Using practical work: strategies to avoid closing down practice

● Judith Hillier ● Olga Ioannidou

Abstract

Practical work has long been regarded as a fundamental part of science education, despite ongoing concerns about its use in lessons, the ways in which it is assessed and the tendency for these ways to close down practice. Project Calibrate, a partnership between researchers at AQA and the University of Oxford Department of Education, has worked with secondary science teachers to explore the use of a new framework to design new GCSE-level written assessments of practical work and how these might guide classroom practice. Findings show that this approach can indeed open up classroom practice and some specific suggestions for ITE and CPD are discussed.

Introduction

For many people, science is intrinsically connected with experiments, with many images of scientists firmly locating them in laboratories. In schools, this translates into an emphasis on the importance of practical work in science lessons, as per Ofsted's recommendation that schools should *'ensure they use practical work and scientific enquiry as the key stimulus to develop scientific knowledge, understanding and skills'* (2010, p.8). There have long been concerns about the use of practical work and the extent to which students are recipe-following, with calls for practical work to be both 'minds-on' and 'hands-on' (Abrahams & Millar, 2008). (Of course, at the moment, the global COVID-19 pandemic has resulted in new restrictions and limitations on the use of practical work in schools.)

Previous initiatives that have sought to support schools with their practical work have included *Getting Practical* (ASE, 2009), *Good Practical Science* (Gatsby, 2017) and the *Guidance Report* published by the Education Endowment Foundation, with the latter including a recommendation to *'use a variety of approaches to practical science'* (2018, p.31). However, the reality is that assessment drives much of classroom teaching and learning and tends to close down practice. For example, the House of Commons Science and Technology Select Committee gathered evidence that the *'high-stakes assessment culture often leads teachers to focus on only those limited skills that will form the basis of formal assessment'* (2011, p.28), finding that *'practicals were limited and focussed very much on meeting the narrow requirements of examination board assessment'* (*ibid,* p.29). It was made clear to the MPs that students only want to focus on content relevant to their examinations; such are the drivers of our educational system that, if practical work is not part of the examinations, students will ask teachers to stop doing practicals. The Select Committee recognised that the assessment of practical work should be designed to encourage good practice, and in 2011 recommended Ofqual to *'require an examination that properly assesses both students' laboratory skills and their technique and understanding of the experimental process'* (*ibid,* p.30). Since then, changes have been made to the assessment of practical work in both A-level and GCSE examinations, but research conducted between 2014 and 2018 found no real increase in the amount of practical work being carried out in schools, nor in the breadth of practical activities (Cramman *et al,* 2019).

In this paper, we present a framework that science teachers can use to open up their use of practical work to support students' learning, and which has been used to design written assessments that assess a broader range of practical skills – tests worth teaching to. The effectiveness of this framework and the written assessments developed from it will be discussed using evidence from teachers who have used the assessments in the classroom, and the implications for us, as teacher educators, will be considered as we work with beginning teachers to open up their use of practical work to support students' learning.

Methodology

Brandon's Matrix

In order to promote scientific thinking, practical investigations have been used as pedagogical means to teach about methods often used in science, commonly called 'the scientific method' (McComas, 2014). Despite its wide use, this representation of scientific methods as a linear step-wise process has been criticised as simplistic and formulaic, since it does not convey the breadth of methodological approaches followed by scientists (Lederman *et al*, 2002). The step-wise process of 'the scientific method' often begins with the construction of a hypothesis that needs to be investigated, often by using experiments to manipulate a variable and observe, for instance, the effect of one variable on another. However, although this is a method commonly used by scientists, it is not the only method applied in science. Scientists use a plethora of methods depending on the type of their research questions and the tools that they have available. For instance, astronomers rely on observations that do not involve the manipulation of variables or hypothesis testing to describe the position of planets and the evolution of stars.

To address this issue, and in order to depict the scientific pluralism as an authentic quality of science, this study proposes the adaptation of a theoretical framework: Brandon's Matrix (Brandon, 1994). Table 1 illustrates a theoretical framework developed by Brandon (1994), which categorises scientific methods according to whether they test a hypothesis and/or manipulate a variable.

According to this theoretical framework, some scientific investigations aim to only measure a parameter without testing a hypothesis. Examples of such investigations can be found in scientific fields that focus on categorisation (e.g. botanology).

Project Calibrate

Capitalising on Brandon's ideas (1994), the aim of Project Calibrate was to design new approaches for the summative assessment of practical science. The design of the new questions was based on the idea that assessment questions are often used as a teaching tool for teaching practical science. Therefore, by designing assessments that include a more balanced representation of scientific methods, students would be provided with more opportunities to engage with 'how science really works'. This could be achieved by developing assessment questions that would include all the types of scientific methods as described by Brandon. As part of the project, examiners, who were science teachers working as examiners for AQA, were recruited and trained in order to develop a set of assessment questions targeting six science topics (chromatography, mixtures and

Table 1. Scientific methods (reproduced from Brandon, 1994, p.63).

	Experiment/Observation	
	Manipulate	**Not Manipulate**
Test Hypothesis	Manipulative hypothesis test.	Non-manipulative hypothesis test.
Measure Parameter	Manipulative description or measure.	Non-manipulative description or measure.

distillation, osmosis, plant ecology, circuits and the electromagnetic spectrum).

Teacher workshops

In order to introduce Brandon's Matrix as a conceptual framework for designing new assessments, as well as a pedagogical tool, Project Calibrate invited experienced science teachers to participate in a 90-minute workshop. Twenty-four science teachers participated in the workshops, in which Brandon's Matrix was introduced, while it was highlighted that the overarching goal of the research project is to help students understand how science works in a 'hands-on' as well as 'minds-on' approach. The research team presented Brandon's Matrix by giving examples for each quadrant from all three science subjects (biology, chemistry and physics). During the workshop, teachers were provided with a lesson plan template that aimed to facilitate the planning of a lesson based around Brandon's Matrix and the designed assessments. The workshop participants used this template to plan a lesson, while discussing advantages and disadvantages of Brandon's Matrix. At the end of the workshop, the designed assessments were distributed to the teachers.

Data collection

The data presented in this study consist of datasets that were collected in two phases. The first phase aimed to explore how the teachers who participated in the teacher workshop perceived Brandon's Matrix. The aim of the second phase was to examine teachers' views of the Matrix as a teaching tool after introducing it to their students. For this purpose, teachers were interviewed regarding the Matrix's effectiveness and its affordances to be integrated in the current curriculum.

Teachers' initial feedback

In this phase, an online survey was distributed to the teachers who participated in the workshop after the end of the training. The questions investigated teachers' views on the designed assessments and their views on whether Brandon's Matrix is a worthwhile pedagogical tool that can be used for teaching practical science. Four teachers (n=4) completed the online surveys, which consisted of open- and closed-ended questions and lasted approximately 5 minutes. Since the questions were closed-ended or short answer open-ended, direct quotes were selected to illustrate teachers' perceptions of Brandon's Matrix and the designed assessments.

Teachers' post-teaching interviews

In the second phase, teachers who were interested in the material presented in the workshop introduced Brandon's Matrix and the designed assessments into their classrooms. The engaged teachers selected one of the six topics presented in the designed assessments. After approximately three months, the teachers were contacted for a semi-structured interview that lasted 10 to 20 minutes. The interview aimed to investigate the ways in which teachers adapted Brandon's Matrix and used it as a teaching tool in their classrooms in order to teach the topics that were presented in the designed assessments. At the same time, the goal of the interview was to examine teachers' views on the designed assessments and the perceived student performance with regard to the assessments. The teachers who implemented the framework and the assessments as a teaching tool were three science teachers (n=3) who taught in state-run schools in the UK. Teacher 1 and Teacher 2 were physics teachers and Teacher 3 was a biology teacher; their teaching experience ranged between 1 and 4 years. The interviews were analysed with the use of deductive, as well as inductive, coding (Braun & Clarke, 2006).
The initial themes were created based on the interview questions, while new codes emerged through inductive coding. This iterative process was completed when all subthemes were agreed upon by all researchers. In the final stage of the coding, representative examples were selected

from the dataset in order to be presented in the narrative of the results.

Key findings

Teachers' initial feedback

The online survey showed that the responders had overall positive views on the usefulness of the framework. More explicitly, teachers mentioned that the Matrix helped them *'think about the ways in which (they) teach practical sciences to (their) classes'*, while it stimulated self-reflection on how they approach practical investigations in different subjects (e.g. *'[Brandon's Matrix helped me see] how I was adding much more detailed thinking to bio RPs (specialism) and less to the chem(istry) and physics ones').*

When asked about potential weaknesses of the Matrix, participants mentioned that they might not directly help students to *'answer AQA exam questions, just gives more context to experimental procedure'*, while it may not be particularly *'accessible for students'*. In terms of the framework's usefulness for designing exam questions, two teachers expressed positive opinions, while two teachers expressed uncertainty about its usefulness in this particular context. With regard to the designed assessments, all the participants showed overall positive views, while one of the participants expressed concerns that they might not have a strong impact on students' learning *'as a stand-alone'*.

Finally, all participants believed that it would be achievable to teach and prepare their students to answer questions within this framework; one teacher suggested that it will help both higher and lower ability students, as the higher ability students *'will get more from it as they will not be overloaded'*, while at the same time *'it may make the ideas more accessible'* for lower ability students.

Teachers' post-teaching interviews

The analysis of teachers' post-teaching interview responses regarding Brandon's Matrix and the designed assessment resulted in the development of three subthemes: a) teachers' understanding of Brandon's Matrix; b) teachers' views of Brandon's Matrix; and c) teachers' views on the assessments.

a) *Teacher understanding of Brandon's Matrix:*

The teachers demonstrated a sound understanding of the Matrix when asked about the concepts of hypothesis testing and manipulating variables:

'In terms of manipulation of a variable, with physics, that'd be impossible because there is stuff we can't manipulate. I'd say that science is a lot more broad than that' (Teacher 2).

Teacher 2 also commented on the use of the scientific method and the need for broader thinking to allow for scientific progress:

'If you look back and see that an awful lot of scientific discovery was done by mistake...if you had to say that people's discovery only came from what we thought was possible, then you wouldn't make any progress' (Teacher 2).

b) *Teacher views on Brandon's Matrix*

The teachers expressed some positive views on the use of Brandon's Matrix in the classroom that encouraged a 'minds-on' approach to practical science:

'I do think it's a valuable teaching tool for making children think about what they're doing in practical science' (Teacher 3).

'It was almost like they felt like they had more ownership of it because they had more say in what they were actually doing...and they understood the logic behind it a little more I think' (Teacher 1).

However, limitations around the time needed to embed the use of the Matrix were also highlighted:

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'I think there's a lot of potential there. But in order to justify that, it would have to be part of the curriculum, because at the same time, when you're doing a research project like this, you don't want to risk filling their heads with things that's not going to be relevant' (Teacher 2).

'I think if we would if we had the time and we had the scope for already open projects, it would be very valuable for how they explore science' (Teacher 3).

c) *Teacher views on the assessments*
Overall, the teachers perceived the assessments as suitable resources:

'I didn't notice a particular difference from what we are used to already' (Teacher 2).

Yet there were concerns that the inclusion of the Matrix may be an additional piece of content for students to study in preparation for their GCSEs:

'I do feel like it's more of an add-on when it came to the assessments, rather than it being explorative' (Teacher 3).

Implications of these findings

The aims of this paper are to present Brandon's Matrix as a framework to support both the teaching and learning of practical work in science, and its assessment in written examinations, and to share some of the evidence we have for the validity and effectiveness of this approach, and hence to consider the implications for us as teacher educators. Having introduced Brandon's Matrix to experienced teachers, how might it be shared with beginning teachers? In what ways could Brandon's Matrix be used in lessons? And more broadly, how do we help beginning teachers to appreciate not just the value of practical work, but how integral it is to the teaching and learning of science (particularly in COVID times)? And how do we help beginning teachers to appreciate previous trends and tensions in the use and assessment of practical work that have led to the current situation in the assessment of science in England?

Brandon's Matrix itself is clearly accessible to experienced science teachers, and the quotes above illustrate the value that they can see in a framework that promotes a broader understanding of what it means to 'do science'. This is also supported by other work we have reported elsewhere (e.g. Ioannidou & Erduran, 2020), but this is dependent on teachers having an understanding of the Nature of Science (NoS) (*ibid*). Other authors have discussed the potential of professional development programmes to educate teachers about the NoS (e.g. Capps *et al,* 2012).

Table 2. Example of one practical activity in each of the Brandon's Matrix quadrants.

	Manipulation of variables	Non-manipulation of variables
	Manipulate	**Not Manipulate**
Hypothesis testing	Measuring how increasing the weight of an object increases its mass.	Using Newton's 2nd Law of Motion (F=ma) to predict the weight of an object with a certain mass (on Earth).
Measure Parameters	Measuring the weights of different objects with different masses	Measuring the mass and weight of an object.

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Both authors and our science colleagues who have been working on Project Calibrate teach on the PGCE course at the University of Oxford, which already includes NoS as part of the curriculum programme. Using Brandon's Matrix in our research has encouraged us to explore ways to emphasise the diversity of scientific methods across the sciences, and the types of knowledge yielded by these different approaches. One example is to show how a practical activity can be positioned in each of the four quadrants of Brandon's Matrix (See Table 2). Beginning teachers could be asked to complete a similar table for a practical activity of their choice.

On the other hand it was clear, both to the teachers and to us as researchers, that many school students would find Brandon's Matrix challenging to understand, and some of its language inaccessible. Previously, in Project Calibrate (Cullinane *et al,* 2019), teachers had raised concerns about the lack of emphasis in current GCSEs on students planning investigative work, and Brandon's Matrix could be used to provide a framework to support this, with suggested examples from the current AQA set of required physics practicals at GCSE shown in Table 3.

Having considered ways of introducing Brandon's Matrix to beginning teachers and to school students, we now turn to the question of how to support beginning teachers to develop the confidence and the skill to make purposeful use of practical work in their teaching. Robin Millar's chapter (1998) on the rhetoric and reality of practical work is one way of challenging assumptions that can be made about the use of practical work, with discussion of this chapter opening up further conversations about the purpose of practical work and how it can be used to support students' learning. Table 4 shows an example of a framework that we have used this year with beginning teachers when they have been trying out practicals in our lab.

The teachers who participated in Project Calibrate were clearly aware of the current assessment requirements and the importance of ensuring that students had the opportunities to meet these. Conversations reported elsewhere (Cullinane *et al,* 2019) showed how the teachers appreciated the historical reasons that had led to the current assessment system as described by Childs and Baird (2020) (see Table 5). Giving beginning teachers an overview of these changes and the reasons behind them supports the development of their professional understanding of some of the drivers and constraints in our educational system. This in turn can help to develop their resilience as teachers, as external regulations have been identified as a risk factor to teacher retention (Beltman *et al,* 2011).

Table 3. Possible framework to support students' planning for practical work (all practicals taken from the *AQA GCSE Physics Required Practical Handbook* (8463) (available at https://filestore.aqa.org.uk/resources/physics/AQA-8463-PRACTICALS-HB.PDF).

	Dependent and independent variables	**Variables being measured**
Making a prediction	*e.g. measuring the effect of force on acceleration at constant mass.*	*e.g. investigating the amount of infrared radiation radiated from different surfaces.*
No prediction made	*e.g. investigating the specific heat capacity of different metals.*	*e.g. measuring the speed of waves in a solid.*

Table 4. Questions to consider for each practical about how it could be used to support students' learning.

Purpose – what could the learning objective be for this practical if it was A demonstration? A class practical?	**Instructions** – how would you want to modify the instructions you were given?
Relevance – how is this phenomenon used in the real world?	**Health and safety** – what controls would you have to put in place to reduce risk?
Explanation – what is the key idea that this practical demonstrates? Can you explain what is happening here?	**Advice** to people who are setting this up for the first time?

Table 5. Different approaches to the assessment of practical science at GCSE in England (from Childs & Baird, 2020).

Era	Years	Performance conditions
Coursework assessment through practical investigations	1992-2006	Conducted through the GCSE course: in the classroom, as homework or as a mixture of both.
Coursework assessment through controlled assessments	2006-2016	Conducted in the classroom under supervision.
Written examination	2016-	Examination conditions.

Conclusion

As Project Calibrate draws to a close, there are three key recommendations that we feel should be shared with the science teacher education community. The first of these is a policy recommendation, namely that written assessment of practical work needs to fully reflect the diversity of approaches to practical work. All teachers would need support with adjusting their practice in response to such a change, but particularly beginning teachers who also need to understand the historical contexts that have led to this.
The other recommendations are both practice-related: we would encourage all teacher educators to introduce teachers and beginning teachers to Brandon's Matrix as a framework to open up the use of practical work, and we would also recommend changes to textbooks and other classroom resources to reflect and foster a greater breadth of approaches to practical work.

Acknowledgements

Funding for research reported in this paper was provided jointly by the Wellcome Trust, Gatsby Foundation and the Royal Society (Grant Number 209659/Z/17/Z) awarded to Sibel Erduran as the Principal Investigator.

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Judith Hillier and **Olga Ioannidou,** University of Oxford Department of Education.
E-mails: **judith.hillier@education.ox.ac.uk** and **olga.ioannidou@education.ox.ac.uk**