hofstein & Lunetta 2003: 49). If practical work has explicit plans to support learners, to effectively utilise the concepts (domain of ideas) as well as to perform the practical task (domain of observables), then it can develop the high-order learning needed in evaluating evidence, development of critical thinking and metacognitive skills (Abrahams & Millar 2008; Katchevich et al. 2011). There is a desperate need for an equitable balance to be established in both domains to enable learners to use underpinning theoretical ideas to appreciate the practical method and competently interpret their observations (Abrahams & Millar 2008). Many key stakeholders are optimistic that these reforms will have a positive impact on the use of practical work at GCSE and A-level (Evans & Wade 2015).

Lunetta et al. (2007) concluded in their second major review of learning and teaching in the science laboratory that:

'Much more must be done to assist teachers in engaging their learners in school science laboratory experiences in ways that optimize the potential of laboratory activities as a unique and crucial medium that promotes the learning of science concepts and procedures...' (p.433)

The new GCSE science curriculum is possibly a step in this direction.

POTENTIAL PITFALLS – WOULD WE SURVIVE IN THE GLOBAL WAR OF SKILLS?

Research findings highlight the weakness of practical skill acquisition in school (Grant 2011:2) which jeopardises the UK's drive to increase the future supply of skilled individuals. The findings reveal widely held perceptions (97%) about the deficit in laboratory skills of new undergraduates in Russell Group universities, despite raising entry requirements (ibid.). The question is whether the changed curriculum would dilute the need for the pupils to 'do' the practical task. Would the reformed curriculum equip school leavers with competency in practical skills, acceptable by universities? Companies nowadays recruit from larger global markets, not relying on local skill supply, asserting the need for 'global meritocracy' (Brown & Tannock 2009:389). Learners in the UK will, in the near future, compete with international learners for career and education opportunities in the escalating global war of skills. They need all the support from the education system in order to develop the competencies needed to compete and survive in this global war of skills.

In 2014, the A-level chemistry curriculum underwent similar curriculum changes involving elimination of direct assessment of lab skill from contributing to a candidate's final grade. In China, the top-ranking country in PISA tables, practical work was also not assessed in the Gaokao examination (taken by A-level learners for the university entrance exam). Practical work was perceived as a low priority by learners, parents and teachers. Interestingly, China ran a pilot programme to integrate practical science project work into the Gaokao examination, aiming to strengthen the knowledge economy (Baruch 2014). The removal of internal practical assessment from the English science curriculum is perceived by some as a devaluation of practical science skills and experience, reducing resourcing (Ofqual 2015) and thus pushing practical science to the periphery (Carter 2014). A potential pitfall of the removal of practical assessment could be less focus on practical work due to budget and resource constraints. Cash-strapped schools could be tempted to show videos or focus on demonstrating the practical work, thereby reducing the chances of learners handling the apparatus, ie acquisition of weaker practical skills. This changed assessment model may result in English learners undertaking less practical work in science, when other high-ranking PISA nations are considering increasing the amount of school practical science work (Carter 2014).

CONCLUSION

The effects of the new GCSE science curriculum will only be evident in a few years' time, after further evaluative studies. On a positive note, these changes have the potential to improve the effectiveness of practical work in the identified area of weakness – the domain of ideas. Teachers and hence learners could see the practical work as 'a means to an end and not as an end in itself'. Rather than limiting discussion of practical results to a single practical session, more time might be spent discussing and analysing results or observations of practical work over a sequence of lessons. On the other hand, the assessment focusing on skills is now removed, so how important would skill acquisition be in the new GCSE chemistry curriculum? The potential pitfall of the removal of practical assessment could be a lack of focus on manipulative skills and eventually decrease in funding for activities, which do not lead to a direct gain in marks at GCSE. Is this model a valid way to assess practical science? What are the implications for learners who wish to pursue a career in science? Only time will tell. ■

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