Science practical work in a COVID-19 world: are teacher demonstrations, videos and textbooks effective replacements for hands-on practical activities?

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Abstract Practical work and experimental science are at the heart of teaching and learning in science classrooms. The COVID-19 pandemic forces secondary school science teachers to make difficult decisions about how best to facilitate practical work safely. We present empirical evidence of the effectiveness of teacher demonstrations and videos in preparing students ($n = 1252$) to answer practical-themed examination questions, in particular those usually taken at age 16 in England. Findings suggest that if circumstances prevent hands-on practical work, schools should deliver student-engaged teacher demonstrations that include purposeful discussion and questioning. Reliance solely upon videos or textbooks is likely to disadvantage students in examinations. The findings could inform practice in other countries and other age ranges.

The purposes and assessment of practical work

Practical work is a required element of the science courses taken by secondary school students in England that lead to General Certificate of Secondary Education (GCSE) and Advanced level (A-level) qualifications (usually awarded at ages 16 and 18, respectively). All over the world, teachers regard hands-on practical work as useful (Holman, 2017), mainly because it encourages student engagement and participation.

Practical work involves the collection of data through observation, investigation, experimentation and measurement. When done in the right way, practical work can be used to help develop students' understanding of scientific phenomena, their understanding of scientific methods and the empirical nature of science, and their ability to use apparatus and follow practical procedures (Millar and Abrahams, 2009). It has also been shown to increase students' engagement and motivation, with many reporting that they find practical work enjoyable (Abrahams, 2011), and can be used to help develop transferrable skills and attributes such as communication, teamwork and perseverance (Holman, 2017). The understanding and attributes developed through practical work enable progression to further study and into science-related and other careers.

Those familiar with the Assessment of Performance Unit (APU) framework for practical assessment developed during the 1980s (Welford, Harlen and Schofield, 1985) will recognise that particular practical competencies can only be assessed if students carry out hands-on practical work. These include, for example, following methods and instructions, using measuring instruments and other apparatus, making observations, and carrying out entire investigations. Other knowledge and understanding of practical work can be assessed through a written test, including, for example, planning parts of investigations and entire investigations, representing information in graphs, tables and charts, interpreting presented information and applying science concepts to make sense of presented information. More recently, Abrahams and Reiss (2015) have formally differentiated between *direct* assessment, in which a student's competency at the manipulation of real objects is determined as they manifest a particular skill, and *indirect* assessment, in which a student's competency is inferred from data they have collected or their write-up of practical work they undertook.

There is a further purpose of practical work in science lessons: to help students to develop the competencies, knowledge and understanding they will need to perform well in assessments. Research suggests that what teachers choose to devote teaching time to is influenced strongly by the summative assessment at the end of a course – sometimes referred to as the 'backwash effect' (Millar, 2013). Thus, the way in which students' practical competencies, knowledge and understanding are assessed is an important driver of the types and amount of practical work that is done during science courses. At the very least, teachers strive to ensure that their students are as well prepared as possible to complete assessments.

Since 2018 in England, students' knowledge and understanding of science practical work at GCSE level has been wholly assessed through questions in the written examination papers taken at the end of the course. There is no direct assessment of students' practical competencies. Practical-themed questions in the examination papers assess knowledge and understanding of the use of a selection of required apparatus and techniques, and count for at least 15% of the overall marks for a GCSE qualification in science (Ofqual, 2015).

Teachers are required to provide students with a sufficient range and amount of practical experience to allow them to develop knowledge and understanding of the use of the required apparatus and techniques. The awarding organisations in England have specified a range of practical activities that they recommend all students should complete in order to develop the required knowledge and understanding, although individual science departments may choose to substitute these with equivalent activities. Students are required to complete at least eight practical activities in each GCSE science subject and to keep a 'contemporaneous record' of the practical work they undertake (for example, in a lab book); students can use their records as a revision aid, and evidence of record-keeping by students may be requested by the awarding organisation. Teachers can choose whether individual practical episodes are conducted as hands-on practical activities or via teacher demonstration; they may also make use of other teaching aids such as videos, simulations and written accounts of practical activities in textbooks and other written resources.

Science practical work in a COVID-19 world

In March 2020, the UK Government instigated partial school closures in response to the COVID-19 pandemic. Although some students, such as the children of key workers, were able to continue attending school, most students were required to be home-schooled with support provided by teachers through the provision of teaching materials and remote/online lessons. These arrangements continued for the remainder of the academic year. Opportunities for students to undertake hands-on science practical work will have been particularly negatively affected by these arrangements.

At the time of writing, it is planned that students in England will return to school in September 2020. Students aged 15–16 will commence the final year of their GCSE studies after having missed at least 5 months of in-school teaching. There will be much to catch up on and cover in preparation for GCSE examinations in summer 2021. Practical work will have to compete for teaching time with, among other things, diagnosing and responding to gaps in students' understanding, catching up on missed content, and developing understanding of new material. Ongoing social distancing guidelines and other public health considerations will affect what is possible for safe learning in the classroom. In this context, science teachers and technicians will have to make difficult decisions about how best to incorporate practical work safely, and how to minimise disadvantage to ensure these students are as well prepared as they can be to answer practical-themed questions in GCSE examinations in 2021.

In July 2020 the qualifications and examinations regulator published changes to GCSE assessment arrangements for summer 2021, following a public consultation (Ofqual, 2020a). With regard to science practical work, students will be permitted to observe teacher demonstrations or simulations that cover the required apparatus and techniques, rather than carrying out hands-on practical work for themselves; it is noted that demonstrations could be carried out remotely in case of further periods of school closure. This proposal is intended to reduce pressures on teaching time and to make it easier to accommodate public health guidelines.

But what effect might reliance upon demonstrations and simulations have on learning and on students' preparedness to answer practical-themed GCSE examination questions?

Study overview and aims

Here we describe interim findings from research conducted by the Practical Assessment in School Science (PASS) project into the use of written examination questions to assess GCSE students' knowledge and understanding of practical work. The principal aim of this research is to identify features of written examination questions that discriminate between students who have experienced different types and amounts of practical work in GCSE science lessons. We have compared the performance, on practical-themed examination questions, of students who undertook practical work themselves as a hands-on activity, with those who watched a teacher demonstration, watched a video demonstration, or read about a practical activity in a form such as that presented in a textbook.

The research also aims to investigate the impacts of the new approach to practical assessment at GCSE level on the general pedagogy associated with practical work in lessons, including on the amount and types of practical work done.

The first year (of two planned years) of data collection was completed during the 2018–2019 academic year, ending in July 2019, before the onset of the COVID-19 pandemic.

In this article we report findings from the first year of data collection that are relevant to teachers making decisions about how to deliver practical work in GCSE science lessons in a COVID-19 world.

Methods

A mixed-methods approach to data collection was employed. Quantitative data on student performance were collected from post-intervention tests, and qualitative data on pedagogy were collected from lesson observations, post-lesson teacher interviews and teacher meetings.

Participating schools were recruited from London and Yorkshire, and represented a variety of types including academies, community schools and faith schools (www.gov.uk/types-of-school). The sample of schools was comparable to national averages on various measures, including percentages of students with special educational needs and disabilities (SEND), with English as an additional language (EAL) and those eligible for free school meals (FSM).

Classes were put into different practical intervention groups: a quarter of the classes carried out each practical as a hands-on activity, and similar proportions watched the practical as a teacher demonstration, or as a video demonstration, or read about it in a form such as that presented in a textbook. Class-level data on student characteristics, including predicted GCSE grades, gender, ethnicity, SEND, EAL and FSM, and years of teacher experience, were collected using teacher surveys; these data were used to construct a matrix that put classes into intervention groups so as to achieve approximately equivalent cohorts undertaking each intervention. The interventions were administered by school staff, using documents provided by the researchers, including student worksheets and instructions for teachers and technicians.

The practical intervention activities (Table 1) enabled students to develop understanding of some of the required apparatus and techniques in GCSE biology, chemistry, combined science, and physics, and are typical of the kinds of practical activities undertaken in GCSE science lessons.

Post-intervention tests (comprising sets of GCSE examination questions that assessed knowledge and understanding of the apparatus and techniques used in the practical activities) were completed by 1252 year 10 students (ages 14–15), following practical interventions administered by teachers.

The questions in the post-intervention tests were sourced from GCSE examinations written by the awarding organisations, and the sets were constructed so that they could be completed in 15–20 minutes of lesson time, following completion of the corresponding practical intervention. The questions assessed knowledge and understanding of practical work in the following broad aspects: knowledge of particular pieces of apparatus and techniques; planning of practical procedures; evaluation and improvement of practical procedures; data processing (including mathematical processing and graphical representation); and interpretation and evaluation of data. Each set of questions comprised one free-response, 6-mark, extended-writing question, followed by 10–20 marks in a series of structured questions worth 1–4 marks each. The structured questions comprised a mix of formats, including objective (in which the answer is chosen from a provided selection), free-response writing, calculations, plotting graphs/charts and drawing diagrams of apparatus.

One-way ANOVA tests (a way to find out whether survey or experiment results are significant) were used to compare differences in student scores for the four different intervention types across the six practical activities. Throughout the analysis the data were checked for normality; the data sets were of sufficient size for this to be unlikely to affect the analysis of a one-way ANOVA test, but, as a check, a Kruskal–Wallis test for non-parametric data was also carried out; this indicated that the results of the one-way ANOVA test could be used with confidence. Any significant differences found with the one-way ANOVA were followed up with Tukey HSD post-hoc tests (a single-step multiple comparison procedure and statistical test).

Table 1 The six practical activities that were the subject of interventions, and the practical techniques they help students to develop

Subject	Practical techniques	Practical activity
Biology	Measuring distribution and abundance of organisms	Quadrat sampling (fieldwork)
	Measuring rate of reaction by measuring production of gas	Collecting gas from the breakdown of H_2O_2 by catalase
Chemistry	Separation and purification	Making the salt copper sulfate
	Measuring rate of reaction by observing a colour change	Disappearing cross for the reaction of sodium thiosulfate and HCl
Physics	Measuring motion	Acceleration of a trolley down a slope
	Measuring extension	Addition of masses to a suspended spring

A sample ($n = 24$) of the intervention lessons was observed, and semi-structured interviews were conducted with 23 of the teachers of the intervention classes. Of the 23 teachers, 12 were female and 11 were male, and the group had a wide range of years of teaching experience (from 1 to 38 years). Observation notes and interview transcripts were scrutinised for insights into how teachers perceived and facilitated the practical work, as well as challenges and opportunities they encountered.

Results

Quantitative analysis after the first year of data collection compared the mean percentage marks achieved by students on the post-intervention tests (GCSE practical question sets) following the different intervention types (Figure 1). This showed that there was a statistically significant difference between some of the intervention types as determined by one-way ANOVA ($F(3,964) = 6.417$, $p = 0.000$). In particular, a Tukey post-hoc test revealed that the mean percentage mark following the teacher demonstration intervention (52.0 ± 17.2%; mean ± standard deviation) was significantly higher than the mean percentage marks following the video intervention (45.4 ± 20.2%, $p = 0.002$, effect size = 0.35) and the reading information intervention (44.5 ± 21.5%, $p = 0.001$, effect size = 0.38). Both effect sizes were large. There was no statistically significant difference between the mean percentage marks after the demonstration intervention (52.0 ± 17.2%) and the hands-on practical intervention (48.9 ± 18.8%, $p = 0.345$).

Lesson observations suggested that the quality of purposeful teacher-led discussion may be part of the reason for the differences in test results. Some high-quality questioning was observed during teacher demonstrations that elicited understanding of key points of practical procedure. During teacher demonstrations, students were given opportunities to test their thinking against the teacher's expert view. In contrast, during hands-on practical work the majority of talk was between students. The quality of student–student talk observed during hands-on practical work varied from focused and insightful to irrelevant and distracted. In some of the observed lessons, students followed a 'recipe'-style procedure during hands-on practical work, which did not always include sufficient elements designed to challenge or stimulate their thinking.

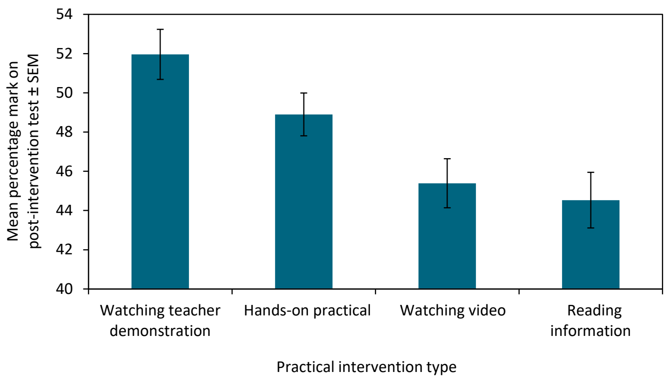

Figure 1 Mean percentage mark on post-intervention test (± standard error of the mean) for each practical intervention type. The difference between the teacher demonstration intervention and the hands-on practical intervention was not statistically significant ($p = 0.345$). Teacher demonstration gave a statistically significant higher mean percentage mark than watching a video ($p = 0.002$) and reading information about the practical ($p = 0.001$); both effect sizes were large.

During lesson observations, many points of good practice were noted during teacher demonstrations of practical activities, including teacher-led discussion and high-quality questioning. Points typical of the kind of good practice observed are summarised in Box 1.

In post-intervention interviews, some of the teachers pointed out that they had deliberately made use of questioning during practical demonstration interventions; for example:

> *As I'm doing the demo, I'm explaining it to them, questioning them at the same time.*

> *When you do the demonstration, obviously you've got your class and you're getting them to think with the questioning.*

Others recognised the benefits of teacher-led discussion and high-quality questioning during practical demonstrations:

> [During the demonstration] *we had a good discussion about what we were doing and why, and I think that allowed them to think.*

> *If I want to really focus them and say, 'Look, these are the key points', I think demonstrating* [is effective]. *I can focus their minds and get them to think about the important bits of the practical and why they're doing it.*

> *If you're a skilled teacher,* [a demonstration] *is a very, very effective way of teaching them about the required practical when it's not about them developing the skill of how to handle the stuff. In terms of learning it's very effective.*

The quantitative data analysis suggested that reliance solely upon videos rather than hands-on practical work or teacher demonstrations would leave students less well prepared to answer practical-themed GCSE questions. However, some teachers noted that videos could be used to supplement hands-on practical work or demonstrations; for example:

> *One of the things we have been trying to do when we are coming up to the core practicals is getting the students to look at videos beforehand.*

Box 1 Key points of good practice from a teacher demonstration of a practical activity

The following points are derived from an excellent teacher demonstration of a practical activity in GCSE chemistry (disappearing cross to measure rate of reaction between sodium thiosulfate and hydrochloric acid) by an expert practitioner, and typify the kind of good practice observed.

- A clear introduction that explains the aim of the practical activity (what it is trying to show or find out), an overview of what will be done and the key observations that will be made.
- Identifying steps in the procedure so that students could focus on the reasons for different procedures or the ways these were carried out. Each step gave students valuable information that supported their learning.
- Questioning about procedure and good practice. During each step, questioning and clarification provided opportunity for student involvement and discussion. For example, apparatus was examined and discussed, with a focus on reasons for choosing each item *(e.g. conical flask with sloped sides to avoid splashes when swirling to mix reagents)* along with the procedure that should be followed to maximise accuracy and precision of results (*e.g. recognising that the black cross on white paper under the conical flask provides good contrast to make it easier to see, that the same cross should be used each time, and that it is best to observe though the top of the conical flask)*.
- Taking opportunities to emphasise key points, including:
  - providing scenarios for students to 'correct' the teacher *(e.g. deliberately not observing from eye-level when reading from a measuring cylinder and then following students' instructions on how to take the measurement)*.
  - requiring students to notice and note key parts of the practical procedure *(e.g. putting on goggles, immediately replacing lids on reagent bottles, bending over to measure levels in measuring cylinders at eye-level, opening doors to prevent build-up of noxious sulfur dioxide gas during the reaction, and later noticing the smell of sulfur dioxide – 'Can anyone smell anything?')*.
- Encouraging some student observers to give a running commentary of the events *(e.g. what they saw as the reaction progressed, describing what happened)*.
- Encouraging thinking and predicting, including voting on what might happen *(e.g. when a variable was changed)*.
- Sometimes, measurements rehearsed before measuring for real.
- Sometimes, limited number of measurements taken, only until confident that students understood how to take them, and then pre-prepared results given to students for the analysis part of the procedure.
- Using the analysis part of the lesson to reflect on and review procedures through small group discussion about the experiment and results.

> *It also made us think about follow-up to the practical work and the detail and terms they need to remember… Originally we saw video as a poor option to seeing it live… now we see it can cover some of the things they may have missed or forgotten in a class practical.*

Some of the interviewed teachers reported that they had considered using demonstration or video as an introduction or follow-up to hands-on practical work. Under normal circumstances, when time and safety considerations permit, this could help students to extend their understanding beyond procedural knowledge to access more substantial understanding of the practical techniques, and to build connections between practical work and theoretical understanding.

Discussion and recommendations

September 2020 marks the start of an academic year like no other. With the need to make up for months of lost classroom teaching time, and ongoing public health requirements such as social distancing, science teachers will be forced to make difficult decisions about what to do in lessons and how best to get practical work done.

Students at age 15–16 in England who will sit GCSE science examinations in summer 2021 need to be well prepared to answer examination questions that assess their knowledge and understanding of the use of particular apparatus and practical techniques. The qualifications and examinations regulator has issued guidance for GCSE assessments in 2021, including the recommendation that students be permitted to observe teacher demonstrations or simulations that cover the required apparatus and techniques, rather than carrying out hands-on practical work for themselves (Ofqual, 2020a). Science teachers must decide how to strike a balance between in-demand curriculum time, public health requirements and what is best for their students' learning.

When we compared the mean percentage mark achieved on the GCSE question sets completed by students after different types of practical intervention, the difference between the hands-on practical intervention and the teacher demonstration intervention was not statistically significant. We recommend that students be given opportunities to carry out hands-on practical work whenever possible, and CLEAPSS (http://science.cleapss.org.uk) has provided guidance on how this can be done safely in a COVID-19 world (see *GL343 Guide to doing practical work during the COVID-19 Pandemic – Science*). Most of the interviewed teachers reported that they believe hands-on practical work supports more in-depth learning and better recall in examinations. This seemed to be particularly the case for students with low attainment levels, as the teachers suggested that, in addition to supporting recall, hands-on practical work could increase these students' interest, motivation and self-esteem when learning science. The qualifications and examinations regulator's analysis of responses to its consultation on assessment arrangements in 2021 acknowledged that the removal of hands-on practical work could disadvantage some students who need to experience practical work first-hand in order to understand what is happening, including the visually impaired and other students with special educational needs and disabilities (Ofqual, 2020b).

However, the interim findings described in this paper indicate that when students did not undertake a hands-on practical activity, those who watched a teacher demonstration of the activity instead achieved significantly higher test scores on average in the GCSE question sets than those who watched a video of the activity or read about it in a form such as that presented in a textbook. Our observations of practical activity lessons, and our discussions with the participating teachers, suggested that focused dialogue between teacher and students during a demonstration was key to the effectiveness of the demonstration in supporting student learning through practical work.

Hence, our research suggests that when circumstances prevent students undertaking hands-on practical work, for example because of pandemic-related public health guidelines, teacher demonstrations can be an effective way of preparing students to answer GCSE examination questions that assess their knowledge and understanding of practical work, when – crucially – the teacher demonstrations include purposeful discussion and questioning that helps students to focus on the practical learning outcome.

Teachers and technicians will face considerable challenges in working out how to deliver practical work safely and effectively for their students in a COVID-19 world. But the evidence presented here indicates that when hands-on practical work is not possible, schools should deliver teacher-led, student-engaged demonstrations that include purposeful discussion and questioning. Our findings also indicate that reliance solely upon videos or written summaries of practical work is likely to reduce the learning that takes place and leave students at a disadvantage in examinations. Though the findings relate to GCSE examinations in England, they could also be applied to inform best practice in doing science practical work with students in other age ranges and in other countries.

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References

Abrahams, I. (2011) Research focus: what does research say about the nature and purpose of practical work? *Education in Science*, **244**, 28–29.

Abrahams, I. and Reiss, M. J. (2015) The assessment of practical skills. *School Science Review*, **96**(357), 40–44.

Holman, J. (2017) *Good Practical Science*. London: The Gatsby Charitable Foundation. Available at: www.gatsby.org.uk/GoodPracticalScience.

Millar, R. (2013) Improving science education: why assessment matters. In *Valuing Assessment in Science Education: Pedagogy, Curriculum, Policy*, ed. Corrigan, D., Gunstone, R. and Jones, A. pp. 55–68. Dordrecht: Springer.

Millar, R. and Abrahams, I. (2009) Practical work: making it more effective. *School Science Review*, **91**(334), 59–64.

Ofqual (2015) *GCSE Subject Level Conditions and Requirements for Single Science (Biology, Chemistry, Physics)* (Ofqual/15/5687). Coventry: Office of Qualifications and Examinations Regulation. Available at: www.gov.uk/government/publications/gcse-9-to-1-subject-level-conditions-and-requirements-for-single-science.

Ofqual (2020a) *Consultation Decisions: Proposed Changes to the Assessment of GCSEs, AS and A levels in 2021* (Ofqual/20/6649). Coventry: Office of Qualifications and Examinations Regulation. Available at: www.gov.uk/government/consultations/proposed-changes-to-the-assessment-of-gcses-as-and-a-levels-in-2021.

Ofqual (2020b) *Analysis of Consultation Responses: Proposed Changes to the Assessment of GCSEs, AS and A levels in 2021* (Ofqual/20/6649/1). Coventry: Office of Qualifications and Examinations Regulation. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/906101/Summer_2021_Consultation_Analysis_310720.pdf.

Welford, G., Harlen, W. and Schofield, B. (1985) *APU Science Report for Teachers 6: Practical Testing at Ages 11, 13 and 15*. London: Assessment of Performance Unit, Department of Education and Science. Available at: www.stem.org.uk/elibrary/resource/27947.

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