Investigating the changes and challenges to practical work in A level physics

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Investigating the changes and challenges to practical work in A level Physics

Jon Burland

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Context

As both a teacher of Physics and a Head of Science at a sixth form college that focuses on academic courses, changes to the A level Science courses have a big impact on me and affect all the classes I teach and the department I manage. For a long time Science courses in England have included practical skills as part of the syllabus and assessed them through various coursework/controlled assessment/practical exams. However in 2015 this changed and practical skills at A level are now assessed as a written, terminal exam alongside the 'theoretical' part of the syllabus. One of the reasons this was done is due to concerns over the accuracy of coursework style assessments, concerns about help from parents, tutors and teachers and concerns around consistency of marking meant that this form of assessment was widely seen as unreliable (Qualifications and Curriculum Authority 2005). The coursework element of the A level had been an 'under-control' part of the course; it was worth 20%, and the students and I knew how they had done before entering the final exams which slightly reduced the pressure. Typically they scored good marks on the coursework meaning that it slightly pushed the grades up. Under this system the practical skills part of the course were often delivered in a single block with students prepared for a specific assessment task or tasks and then allowed to forget it and move on once this was complete – a problem for those stake holders who need school leavers to have good practical skills but helpful for the students who had one less thing to revise. The previous system also meant there was a clear divide between assessed practical work and practical work done for other reasons. Under the new system, students need a deeper understanding of practical skills to be ready for the large range of possible questions in the exam and as the practical assessment that affects their A level grade is part of a terminal exam they need to process and communicate their practical skills in a different way.

I teach at a sixth form college of around 600 students in inner London. It caters for a range of students taking A level courses although this project only focused on A-level Physics. Students join

from over 100 secondary schools across London and come from a very wide range of different minority ethnic groups. About 35% students are known to be eligible for free school meals. There are nearly 100 in the first year of A level Physics and around 60 in the second, this discrepancy is partly due to the school increasing in size and partially due to a drop out of around 15% at the end of Y12. Currently, we teach the OCR B Advancing Physics course. Under the old system this course contained 4 written exams; two worth 15% and two worth 25% of the A level grade, with practical skills assessed through two coursework units each worth 10% of the overall grade and each containing two separate tasks. Half of the exams were completed at the end of the first year and the coursework tasks were completed at a time decided by the teacher. Under the new system, the course has three terminal exams worth 41%, 37% and 22%, the smallest of which, called "Practical Skills in Physics", contains the practical assessment element of the course. In addition to this, students receive a pass or fail on the practical endorsement (PE), a requirement that they complete at least 12 from a list of practicals. While this does not count towards the A level grade, universities are typically requiring the practical endorsement is passed as part of standard offers. Last year, the first of the new system, all our students passed the PE and we had a successful monitoring visit from OCR so this is not an important focus for this project. In the exam content our students performed broadly similarly (2% below the OCR B average) in all three papers but on the practical skills paper there was a very different distribution of marks. The range of marks was narrower than on the other papers with lower average mark and a lower correlation to the overall mark, see fig 1 below.

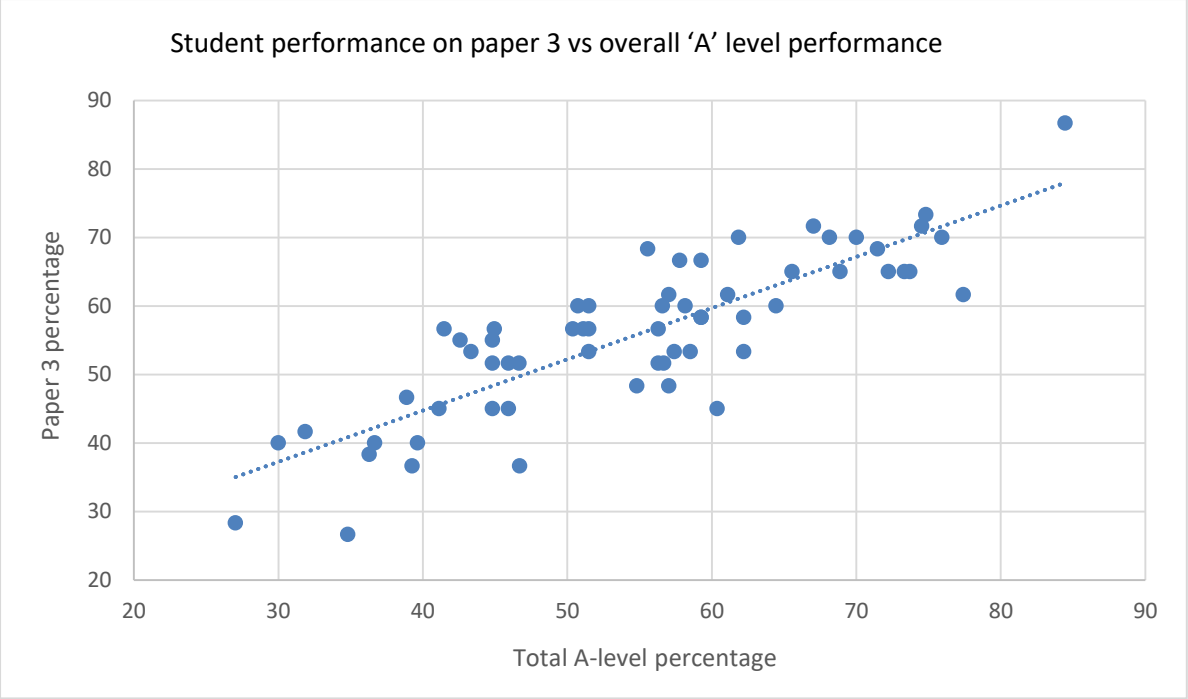


Fig 1 – student performance on the practical skills paper 3 vs over 'A' level performance.

This suggests that our preparation for paper 3 is not allowing students to discriminate themselves, with high achieving and low achieving candidates scouring more similar marks on the practical skills paper. As our performance gap is consistent across all 3 papers there may be other centres in a similar position. This may suggest that the practical skills questions lack validity, a suggestion backed up by early research into the impact of the reforms (Ofqual 2017 p23). Nevertheless working on preparing our pupils better for the practical skills paper is a priority for our department for this year.

Aims

The ultimate aim of this work is to improve student outcomes in examination-assessed practical skills in A level Physics. I will be trialling a new approach with two of the six first year A level classes this year with the aim of using this trial to inform a full rewriting of the departmental scheme of work for September 2018. Learning and teaching these skills can be quite different from traditional science learning and to inform the new approach I will begin by seeking an understanding of the underlying pedagogy and previous studies into effective practical work before looking any my specific context by carrying out my own research with the help of students and teachers within the department. This will involve considering the role of practical work in learning science, how it is similar/different to and how it supports the learning of scientific 'theory', how this relates specifically to A level Physics and the specific issues that are present in my classroom.

The role of practical work in science:

It can be difficult to explain what science is. Experts struggle to come up with a clear definition that covers all branches of science and there is also debate about if some areas of study are branches of science. Feynman once defined science as "the belief in the ignorance of experts" (Feynman 1969); as he was giving his opinion in the capacity of an expert, this may be a rare example of poor logic by Feynman but highlights how hard it is to agree on a definition. However, observation of phenomena and making deductions from those observations is widely recognised as being important to "doing" science. Bacon, considered by many to be the father of the 'scientific method', was clear that observation and induction were they key to the scientific method (Bacon 1620). A there is debate about the merits of different methodologies in science and flaws in Bacon's approach were pointed out as early as two years after Bacon's death by Harvey (who applied Bacon's approach to study anatomy, explaining the circulatory system) who argued that the Bacon's method neglected the

importance of judgement about what to obverse (Harvey 1628). However, there are no credible challenges to the notion that practical experimentation (observation) is core to science.

Practical work in science education:

"The worst science teachers make no attempt at all to embellish the curriculum by taking their students out of the classroom […] and they make minimum effort to run practical classes. Indeed, their sole aim appears to be to cover the curriculum so that their students will achieve the highest grades possible in examinations, even by abandoning many of the practical classes if that should prove necessary." Dr Brian Iddon MP, January 16, 2008 (Dillon 2008 p10)

Because of the role of practical work in doing science, the concept that practical work is useful when learning science is often assumed. Some high profile individuals and organisations, without any background in science education, but money or a media mouthpiece, often assume that it is important but without a clear justification of why, sometimes referring to supportive experts. Lord Sainsbury wrote "In recent years, with the introduction of new science GCSE and A levels there has been an inevitable concern that the focus of schools on practical science could wane" (Gatsby 2017 p5). His comments and subsequent funding of a review of school practical work through his Gatsby Foundation lead to alarmist headlines like "High-stakes exams are preventing practical science work" appearing in the Times Educational Supplement (TES 2017). In Robert's report, a 2002 review into the supply of science and engineering skills to the UK economy, a major recommendation was that investment in school labs would inspire and motivate students to take these subjects further (Roberts 2002). The House of Commons Science and Technology Committee 2002 commented that: "In our view, practical work, including fieldwork, is a vital part of science education." A further Science and Technology Committee report in 2011 comes from a similar viewpoint proposing

spending on school science facilities and commenting “Science is a practical subject. If students are to follow a scientific career, either through university and on to research or to work in the new technological businesses of the future, they will need to understand how the knowledge and facts that they acquire in classroom lessons have been gathered and agreed” (House of Commons 2011 p3). A survey of 14-18 year olds’ attitudes and experiences of practical science by the Wellcome Trust they found “our data reveals a worrying variation in the frequency of hands-on work, with 29% of year 10 and 11 students saying they do it less than once a month. Half reported doing practical work at least fortnightly and we recommend this as an absolute minimum.” (Welcome Trust 2017). Why is the variation worrying and why is fortnightly an absolute minimum? Does an organisation with a clearly established view on an issue funding research which supports its own view add much to the debate?

To those who work in the field it is clear that the issue of practical work is not so simple, although it is widely accepted that practical work is important (Jenkins 1979), even by those who have challenged some of the conventional thinking around practical work (Abrahams and Millar 2008, Hodson 1994). However to simplify this down to a rule, as the Wellcome Trust do that practical work should be done every two weeks as a minimum, is naïve. This view is summed up by Professor Justin Dillon of the University of Exeter who comments "there is a danger that the rhetoric surrounding 'practical work' neglects important findings from research and ignores the complexity of several key issues relating to the teaching of science in schools" (Dillon 2008).

In a study of 25 science lessons in English secondary schools into the effectiveness of practical work in learning science found that many practical tasks lacked cognitive challenge and more time was spent ‘doing’ rather than learning (Abrahams and Millar 2008). The study analysed practical lessons

through a set of framework based on the idea that practical work involves students working in a domain of observables (objects, materials, phenomena) with the intention that this develops their domain of ideas (underlying scientific concepts). This is a distinction made by Tiberghien (, 2000) and is only relevant to practical work is being done with the intention of supporting theoretical concepts rather than developing practical skills and techniques directly. Lunetta argues that laboratory inquiry alone is not sufficient to enable students to construct the "complex conceptual understandings of the contemporary scientific community. If students 'understandings are to be changed towards those of accepted science, then intervention and negotiation with an authority, usually a teacher, is essential." (Lunetta 1998 p252). Essentially this means that the teacher needs to support the student in linking the domain of observables to the domain of ideas as students struggle to do this themselves. Using the domain/ideas framework Abrahams and Millar divided all the learning time spent in the 25 lessons into 3 categories which fitted into the domain/ideas framework.

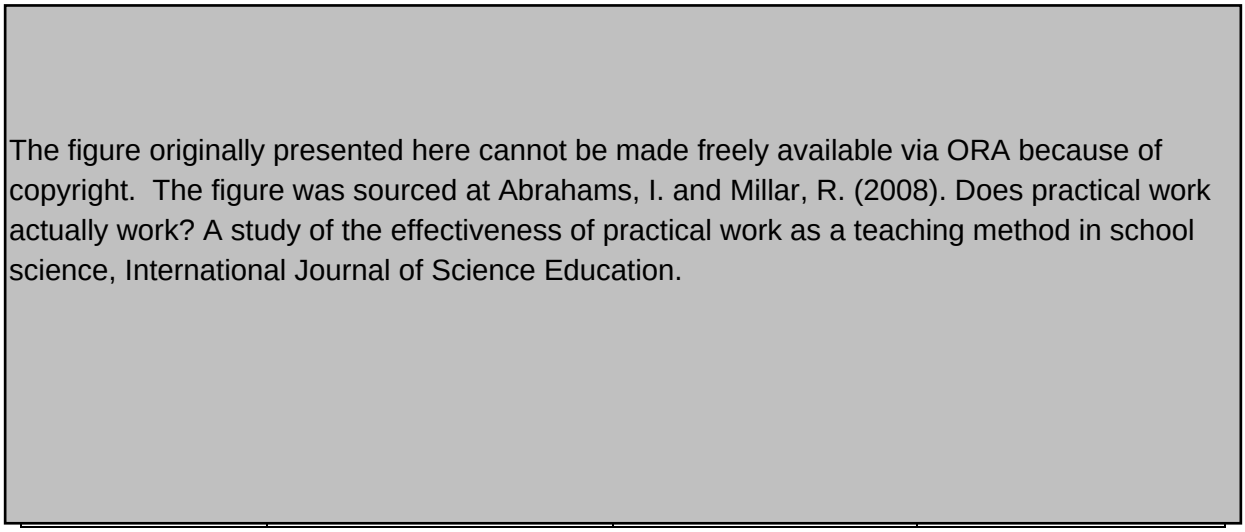


Fig 2: Summary of Abraham's and Millar's observation of 25 UK Science lessons, (Abrahams and Millar 2008).

This shows that a huge proportion of lesson time is spent on students "doing" but very little time spent linking what they have done to the underlying scientific ideas. The conclusion is that, if Lunetta is correct, a lot of practical work done in schools does not lead to students developing understanding

of underlying scientific concepts. That students should be thinking hard rather than just 'doing' to learn affectively seems uncontroversial and fits with the idea that tasks should be focused on the learning objectives. Millar argues that understanding the purpose of practical work in Science education remains a problem and this leads to an unclear focus from teachers potentially limiting the learning outcomes for students (Millar 1998). A further complication with practical work is that it is normal for teachers to assume that busy students are learning, teachers look for "off task" behaviour to identify students who are not achieving, or to use practical work as a tool to manage behaviour – keep students on tanks even if they are not learning (Swain, Monk & Johnson 2000, Wickman 2002, Bennett 2010 p29). As Abraham and Millar's study suggests that despite being on task students are not learning, it may be the case that teachers identify this lack of learning less easily than in non-practical lessons.

Although it is clear that experimentation is at the core of science and this study does highlight a good example of practical work enabling learning in their sample of 25 lessons these findings makes it clear that considering carefully why practical work is effective helps us understand how to use practical work effectively (or avoid using it ineffectively).

Why do practical work when learning Science?

Although it is often assumed that practical work is important in learning science there is merit in considering why this is the case as it might be productive in improving the quality of practical work done. In a response to a House of Commons Select Committee, the Science Community Representing Education (SCORE) break it down to 3 categories:

- to enable and enhance the learning of scientific concepts;

- to engender an understanding of the scientific process;
- to develop laboratory skills.

(House of Commons 2011 p8)

I will look at each of these separately and add a fourth, implied as relevant by some of the views discussed above:

- to improve student motivation & inspire further study of science

To develop laboratory skills: One of these reasons is that doing practical work develops practical skills as these skills are needed for employment or higher level study (Grant 2011,UK Commission for Employment and Skills (UKCES) 2015 p29, National audit office (NAO) 2018 p7, House of Commons 2011 p8). It helps to have a clear definition of practical skills but views on practical skills are surprisingly broad, with no agreed definition and quite a wide range of activities with differing aims and objectives covered (Lunneta & Tamir 1979). Not only is this unclear in schools, but the situation with employers is similar; some employers want generic skills associated with science but others want specific competencies (UKCES 2011 p5). Weaver argues that because of variation in what is needed between different employers the solution is for more on the job training and apprentices to develop the precise skills needed, which should be combined with better links between educational institutions and employers (Weaver 2017). Academic literature tends to include the idea that manipulating/observing real objects makes something a practical skill (Abrahams, Reiss & Sharpe 2013). Hodson takes this further, describing them as including procedural understanding and certain process skills which are 'generalizable, transferable from one context to another and readily applicable in any context without requiring conceptual understanding' (p?). He acknowledges that there may also be specific skills of observation and manipulation (i.e. use of specific equipment) but does not seem to regard this as a core practical skill (Hodson 1994). In their A level practical

handbook OCR state; “During the study of science, candidates are expected to acquire experience of planning, carrying out, interpreting, analysing and evaluating of experiments” (OCR 2017). This seems to some extent to tie into the idea of manipulating and observing objects and include the idea of general process skills.

The English National Curriculum, a common programme of study used in schools that is designed to ensure nationwide uniformity of content and standards, sets out to develop a range of practical skills. Labelling these ‘working scientifically’ they become increasingly complex as a child moves through their compulsory education (National Curriculum: Science 2015). Mastering these at each stage of the curriculum enables access to the next stage of curriculum. Universities want new students to reach a certain standard of practical work so that they can assume it as prior knowledge and plan their syllabuses accordingly and indeed expressed concern about a potential decline in practical skills when A level reforms were proposed. The vice chancellor of Brunel University, Julia Buckingham commented “Taking practical work out of A-level grades could see schools put less effort into teaching those skills, leaving undergraduates ill equipped to study science at university” (Adams 2014). This is a clear argument in favour or including practical skills in school science to allow students to access higher level study.

However, there are counter arguments to including practical skills in the curriculum for this reason. Although almost all who end up in research jobs have received extensive science education, the majority of those on even high level science courses do not end up working in a practical scientific field, with 40% of Science, Technology, Engineering and Medical (STEM) graduates not entering STEM based professions (UKCES 2011 p19). Instead these people are studying science for the transferable skills. So to what extent are the practical elements of a science curriculum

transferable? In the OCR A level Physics course some of the practical skills (given in appendix 1) are more transferable than others. For example "use of a signal generator and oscilloscope" (OCR 2016, p12), this does not have enormous transferability but would help students doing moving on to university level physical science courses. Other aspects such as "how to evaluate results and draw conclusions" (OCR 2016, page 9) is clearly far more transferable. Organisations pushing for more students to study STEM subjects often include it or something similar on a list of sought after skills STEM graduates have (Gaia 2018, Careerwise 2018). However these skills do not come under some definitions of practical skills (they don't require manipulation of equipment or observation). In fact these analytical skills could be developed using measurements made by someone else or in a non-scientific subject. If the aim of the practical element is just to allow students to do university level practical physics there is a risk of a disparity in transferability between practical and theoretical elements of the course.

Develop a better understanding of theoretical concepts: Observing phenomena can help with understanding, as early as 1855 it was argued that using practical work to show students *applications* helped them remember and understand theoretical ideas (Edgeworth and Edgeworth 1855). This idea comes up in other subjects through field trips which are often argued to be beneficial and enriching (Greene et al). In History when learning about castles many teachers will take students to a castle. In Geography when learning about geographical changes teachers often take students to see examples. Even in English lessons it is not uncommon for students to be taken to see a play when learning about plays. In Science education practical work as well as field trips are methods of giving students the chance to understand in a different way, making the abstract more concrete. A classic example of this would be dropping a magnet through a copper pipe to show Lenz's law. Students expect objects to fall straight through but instead magnetic objects fall far slower than nonmagnetic objects. Students are then led to the conclusion that the slowness of the

fall implies the presence of an additional force and through support from the teacher what causes the force, this leads to a better understanding of Lenz's Law. Woolnough et al claim both "being a problem solving scientist and getting a 'feel for phenomena'" (Woolnough et al 1985) as important reasons to do practical Science. It is accepted by parliamentary reports (House of Commons 2011 p8) and even those who question the conventional wisdom on practical work in science education acknowledge it is a reasonable argument (Hodson 1990 p34).

Like in any aspect of teaching practical work can be used with high or low effectiveness. Driver argues that practicals when students can't see the link between what they're learning about and the experiment being done doesn't necessarily progress understanding (Driver 1983). This would be backed up by Abraham's and Miller's study discussed above in fig 2. Teachers who are already aware of the link between a particular experiment and a theoretical concept have been shown to assume that students can see the link when actually they can't and although they do the experiment they don't always see the relevance (Lunetta et al 2007).

In my experience there are examples of phenomena that I find students understand better through use of simulations rather than actual practical experiments. An example of this is the photoelectric effect; a common experiment demonstrated in classrooms is to show the effect of high frequency light on a gold leaf electroscope. As neither the light nor photoelectrons are visible to the students observing the demonstration, it can be hard for them to understand the significance of the movement of the gold leaf. My experience has been that showing students a simulation first which makes the light and electrons visible help students understand the process, this fits with importance of visualisation in learning some aspects of science (Bleed 2005, McClean et al 2005). Mnguni et al argue that visualisation skills a very important in learning biochemistry (Mnguni et al 2016), some of

these skills may be applicable in understanding some physics process. There are increasingly views that this can be further developed through use of augmented/virtual reality (Saidin et al 2015). These ideas may fit with the argument (made by Lunetta and others above) that the key is understanding the link to a theoretical concept. If the simulation is more effective in allowing students to see the link to theoretical concepts than an experimental approach it may be more useful than traditional practical work. However, the use of both simulations and practical work should be designed to help develop students' understanding of the more abstract, theoretical ideas.,

To enable students to developing an understanding of scientific methodology: Another argument in favour of using practical work in science lessons is that it reflects the scientific method and shows scientific knowledge is based on empirical observations and analysis (House of Commons 2011). This is suggests students can develop understanding of how scientific inquiry proceeds and understand how scientists construct explanations of natural phenomena by replicating this process at school. However this is made complicated as there is no universal to science for school science to mirror (Chalmers 2006, Segal 1997). In many ways, much of school science follows a Bacon approach (emphasising the making of observations), rather than a Harvey approach (which focuses on identifying what observations need to be made). This approach is sometimes described by teachers as recipe style experiments, where students are simply following instructions in a similar way to when cooking (Baconist) rather than making the recipe (Harveyist). For educators, it is worth considering the extent to which students need understanding of scientific methodology to learn science, the eminent philosopher of science commented on scientists' explicit knowledge of their practices that 'most scientists tend to understand little more about science than fish about hydrodynamics' (Lakatos, 1970). It has been argued that inquiry could be learnt effectively through other subjects or even that practical work should be a subject in its worn right (Clarkson and Wright 1992). There is a question about how much time can be spent of understanding of methods at the

expense of understanding concepts which for some are the main characteristic of Science (Millar and Driver 1987).

This has some links to the idea of discovery learning where students are expected to observe and discover relationships/facts. Armstrong, an influential early science educationist, argued that a curriculum overloaded with facts was detrimental to student enjoyment and in training effective scientists. Instead he argued for learners to be able to see and understand how scientific discoveries are made which lead to increased inquiry lead teaching and pupil investigation (Armstrong 1903). Implementation of his ideas in the early 20th century English schools was quite rapid but the ideas were criticized, potentially due to issues with teacher training at the time (Jenkins 1979). Today aspects of his approach are still used, with students encouraged to reach conclusions based on observations made in practical work, an inductive approach. This technique has been criticized when over-used for providing a false view of science and overemphasizing the process at the expense of understanding concepts (Kirschner 1992).

Impact on student motivation: There is a general assumption that students enjoy practical work, this has been to suggest that more practical work in schools will lead to an increase in uptake of science subjects at university (Gatsby 2017, Kerr 1963). In this instance there is a firm research base behind the assumption, study after study has found students enjoy practical work (Woodley, 2009; Hampden-Thomson and Bennet 2013; Cerini et al., 2003, p. 10; Gerstner and Bogner, 2010) although far less work has been done on if this enjoyment influences their decisions to pursue science at university. It has been found that the students who enjoy practical work the most are those who have little interest in the science, focusing on these students may be counterproductive if the aim is improving university applications (Abrahams 2009).

Sometimes practical work is done to engage a student with a concenpt or make it relivent to them. Adey argues that simply making an idea more relevant to a student does not necessarily result in more learning (Adey 1997). Sharpe argues that learning is especially unlikely to be achieved when practical work is done to engage or mange behaviour arguing *"just because students find doing practical work 'enjoyable' does not mean that students will be thinking or learning about what they are doing, rather the opportunity to have the freedom of something different in learning science. In such a case, a possible purpose to enhance scientific knowledge via practical work seems difficult to attain."* (Sharpe 2012 p42). While none of these are saying practical work *can't* help learning they are all saying that learning is not an inevitable consequence of doing practical work. The underlying theme seems to be that students need to have a clear understanding of how the experiment links to the theoretical concepts.

Practical work is obviously not one single activity and different types of activity impact on student motivation differently. Comparative studies of student engagement in different forms of practical activity are more limited. In a study of undergraduate enjoyment of practical tasks it was found that enjoyment linked to the level of freedom given to students (Kohnle et al. 2012). However there is a negative effect on enjoyment when students do practical work which does not work as intended and giving them more freedom increases the chance of failure. In addition practical work can't be isolated from the topic it is being studied which also has a large impact on motivation. There is evidence that this can be mitigated by demonstrations from teachers enthusiastic about the topic (Murray and Reiss 2005) but demonstrations would not fit many people's definition of practical work. This suggests that different types of practical work can affect motivation in different ways. Although enjoying lessons can increase students' motivation to work and therefore improve their learning it is not the ultimate aim of education. Teachers therefore need to balance the time spent

on practical work with other activities carefully, especially if the aim of a piece of practical work is done to improve engagement.

Assessment of practical skills

A further challenge surrounding practical skills in Science is that even when you have decided what is relevant to the curriculum there is the question of how to assess it. As with any assessment it is important to be clear about what you are trying to assess and to determine an appropriate means of assessing it (Black and William 1998). Added on to this there is a problem that in the English education system, harsh accountability tends to mean assessment drives what happens in the classroom (ARG, 2001). Therefore when trying to redirect the focus of English education towards new priorities (practical skills), the changes to form of assessments need to be as clear as the changes to curriculum.

In a review of assessment of practical science in it was found that there is no established standard approaches and academic literature in this area is limited (Abrahams, Reiss & Sharpe 2013). Their study compared approaches used by different examining bodies in England for science and in countries which scored similar higher achieving in PISA science tests. They also considered how assessment of practical skills is done in non-science subjects in England. To provide a framework for comparison the study classified assessment techniques as either direct or indirect. Indirect assessments of practical skills (IAPS), such as traditional written exams and written work linked to practical investigations, (e.g. planning or evaluating experiments) fits in more easily with other assessment methods, but is limited in its ability to assess all aspects of practical work, (e.g. an accurate way to assess if someone can use a voltmeter is to observe them using one rather than ask them to write about how to use one). Direct assessment of practical skills (DAPS) such as having

students observed by teachers or examiners when doing laboratory work is used significantly less in UK science although is fairly common in high achieving PISA science countries such as China, Finland and Singapore. This suggests that an increase to DAPS would improve standards of practical skills in the UK. There is already quite a lot of DAPS in Music and MFL in the UK although these are subjects where the validity of assessments can be moderated easily through audio recordings; there is not an obvious equivalent for Science practical skills.

In many ways the updated A level curriculum shows good understanding of these issues, both universities and employers made it clear that they wanted higher levels of practical skills in school leavers. The awarding bodies responded to this by recognising that the decline in practical skills was linked to the lack of robustness in practical assessment, removing coursework and increasing the demand and robustness of practical skills in written assessments. They even introduced DAPS, through the practical endorsement which PISA tests shows is correlated to higher outcomes of practical skills. However the reforms then run into the accountability system in UK state education. It is has been argued (James 2005, Burgess and Ratto 2003, Burgess and Croxson 2001) that in public sector organisations with complex aims that performance targets linked to pay which have a narrow focus can lead to dysfunctional behaviour - behaviour which ensures the target is met but at the expense of the wider values and aims of the organisation. As pass rates have become part of teacher performance management in English schools, and this is linked to pay, teachers who 'mark harshly' are jeopardising their pay, careers and progression. It is possible they will find it difficult to be impartial in their assessments. In addition, the practical endorsement is only a pass/fail so therefore lacks the ability to differentiate between students, and as it does not contribute to the A level grade. That it lacks significance is backed up by SCORE's own, seemingly contradictory advice which says *"Asking for the endorsement alongside the main grade for A-levels in biology, chemistry and physics, ensures that students obtain the vital skills that practical science develops"* but goes on

to add *"The SCORE partners would encourage you to distinguish between public statements of admissions policy, which we strongly recommend should refer to the need to pass the endorsement, and any individual student who may have failed to achieve the practical element…"* (SCORE 2015 p4). Essentially this could be interpreted as telling universities to say it is important but overlook it if convenient.

The burden of improving the practical skills therefore falls on to indirect assessments of practical skills (IAPS) which, in the current curriculum, take the form of written exams. This is much less of a reform than many envisaged when changes were consulted on and potentially falls into the trap being "a system so dominated by summative assessment that chance to experience and develop practical skills is very limited" (Keiler & Woolnough 2002). Previous studies found that the problem with IAPS were that it was difficult to assess a wide range of skills:

"the current model of assessment of practical skills and abilities, with written examinations questions on practical work examining only a very limited range of abilities" (Bennett and Kennedy 2001).

Can the new IAPS be designed in such a way as to mitigate these problems? An early study comparing the last cohort to do the pre-reform A level to the first cohort to complete the reformed A level found no significant difference in their practical skills in Physics (Ofqual 2018 p4, Schoolsweek 2018).

Impact of assessment on motivation: My anecdotal view was that when the PE was announced it was fairly a common view among teachers that the new 12 core practicals were mostly experiments that you would do anyway (under the old system I did most of core experiments to support learning)

and that the changes were therefore not that significant. However this assumes that assessment element won't impact on students ability to learn while conducting the practical's.

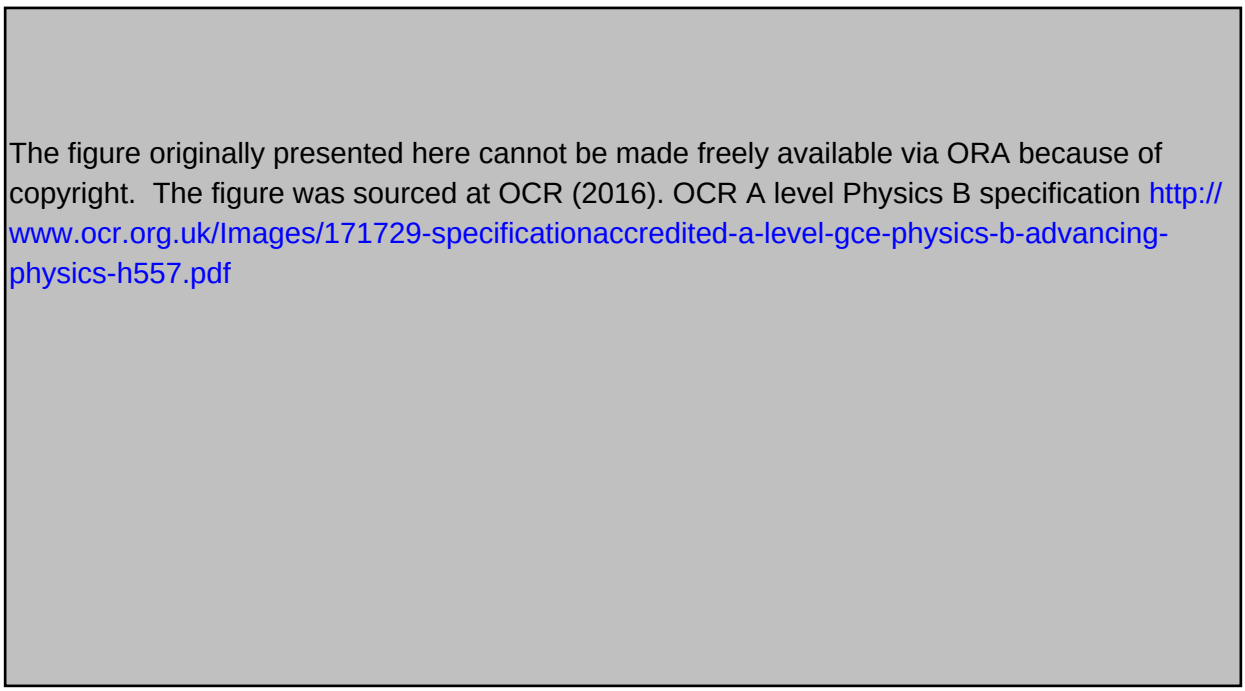
In their seminal work on formative assessment Black and Wiliam point out that *"The ways in which assessment can affect the motivation and self-esteem of pupils … deserve careful attention."* (page 3) and "*As researchers the world over have found, high-stakes external tests always dominate teaching and assessment*." (page 4) (Black and Wiliam 1998). They make the argument that formative assessment, that is assessment which informs learning through modifying the subsequent actions of teachers or students, improves outcomes but that summative assessment, that is assessment which purely measures learning does not. The practical endorsement taken in the form of the resources provided by exam boards would be seen as very much at the summative end of the assessment spectrum. It is high stakes and external. Students are given prescriptive tasks and judged in a binary, pass/fail way on large number of narrow criteria. Feedback to students beyond what has been passed and what has been failed is not a requirement and students are not allowed to modify work which has been assessed (although they may be assessed on the same criteria in the context of another experiment). It is possible some students approach this with a similar mind-set to an external exam. Unfortunately with there being 12 core practicals, each taking a couple of hours, they are far more time consuming that external exams and teachers can't afford to fall into 'assessment mode' and disengage from learning.

In a study comparing methods of assessing 5th grade science students (clearly not the best comparison for A level Physics) it was found that students being assessed through highly structured lab work had the lowest motivation, goal orientation and increase in scientific knowledge compared to more open practical investigation (2nd) and pen and paper testing (1st) (Stefanou & Parkes 2003). The core practicals set by the exam board (they can be modified) would mostly fit the description of 'highly structured'. Could the change of practical work from a learning activity to an

assessment affect students' ability to use practical work to support learning theory or impact motivation? This is likely to vary from student to student and how teacher influence their perception of the assessment.

The Changes to A level Physics

What exactly is it that students need to be prepared for? As mentioned initially, under the old system practical assessment was not part of the terminal assessment, it only needed to be understood sufficiently to do the prescribed task, now students need to apply their knowledge to the greater range of possible questions and to retain that knowledge for the terminal exam. OCR break down the practical element of their specification into skills that will be assessed in the exam and skills assessed in the practical endorsement. Both of these sections are then broken into planning, implementing, analysis and evaluation skills. Below are the skills relevant for the terminal exam.



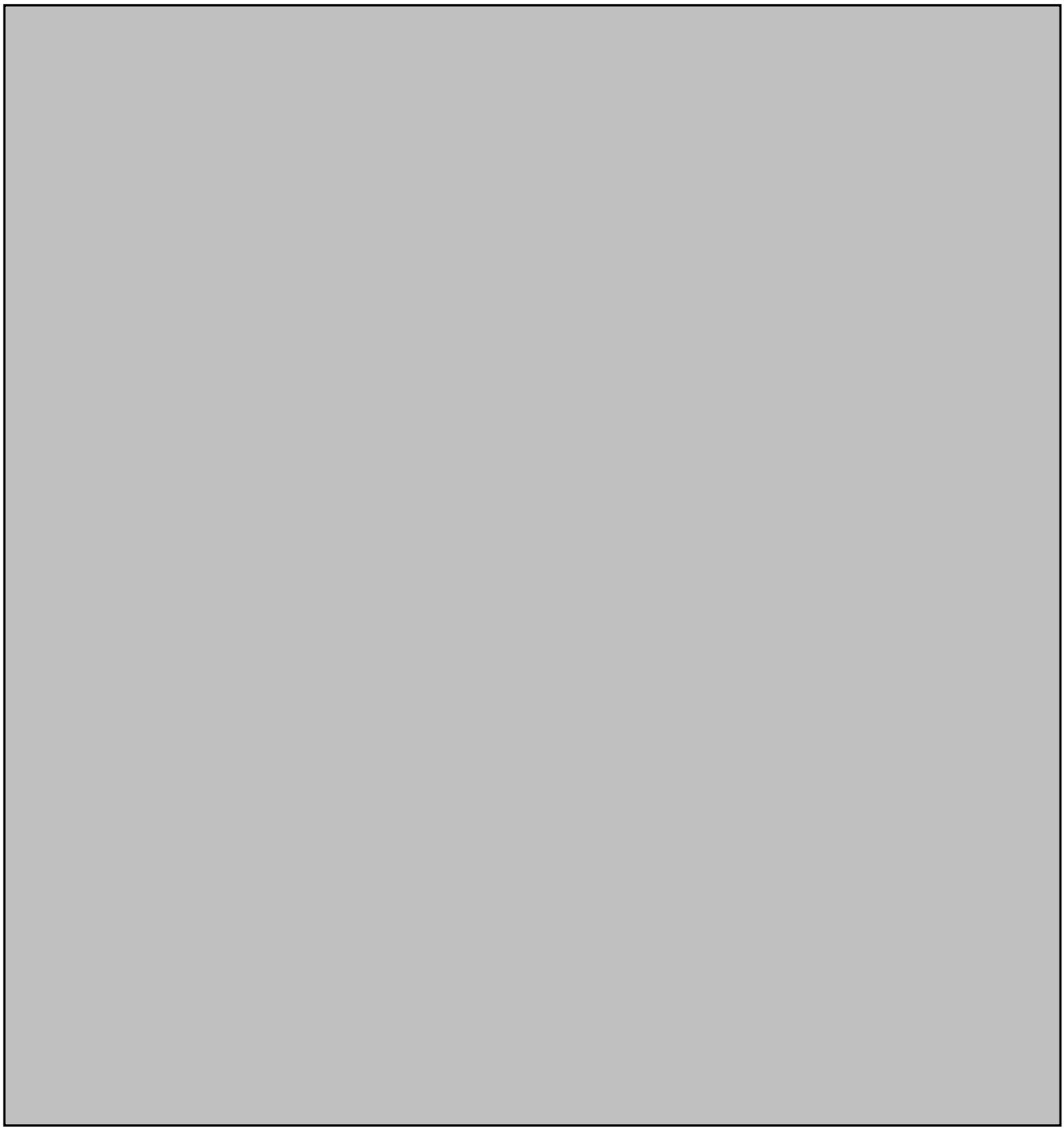


Fig 3 practical skills that can be assessed in the exam (OCR 2016)

Perhaps as a consequence of practical skills being procedural and applicable to many situations these skills are all rather broad. This makes them difficult to interpret with several of them being so broad they could describe relevant learning focuses for students from key stage three to undergraduate level. I think it would be not be possible to work out what to teach without seeing examples or being familiar with what was expected of students in the past. So what are the relevant sources of information that can be used to interpret this specification? I feel that the specimen

papers provided by OCR are probably the single most useful thing, as these show how the examiners envisage the new papers although they have less quality control or development of mark schemes than papers used for real assessments. I also think some of the old specification papers are still useful, as although the mode of assessment has changed, much of what is being assessed has changed far less. Looking at what was expected of candidates in terms of specific skills (eg graph drawing, mathematical analysis, and uncertainties) and ensuring they meet those standards is likely to mean they still meet the standards of the new system. In addition to this sharing ideas and resources with other teachers will, as always, be important. Seeing how they interpret the requirements and comparing that with your own interpretation either enforces what you are doing as being correct (justifying spending time on it) or makes you think about things you should be doing or are currently doing but may not be important. This can take place at a number of levels, firstly inside the department, with colleagues in local schools and at a national level online.

Methodology

At the start of the project one of the anticipated outcomes was that I would be developing a sequence of lessons to deliver practical skills. Having looked at the issues in literature the next step to doing this effectively is to understand the current practice in my school, and the attitudes of staff and students. I have broken my original aims into 4 more specific research questions to help me focus my work.

1. What are teachers' and students' attitudes towards practical work and its assessment?
2. What effects does a sequence of lessons on practical skills have on students' learning?
3. What effects does a sequence of lessons on practical skills have on students' attitudes and motivation?

To answer these questions I will be collecting data from a range of different sources in order to make decisions about how to structure this work. These will include teacher interviews, students' surveys, students' assessment, observation by colleagues and possibly student interviews.

Research model: As I am developing a sequence of lessons that only happen once a year I don't feel that a cyclical form of research would be suitable, there is not chance to reflect on and develop the implemented changes. Instead I have a specific problem, which I need to understand clearly though gathering data from a range of different sources which will take several different forms before taking action, for this reason I feel that practitioner research is most suitable (Kara 2012). A disadvantage in this approach is that it limits the opportunity to reflect on and modify approaches made and will require me to remove initial preconceptions but I feel it is the most appropriate for my problem.

Ethics: The first stage to ensuring the study was conducted ethically was to seek permission from the head teacher to do the work within the school. In doing this I set out that all data would be anonymized, that students would not be doing any activities outside of the normal and that staff and student involvement would be optional at each stage and participants clear about how the data collected would be used. There are a range of different research methods being used in my work and the ethical implications of each of them are discussed in more detail when each research tool is introduced, all received curec approval.

Teacher interviews

I need to use the ideas raised by the literature to improve the practical skills of the students at my school but many of the ideas raised in the literature are generalised, overall trends. Not all of the ideas above refer directly to A level Physics, an urban school with a diverse intake or even the English education system. In any 'overall' situation there will be outliers and anomalies. I hope that talking to teachers and getting their opinions, informed by their experiences at my school will help me understand how the ideas in the literature relate to my context. With the consent of the teachers I plan to conduct these as informal interviews with a set question list but the flexibility to explore any relevant ideas the teachers raise in their responses. I will do the interviews as individual 1-1 interviews as I want to get the views of each individual without there being the temptation to simply echo what is said by others.

There are of course ethical considerations when performing such interviews. The head gave approval for the research in response to a formal letter (see appendix 2) and teacher participation was optional, again sought by a formal letter (see appendix 3). Teachers further had the option not to have interviews recorded but all chose to do so. There is a question of the power balance (I was Head of Science) and to what extent teachers felt free to turn down the invitation to be part of the

study. To mitigate this it was made clear that responses would be anonymised, including not attributing comments to even anonymised teachers in the analysis (with only 3 teachers in the department it would be too easy to attribute comments to an individual) although this will limit the impact of the analysis. As the aim of the work is to help the department improve the delivery of practical skills – something which all regarded as a development priority there was a willingness to participate in an open way. This approach was CUREC approved.

Questions: While I had some set questions to ask I was keen to follow-up any relevant points the teachers raised so the interviews were semi-structured. For this reason I have put the 9 questions (see appendix 4) into 6 categories which relate to different aspects of the literature so that I can explore teachers' views of each aspect raised by the literature (shown in Figure 5). When analysing, I will use these 6 categories rather than the 9 set questions at it should be easier to incorporate the follow up questions into the analysis.

Analysis of the teacher interviews: For each category, relevant teacher quotes will be listed and then discussed the quotes in relation to the literature, before listing key points to be considered in the next stage of the research (see Figure 4).

Category title

- Anonymous teacher quotes

Discussion of issues raised by teachers.

❖ Core idea/summary of a key point.

Fig 4 – Format for the structure of the analysis of the teacher interviews.

Focus	Questions	Reason for asking the question
The importance of practical work	*1)To what extent do you feel it is important students do practical work when learning A level Physics?*	This is the initial question and gives an early indication of how the teacher views purpose of practical learning which is an important when considering their responses to further questions. The four ideas suggested in the literature for doing practical work (scientific method, lab skills, enhancing understanding of theoretical concepts & motivation) may have different importance's in Physics A level compared to Science as a whole so it will be interesting to see which of these they emphasize.
The challenges of practical work	2) What are the challenges you face when doing practical work? 3) What are the aspects of practical work which most challenge students?	Both of these questions relate to similar ideas but are asked as separate questions in order to get the interviewee to consider the both role of the teacher and the student. Essentially this question is trying to invite open comments about the difficulties with practical work. The idea being that to improve something it is important to understand its problems.
Assessed practicals	4) In what ways do you approach assessed practicals differently to other practical work? 5) In what ways do students approach assessed practical differently to normal practical?	Again these questions are focusing on the same idea but broken into a teacher and a student version. One of the problems we have in the school is that the assessed practical's (forming part of the practical endorsement) take a lot of time and it is important to make sure these are as beneficial to learning as possible. To do this understanding the differences is important.
Student motivation	6) To what extent do you feel practical work affects student motivation?	When looking at the literature the idea that practical work inspires/motivates/engages students came up several times. By identifying common motivating themes it could help come up with a better approach to practical work.
Key aspects	7) How do you ensure that students are learning practical skills required for the exam when doing practical work? 8) How do you ensure that students are able to understand how the practical work links to theory they have learn?	These two questions relate to the two of the four literatures identified reasons to do practical work which are directly assessed in A level Physics. The aim of the question is to be open and lead to a discussion of learning and teaching strategies' that relate to these two ideas.
Assessment	9) How do you check students have learnt what you wanted them to learn when doing practical work?	This aims to be open and lead to a discussion of assessment in practical lessons, current practice and its challenges.

Fig 5 – Interview questions for teachers and the reason for each question.

Importance of practical work

- It's really important that is what physics is.
- Practical work is at the core of physics.
- If they don't do it they won't be able to cope with labs at university
- Students do less work with their hands in everyday life than in the past, maybe practical work helps develop these skills.
- It can be quite time consuming and takes time away from the rest of the curriculum, eg developing mathematical skills for problem solving, I am not sure the balance is currently correct.

From this it is clear that the teachers consider practical work to be important for two of the four reasons mentioned in the literature. Primarily because of the role it plays in physics which would fall under 'engender an understanding of the scientific processes'. Secondly the idea of developing practical skills is referred to, interestingly both in terms of preparation for university lab work and as being generally useful. This is not really mentioned in the literature but would be a counter argument to the idea that practical skills are only useful to those going on to specific areas of further study or employment. The idea of embedding theory and student motivation are not raised here and could therefore be ideas worth discussing if it is concluded that changing teacher attitudes is an important part of developing practical work in the department. The issue about the balance of practical skills taking time away from other aspects of the curriculum was only raised by one teacher but is an interesting one and is not discussed in the literature. From the literature it is clear that UK does more lab based work than many other developed education systems (Nott 1997), although there is a question about how effective this practical work is and if it is the best thing for students (although beyond the scope of this work).

- ❖ It is clear that the department is commited to promoting the importance of practical work in A level students.

Challenges of practical work:

For students:

- Not thinking about what they are doing. Leads to them making mistakes and having to redo things which they find frustrating. They can make small mistakes which are difficult for teachers to notice but have a big impact (eg electricity).
- It is hard to link what they have done to the theory so they end up following a recipe and can't or don't bother linking to the theory. I am thinking I need to make more of an effort to set a problem in the context of the practical to help them make the link.
- They can focus on seeing the practical work just as an example of theory and not engage with practical skills

For teachers:

- Getting the balance right between telling them what to do so they don't make mistakes and letting them get on with it so that they can work things.
- How much detail I should I go into when explaining before the experiment? How should I balance that with the need for students to follow instructions?
- Sometime you just need to get the practical finished maybe to show an effect or so that students can do some analysis and it can feel like the practical element is just students following a recipe.
- Timing can be hard to manage, students work at very different rates and this can be exacerbated through problems with equipment.

All of these points are in many ways linked, with the issue being how much the students are thinking during practical work. From the teacher side the idea of a balance between allowing students to make mistakes and learn from those mistakes vs supporting students so that they can complete the work and learn from the completed experiment is mentioned. This idea comes up in the literature

as well althought framed in a different way. Lunetta talked about the idea of students needing to be taught how to link what is observed in the lab to theoretical concepts (year). Abramhams and Miller's research (year) showing that a lot of practical work lacks cognative challenge and emphasises the doing of work rather than the thinking about concepts. It seems that in our context this element of the literature is very much about balancing the cognitive challenge of doing the practical work with the need to get the practical work 'done' to learn from the results or follow up analysis. The teachers seem to be grappling with the following dilemmas: At times if the 'doing part' of a practical is not crucial to the learning objectives is it ok for students to follow a recipe? Is there a good approach to balancing the need for students to be challenged by 'doing' the practical work and still get results that support the theory? To what extent can we solve these problems with more differentiation in practical work? These suggest the following implications:

- With a limited amount of lesson time we need to be more critcal in deciding when we will allow students to investigate freely and learn from mistakes and when we need to support them to learn.
- When the practical work is being done primarily for the results it produces or to learn from analysis, teachers need to be clear that it is ok to support the struggling students in order for the lesson to move on at a quick pace.
- Students need to be clear about practical learning objectives and teachers need to assess that these have been met.

The differences between assessed practicals and other practical work:

For teachers:

- I give more guidance about things to check before the experiment starts to offset the reduced support during the experiment

- Lack of support during the experiment leads to more mistakes which mean students get poor results and are demotivated by the end.
- I would give more help if I wasn't limited by the rules of the core practical if I could. I probably give more help than I should as I want the students to learn but I don't mark them down for this as much as I should. The administration of it is a hassle.
- As a new teacher I don't do much practical work. When I do non -assessed practical I tend to do it in the same way as the assessed practical so that I can practise getting the systems right.
- The core practicals are long and it can be difficult to fit them into a lesson. There is an issue of time and as students work at different speeds
- Because the practical endorsement pass rate is part of my performance management it is difficult to be impartial.

For students:

- Last year students didn't like practical work because they knew it was assessed and were scared of it. They thought there was a lot of pressure and asked at the end if they passed and it shouldn't be about that. This year *(we haven't discussed the practical endorsement)* they haven't taken it seriously enough, partly because I haven't driven home the practical learning as being important. How you frame it has a big impact and I haven't got that right yet.
- They know the lab book is important and no matter how much we tell them not to, some waste a lot of time on its presentation.
- There is anxiety about the assessment aspect among some students

These responces are largely negative about the core practical system. From the teacher perspective there is concern that the limited support that can be given in the assessment limits the learning oppertunities. This is leading to teachers to adapt their approach by giving some of that support before the assessment starts but also acknowlegement that to maximise learning they are bending the rules a bit. This is agreeing with Lunetta's argument that for students to link lab phenomena to theory the teacher has to play an active role and that the requirements of the core practical are preventing this from happening as effectivley as possible. A counter point would be that the teacher should just be marking the students down as not meeting certain criteria when support is being given. However this ignores the grey area where judgment is needed when assessing competancies as either pass or fail. It could suggest that the teacher feels pressure to ensure students pass which would fit into the idea of public sector incentives causing dysfunctional behaviour raised by Burgess and Ratto, (assuming that overly generous assessment counts as dysfunctional behaviour). The national pass rate for the first cohort to sit the practical endorsement was 99% (Witter 2018 p4) which is very high. This might suggest that the award does not discriminate effectively or teachers at many centres are also under pressure to ensure students pass rather than assess meaningfully. However it may be that it was designed to be a sort of standard everyone was expected to reach, so the high pass rate was expected. If it is supposed to be a discriminatory assessment having such a high pass rate means achieving pass has little meaning, what does a qualification mean if everyone has it? This is further brought into doubt by the comment from a teacher responsible for the assessment that it is difficult to be impartial due to the pass rate being linked to performance management (which is linked to pay progression). This backs up the ideas of James, Burgess, Ratto and Caxton in the literature about narrow performance targets in organisations with complex aims.

- It does seem that the assessment aspect of the core practical is getting in the way of learning and we need to consider how we as teachers approach the practical endorsement to maximise learning and influence how the students perceive it.

In addition to this teachers are raising concerns about the timing of practical activities and administration of core practicals, with new teachers feeling they need to do all practicals in this way to practise complying with the regulations. If the first part of the teacher comments is correct this is getting in the way of learning.

- Some of this might be solvable with better training on how to conduct core practicals for new and inexperienced staff and a more organised departmental approach to catch up on unfinished work.

Teacher thoughts on how students approach core practicals refer to a change in departmental approach between the year 12 and year 13 cohorts. The older cohort were told about the assessment and some of the requirements that they needed to be aware of, this led to some students fearing the assessment and becoming less open to learning but producing work that was good evidence of their practical skills. This fits with what Black and William have highlighted when considering the problems of formative assessment and how it affects student motivations and attitudes to learning. In response to this with the following cohort were not told about the practical endorsement directly, instead trying to conduct the formal assessments aspect in a more subtle way in lessons which obsessively were no different to practical work conducted purely for learning reasons. This solved the fear of assessment issue but lead to some students taking the work less seriously than is needed to pass the practical endorsement. Other students had bits of information from other sources (friends in other schools or doing other science subjects) causing some awareness of the practical endorsement but without full understanding of what was required. This lead to a small number of students obsessing over their lab books, believing that everything in it had to be perfect which is not useful to their learning or important to passing the practical endorsement.

- ❖ Getting the balance between students understanding the assessment requirments and the need to learn while doing practical work is difficult and we don't yet have it correct.

Motivation:

- They don't like it, I think it is important for them to keep going at things they don't like.
- They think it doesn't work and they think it is boring, I don't know if that is about school based practical work, possibly a legacy from GCSE where practical can be limited by class size.
- They like demos
- When you have a whole big process that they have to go through they don't like it.
- A handful of them are really pleased when they get a good value. For a lot of them it's about 'getting the answer'. A lot of them don't like the idea of more open ended work and are unwilling to try something and see what happens.
- They can get the same amount of motivation from a quick demo. The practical work they can quite like but they tend to find the analysis a drag.
- They lose enthusiasm for practicals as they get older and are certainly less wowed than younger students. I don't think it inspires them but it is important to do as it is such an important part of Physics.
- For KS3 it is a good thing to incorporate demos and practicals to break up long lessons and provide variation in the activities, I don't find this so much in KS5.
- Some students who are not interested in practical go off task, so there are challenges to manage behaviour.
- Younger classes are more engaged with it, there is more of a sense of wonder. In Y12; some are engaged, some are frustrated, some feel I can't do it I don't like practicals.

From this it is pretty clear that with the exception of demos practical work is not an important source of motivation for students in our key stage 5 classes. This is at odds with the a widely held view from the literature but the teachers are acknowleging that their experiences with younger students (at other schools, I work at a sixth form college) are different. This fits with the Abraham's study (year) showing that the motivational effect of practical work had the greatest impact on students who did not like science, as the A level course requires students to choose to study it is reasonable to assume that most of the students who were motivated by practical work opted for other courses. It is clear that our students find demonstrations are engaging. It is also clear that some students like getting the right answer but are demotivated by practical work that 'doesn't work'. Whether the answer to this is to design experiments that work more reliably (not really the point of science) or change the mindset of science (something harder to do with 17 year olds than 11 year olds) is unclear, this also links to the comment that the range of experiances our students have with practical work before joining us has an influence on how they percieve practical work.

- Use of demos is a good way to motivate and engage classes

Key aspects of learning while doing practical work:

Learning of practical skills:

- Rigid instructions for what needed to be in the post experiment write up to ensure they did the things that needed to be practised. It can be difficult to get all students to complete the write ups to the best of their ability as they don't see it as important. It is not part of the practical endorsement, when they have got the 'doing' part of the experiment done some think it's finished.

- Checking they are completing the analysis and doing some of the lab book basics right. I am increasingly spending more time teaching them how to analyse, it seems that the majority of the practical skills they need are analysis.
- When we did practical skills at the start of Y12 students found it very boring and it made a negative first impression of Physics. Doing practical skills without a clear context did not work.
- Interspersing practical skills throughout the theoretical topics has made it hard to ensure students focus on the practical learning objectives.

Linking practical work to theory:

- I find this much more effective through demos. I can use lots of questioning to lead students through the thought process that links the observed phenomena to the theory. I think they learn more from this & it is quick**er**. The assessed practicals get lost between supporting theory and practical skills.
- This is the most important reason to do practical work and it should happen after the theory has been introduced. I have started to do more demos and I think this has really helped students understand theory, far more than doing the core practicals.

Teacher responses in this area are limited, supporting the idea that it is not a strength of the department and therefore a good focus for this project. To develop practical skills teachers are focusing on the post experimental work, particularly as much of the examined practical skills are analysis based. However there is acknowlegement that not all students are doing this to the best of their ability, partly as it is being done with the practical endorsement experiments but not directly assessed in the practical endorsement and partly as some students see the practical as done once the experimental work is complete. This seems to be a problem not understanding what it is they need to learn, similar to the idea above that students need a good understanding of assessment

criteria and learning objectives. Teachers are also raising issues around how we are structuring practical skills in the course and how students perceive the importance of practical learning.

- ❖ Students need to have a better understanding of the requirements of the course and teachers need to raise expectations for post experimental work
- ❖ How we fit practical skills structurally into the course needs to be reconsidered.

With regaurd to using practical work to link to theory it is clear that teachers see this as important but the regulations around core practicals make this difficult and that demos (which don't fit most definitions of practical work) are the most effective way to do this. This further backs up the ideas of Lunetta et al as discussed in the literature above.

- ❖ Use of teacher led demos helps students understand the links between observed phenomena and theoretical concepts

Assessment of practical work:

- In the core practicals I used a grid of the student names and the practical compertancies and record which students havn't met a particular skill
- As most of the 'practical skills' for the exam are analysis based post follow up Qs in lab books or even just problem sheets are used for this. It doesn't need to be linked to an actucal experiment students have done although experimental work is a good opportunity to practise these skills.
- We had the monitoring visit for the practical endoremenet which was passed so I suppose we are doing that assessment well, the assessment of practical skills needed for the exam is more difficult and I don't feel that it is best done during practical activities.

- Beyond reviewing the lab books it is quite hard to assess learning in practical lessons, a lot of the normal AfL techniques need a lot of addapting and the varying time taken by students to complete pracitcal work can make it difficult to have a fixed plenary completed by all at the end of the lesson, esspecialy in assessed practicals.

Two of the comments here refer to the the assessment for the practical endorement and imply that teachers are comfortable with how to assess this (although there are expresssions of frustration with some of the requirements in the comments above). The two other comments about the exam assessed practical skills imply that assesseing these is difficult in practical lessons. Marking of lab books happens but some of the normal assessment activities are not occuring in practical lessons meaning that teaching of practical skills is not informed by assessment as robust as in normal lessons.

❖ There needs to be improvement of assessment of the exam based practical skills.

Collating the key points

❖ Students need to have a better understanding of the practical skills requirements of the practical endorsement and exams and teachers need to raise expectations for post experimental work
❖ There needs to be improvement of assessment of the exam based practical skills.
❖ Use of teacher led demonstrations helps students understand the links between observed phenomena and theoretical concepts
❖ Use of demonstrations is a good way to motivate and engage classes
❖ Getting the balance between students meeting the PE requirements and the need to learn the exam assessed skills while doing practical work is difficult and we don't yet have it correct.
❖ Improved better training on how to conduct core practicals for new and inexperienced staff and a more organised departmental approach to catch up on unfinished work is needed.

- The assessment aspect of the core practical is getting in the way of learning and we need to consider how we as teachers approach the practical endorsement to maximise learning and influence how the students perceive it.
- With a limited amount of lesson time we need to be more critcal in deciding when we will allow students to investigate freely and learn from mistakes and when we need to support them to learn.
- When the practical work is being done primarily for the results it produces or to learn from analysis teachers need to be clear that it is ok to support the struggling students in order for the lesson to move on at a quick pace.

Delivering practical skills for the new A level syllabus

Ethical considerations: Like the teacher interviews the research with students received CUREC approval. The information gathered from students includeds test data and student self reflections on their understanding and attidtudes to practical work, nothing more than is normal for a teacher to gather, which limited the potential issues. The head teacher consent covered research with students as well as the teacher interviews discussed above. The data gathered was stored electronically in accordance with the data protection act and hard copies destroyed after use. All findings and analysis in this assignment have been anonymised.

Surveys: I began my research with students by doing a survey (see appendix 5). Having got the views of teachers I felt it would be useful to compare what they said to what students said. If the two agree this increases the reliability of any conclusions/next steps based on what has been said. Additionaly this further helps me understand the ideas raised by the literature in the context of my school, hopefully making the new practical skills programme more effective. After looking at ideas

on survey design I decided to use an anonymous survey with the students to improve the honesty of their answers and to use a scale which removed neutral options (they had to agree or disagree with each statement) both of these are common practices in survey design (Nardi 2006, Alreck and Settle 2004). Students were given 10 statements (labelled a to j below) and asked to rate them anonymously on a 1-4 scale from 1 strongly disagree, 2 - disagree, 3 - agree, 4 - strongly agree.

Motivation:

a) I enjoy doing practical work
b) The opportunity to do practical work was a reason for me choosing A-level Physics
c) The opportunity to do practical work would make me more likely to choose a subject at university

These three questions relate to motivation. As discussed above some of the literature shows that some hold a view that practical work is motivating and promotes uptake of science beyond school, both b) and c) are designed to test this. Teacher interviews suggesting that student attitudes to practical work are at best mixed in my school, a) is designed to test this.

Learning:

d) Practical work helps me understand theory I have learnt in class
e) We have done too little practical work so far in Physics A-level
f) Practical work is time consuming and not a good use of class time
g) I learn something new when doing practical work in class
h) I have been taught practical skills in some of the experiments I have done this year

These five questions relate to learning. Both d) and h) are about two of the three main reasons to do practical work given by the literature: developing skills and supporting the learning of theory. The third idea about understanding the scientific method is not emphasised by the course or developed formally in lessons so I decided not to include it to avoid any confusion on the part of the students. The questions e), f) and g) all relate to the idea of ensuring learning is happening during practical work, mentioned by Lunetta and Abrahams in the literature. It was also raised in the teacher interviews with questions raised over to what extent it was ok for students to 'follow recipes' and to what extent practical work is supporting learning.

Assessment:

i) I understand what the practical endorsement is

j) I am aware of how practical skills are assessed in A level Physics exams

Both questions relate specifically to the changes made to how we get the students to think about the practical endorsement. As mentioned above initially we told students about the practical endorsement requirements to ensure they had the best chance of meeting them. Students thought it was a lot of pressure and we were concerned that the summative assessment was limiting learning, as discussed by Black and Williams. The following year we haven't discussed the practical endorsement at all, instead doing the assessments subtly in practicals that the students would see as normal learning activities, this reduced the assessment anxiety but some students have taken practicals less seriously. The teacher interviews make it clear that neither approach is perfect and we don't have the balance between balancing assessment anxiety with ensuring students take it seriously correct. In these questions I looked at how aware students are of the PE and exam assessments, despite the lack of information from teachers.

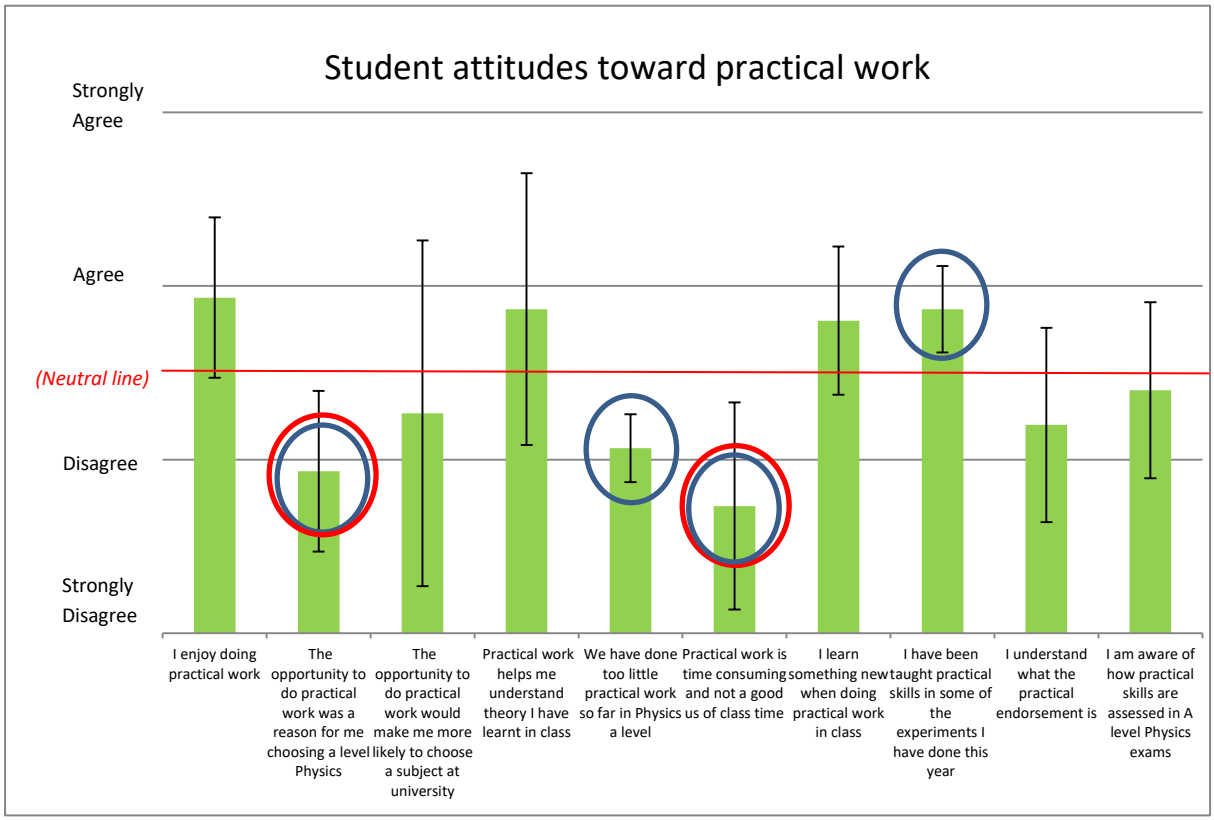


Fig 6 – this graph shows the self-reported attitudes to aspects of practical learning and assessment in A level physics in a sample of 17 year 12 students. The 1-4 scale is defined above. The red line indicated the neutral point of neither disagreeing or agreeing.

Students answered this survey in January 2018 at the beginning of their second term of A level Physics, shortly after ethical approval was given for the study. The 15 students had all previously studied at different secondary schools up to GCSE level and their differing experiences at secondary school are likely to still be significant influences on their perception of practical skills this early into their A level Physics course. At the point of completing the survey students had not completed any assessed practical work in Physics (although those studying Biology and Chemistry had done some in those subjects). The class had completed a number of experiments whilst studying electricity and forces and motion. They had also observed many teacher demonstrations when studying waves and

quantum effects. The error bars represent the variance of student responses: small error bars shows many students gave similar answers, larger error bars indicate more diverse answers. Eight of the ten questions have an average responses between disagree and agree, the two circled red, didn't). Only four of the ten questions have a range (average response plus or minus variance) which is closest to strong agreement or disagreement. I drew a neutral line halfway between agree and disagree. Only four of the statements gave a significant agreement or disagreement in their response, where the full range of expected answers does not cross this neutral line (circled blue). This shows that the most statements did not lead to many strong agreements or disagreements and opinion was often split.

Motivation: At first glance the motivation questions give responses inconsistent with each other. The statement " a) I enjoy doing practical work" had the highest level of agreement (mean response) of all the statements but the range of answers given mean some students agreed strongly and others disagreed. The statement "b) the opportunity to do practical work was a reason for me choosing a level Physics" was the second most strongly disagreed with statement and was significantly negative (full range below neutral line). The conclusion to this is that most students enjoy practical work but it was not a factor in choosing Physics A level. This disagrees with some of the proponents of practical work in the literature e.g. parliamentary reports or Gatsby but is consistent with the teacher interviews. The conclusion for my practical skills programme is that I do not need to be overly focused on improving student outcomes by improving engagement, students broadly like practical work. I will look at how this has changed after the programme is complete.

The third question "c) the opportunity to do practical work would make me more likely to choose a subject at university has the largest range of all the statements. This question directly relates to

ideas that a way of improving the uptake of STEM is to improve students' access to practical work. Finding this particularly interesting I went back to the class – repeated this question and asked students to state their university choice to see if there is a link. The results can be seen in fig 7 below.

Student answer	Chemistry	Medicine	Physical Science	Engineering	Maths	Computing	Other
Strongly agree		1		1			
Agree			1	2		1	
Disagree	1	1		1	1		1
Strongly disagree		1	1		1	1	

Fig 7, the opportunity to do practical work would make me more likely to choose a subject at university – breakdown by most likely university subject.

This survey suggests that there is no clear link in the availability of practical work and reason to choose a subject at university, with the possible exception of those considering engineering, this would disagree with some of the literature arguing for more practical work in schools to promote uptake of science subjects. However due to attendance issues on the day this data was collected the set is very small which severely limits the ability to draw conclusions and as these are first year A level students the university subjects are only a 'most likely' choices, for some students these choices are very likely to change. As the link to university subject was not part of the original survey and completed later it is possible some students changed their answers, and that due to student absence a small number of participants changed. The average answer is unchanged so there is likely little change.

Learning: Two of the learning statements are closely linked to motivation and both give significant disagreement responses. The statement "practical work is time consuming and not a good use of class time" was the most strongly disagreed with statement which means I felt that I did not need to worry too much about overdoing the practical work. The statement "we have done too little practical work so far" was also disagreed with. I was somewhat surprised by this as I felt that to this point I have done less practical work with the class that I would have normally done, in the knowledge that there was a long sequence of lessons related to practical work coming up. The three other learning questions gave similar responses indicating that there is some agreement with the idea that students learn new things and consolidate understanding of theory when doing practical work although this is not unanimous. Finally there is a mild but significant agreement with the idea that students have been taught practical skills during the practical work they have already done. This suggests the teachers are perhaps reflecting pessimistically on the current situation and that the issues raised by Abrahams about students not learning while doing practical works are not an endemic problem at present. It is possible that the student reflections on their learning are not entirely accurate, possibly due to the delay between doing practical work and completing the survey or due to students not thinking deeply about learning. My conclusions from this were that students are keen to do more practical work and already find what they have done useful. I therefore did not need to worry about a decrease in engagement (at least in the short term) but did need to assess what they already know in order to ensure that what I teach them is relevant, this was done through the baseline assessment.

Assessment: Both of these questions gave similar responses and show students do not have much understanding of practical assessment which is what we wanted at this stage. I anticipated the variation in answers comes from students who do Biology/Chemistry understanding that there must be an equivalent in Physics. As there already seemsed to be some knowledge of the practical

endorsement I decided to discuss practical assessment with the class as teacher interviews suggest this led to confusion and some students completing unnecessary work (eg lab book presentation). I decided to do this in a way which primarily reassured students, while explaining what it was I emphasized that last year everyone passed and that the important aspect of practical work was preparing for the exam.

Baseline assessment

The next stage was to look at what aspects of practical skills the students already knew about from the practical work already done, to do this I developed a baseline assessment (Appendix 6). The OCR criteria, based on Ofqual guidelines are given in Fig 3 and these set out what students can be tested on in the exam. Unfortunately these criteria are broad and difficult to interoperate. For example criteria like "(b) use of appropriate mathematical skills for analysis of quantitative data" could be included in a specification for a huge range of abilities, for an 11 year old this may mean simply finding the average of several repeat readings but for a third year undergraduate it could include an enormous amount of statistical processing. To understand what it means for A level Physics examples of what has been asked in old assessments, specimen new assessments and cross referencing these with colleagues and the wider Physics teaching community was needed. I reformatted them into the list of 10 criteria which regularly feature in exams:

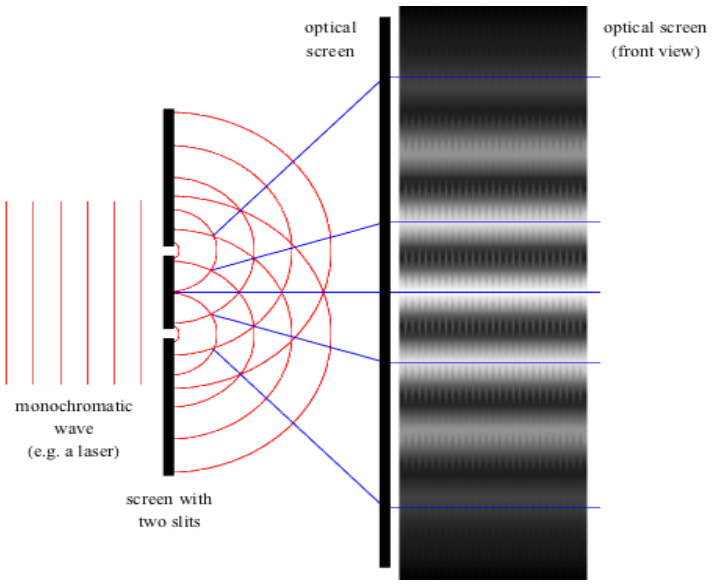
1. Identifying variables
2. Measurement techniques to reduce uncertainty (eg measuring across multiple oscillations)
4. Drawing tables
5. Drawing graphs
5. Using gradients (eg finding the gradient and identifying what it tells us, including putting equations in the form y=mx+c)

6. Using Y intercepts (similar to gradients)
7. Percentage uncertainty calculations and error propagation
8. Dealing with error from graphs (error bars and multiple lines of best fit)
9. Precision and accuracy (including comparisons of percentage difference to percentage uncertainty)
10. Writing and improving methods (the key being to focus on the largest source of uncertainty)

The sequence of lessons I developed had the aim of making students competent on these by the end of Y12. The baseline assessment had one question designed to test the student on each of these skills. The questions were designed to be straightforward, assessing only that particular skill with no crossover between skills or trick questions. All the questions were set in the same context – Young's double slit experiment (see fig 8). I chose this as I feel it is the experiment the students are most used to. I am confident they understand how it works having seen it as a demonstration 3 times (when explaining interference, as a comparison to a diffraction grating and as an example when explaining how phasors and quantum probabilities worked) and it was a key part of explanations earlier in the year. I wanted to ensure the context did not add confusion as I was only trying to assess their practical skills. Another option would have been to assess these 10 practical

Fig 8 – Young's double slit experiment.

The double slit experiment is an important example of wave behaviour. Typically set up with waves from one source diffracting through two apertures, as the waves cross each other an effect known as superposition occurs. At the point where the waves meet a combination of the two waves forms, the resultant wave which forms amplitude is the vector sum of the original waves. That this phenomena is observable in light is a key piece of evidence for the wave nature of light. Experimentally key variables (slit separation, slit to screen distance and fringe spacing) in the experiment can be altered and measured in order to determine the wavelength of the wave source.



skills without a context but the teacher interviews made it clear context free practical skills had caused problems in the past.

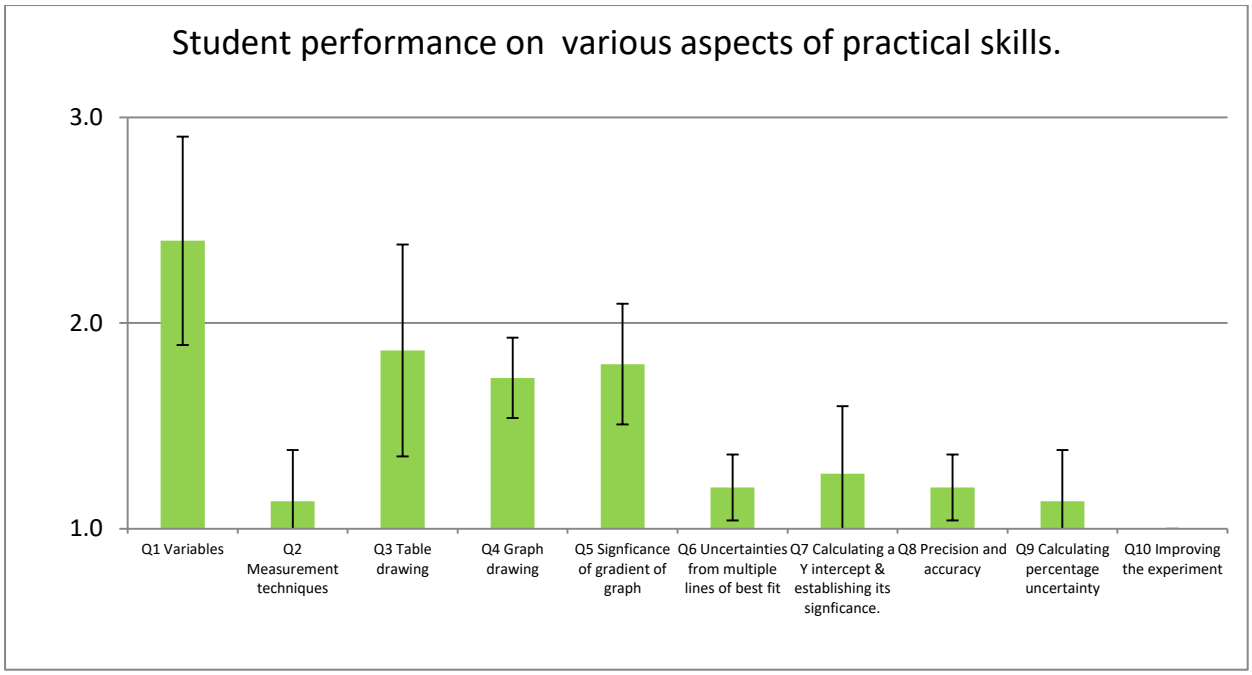


Fig 9 – Baseline test covering 10 core practical skills.

Student responses were marked on a 1-3 scale (1- no response or concept not understood, 2- student shows some understanding, 3- student shows good understanding of the practical skill and responds appropriately). This scale was used as I am looking only to assess their initial knowledge, it is flexible, allowing me to look at what the student has done and infer their understanding without the confines of a mark scheme where I can only credit specific predefined responses.

Q1 Variables – I expected students to do well on this question and they did, it is a fairly basic idea and one which I expect students to cover at both KS3 and KS4. Most students answered this suitably and the most common mistake was mixing up the independent and dependent variable. I don't feel that this needs to be a significant focus of the upcoming practical programme although it would be important that students are reminded and I use terminology correctly.

Q3 Tables, Q4 Graphs & Q5 Gradients – Most students showed they had some level of understanding of these ideas. Most students drew sensible but not perfect graphs and tables and were able to calculate the gradient. Only a few students could find the wavelength from the gradient of their graphs. These ideas need to be addressed and covered but I needed to plan for a reasonable level of prior knowledge and not spend too much time on this.

The remaining questions – The majority of students showed no A level standard knowledge of these ideas. The program I was designing needed to address all these areas and not assume any prior knowledge.

As not all aspects of practical skills could be easily covered within the context of the Young's double slit experiment and my 10 core concepts do not cover some of the minutiae I used the specification (OCR 2016 p8-13) and examples of exam questions to identify what else was relevant. While these issues are not core concepts they are things that students need to know. As these are a more disparate selection of skills it was difficult to fit them into a single context so I decided student self-assessment was the best way to test them (see appendix 7). A large range of factors affect the accuracy of student self-assessments (Gavin et al 2015, Bolvar-Cruz et al 2015, Flachikov & Boud 1989). To understand the accuracy of the student self-assessment in my survey, four of the self-assessment statements corresponded to questions that were assessed on the baseline assessment. The comparison between the self-assessment value and the teacher assessment value could be used to evaluate the accuracy of the self-assessment. As with the attitudes survey above a scale with no neutral option was used and the survey was anonymous.

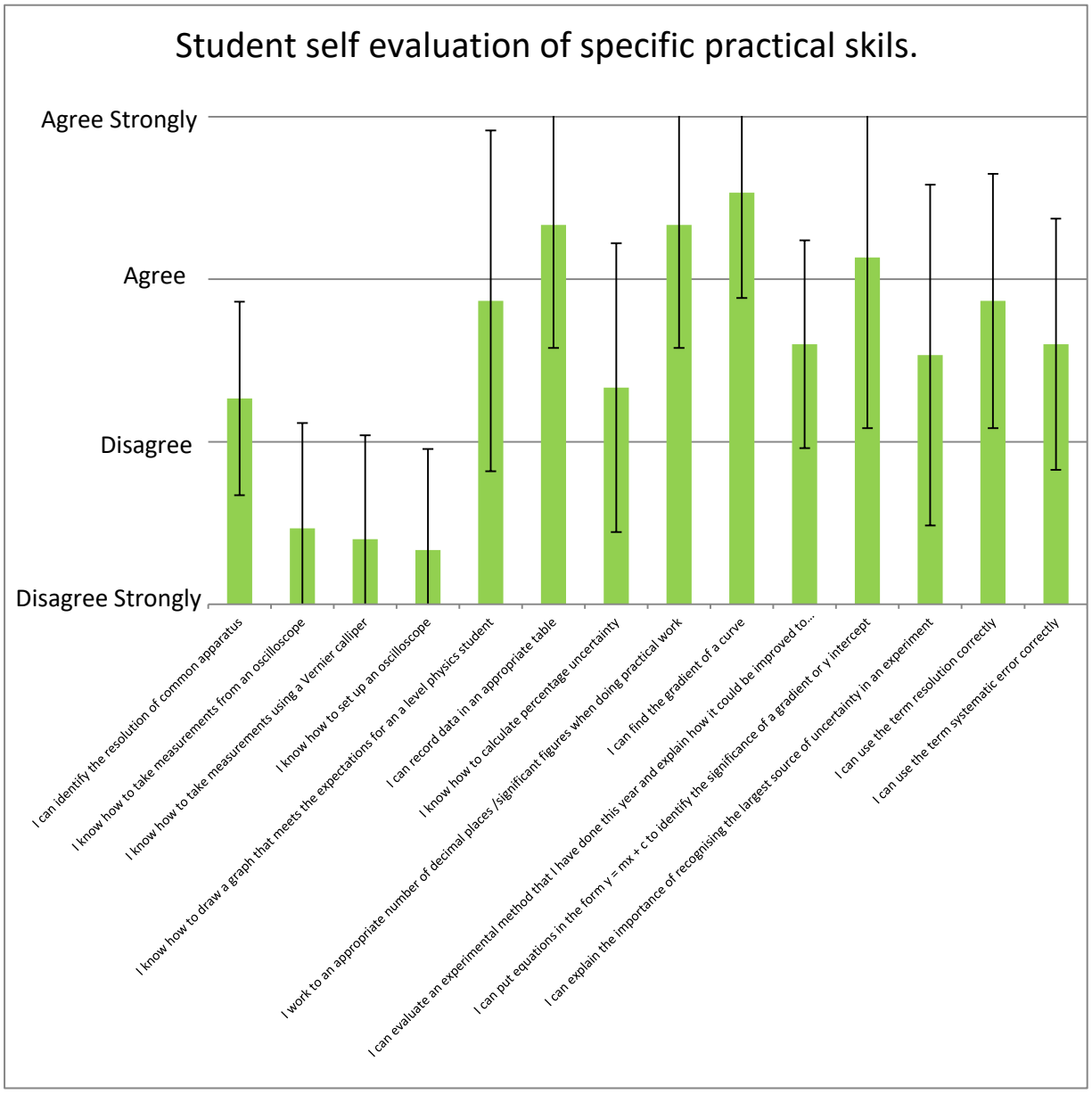


Fig 10 – Student self-evaluation of specific practical skills.

The four questions on the self-evaluation which were also on the teacher assessed baseline test give the same order of competence, with table drawing ranked highest by both, then significance of gradients then graph drawing then uncertainty calculations. This suggests that the student self-evaluations are accurate in ranking different skills. However the student self-evaluations seem to

overestimate their competence. On the baseline test almost all students were unable to calculate percentage uncertainty correctly however in the self-evaluation the answers were very varied with many students feeling that they could do it. This overestimation is found across all four control questions. The student self-evaluations therefore are useful in identifying which areas need to be prioritised over others but should not be taken as an accurate measure of the students' ability.

Designing a sequence of lessons to cover practical skills.

While analysing the baseline data I was also thinking about the structure of the programme on practical skills. Considering what the literature says about learning objectives in lessons and across a sequence of lessons and the issues raised in teacher interviews about students not engaging with the practical learning I have decided to:

- Make all learning objectives relate to practical skills and so students focus on them rather than the applied context.
- Make the lessons into a sequence on practical skills which will allow students to link the individual objectives together, better understand the underlying ideas and develop the individual objectives into larger unit level objectives rather than seeing them as separate unrelated things.
- Use a context for practical skills that the students are familiar with so that their learning can be focused on the practical skills not the physics related to the context.

This third variation to the course structure will hopefully avoid some of the problems raised in the teacher interviews about interspersing practical skills throughout the year but also avoid the problems of teaching it as a sequence at the start of the year where students can't see applications of what they are learning, finding it dull and irrelevant. For the same reasons that it made a good context for the background test I decided to use the Young's double slit experiment as the context.

Students were familiar with it, had seen the effect demonstrated and understood the theory but had not done any practical work with it themselves. To the students I framed the work as a project, their aim was to determine the wavelength of a laser and would be learning how to plan, carry out, analyse and evaluate experiments while doing so.

Planning: While I was confident that the students would be able to make basic measurements and substitute these into a formula I emphasized that the aim of the plan was to enable them to come up with a very accurate value for the unknown wavelength of the laser. The learning objectives for this lesson were:

i) To recall and identify independent, dependent and control variables.

ii) To identify an appropriate method to determine the wavelength of a monochromatic light source.

iii) To identify significant sources of uncertainty in this experiment and suggest suitable improvements to the method to reduce these.

iv) To describe and explain measurement techniques appropriate to this experiment.

This lesson went well with several students remembering which variable was which through a widely used song. The starter on types of variables was brief as the baseline tests suggested it should be. A class discussion began the main bit of the lesson, about the importance of identifying the principal source of uncertainty when planning. This was introduced by showing students three measurements with an uncertainty where two were negligible and one caused a significant uncertainty in the final calculation, starting in paired discussions students were able to identify that improving the measurements with negligible uncertainty was pointless while the large source of uncertainty remained unchanged. When applying this idea to their experiment several students

were able to speculate correctly that fringe separation would be the primary source of uncertainty and the reminder understood why this was the case after discussion. The class then broke into paired discussion to suggest ways to reduce this uncertainty. These suggestions were then shared with the class and their merits discussed, with all but one pair coming up with a suggestion that showed good understanding. I then pointed out some examples of measurement techniques they had used to reduce the largest source of error in other experiments they had completed – emphasising that the technique changes with the experiment but the process of identifying the largest source of uncertainty and identify how it can be reduced is common to many experiments. In the later part of the lesson I introduced a common structure for planning investigations, which included significant sections on reducing uncertainty and measurement techniques. Due to time constraints students had to complete writing out their plans for homework using the structure given.

Carrying out the experiment: This lesson did not include lots of practical skills development. However for the sake of students seeing the projects as important I felt students should be given plenty of time to carry out the experiment carefully and take it seriously. I linked table drawing into this lesson which the baseline assessment suggested needed to be covered but not in too much detail. The learning objectives were:

i) To recall and explain the criteria for a correctly drawn table

ii) To make measurements and record these in a suitable format

iii) To complete a young double slit experiment safely and using the equipment provided to an appropriate level of precision.

The lesson began with peer feedback on each other's methods (homework from the previous lesson); these were then collected in for teacher feedback. The criteria for drawing a table were discussed and explain to the class, students were then asked to draw their blank tables out for me to

check before starting the experiment. After a reminder about safety instructions and the importance of working carefully students spent the lesson taking and recording measurements, I was very impressed with how carefully they worked – beyond what I am used to at this school suggesting a high level of engagement the project format. Due to a school peer observation initiative I was fortunate enough to be observed by an experienced Biology teacher for this lesson; extracts from his feedback, which he gave consent for use in this study, are below which support my reflections on student engagement and motivation:

It is clear that most groups decided to do use a large slit-screen distance to maximise the fringe spacing, this took up a lot of space but groups cooperated well with each other, sharing space and equipment as needed. Students worked with enormous care and showed a determination to get reliable results beyond what was normally expected.

Due to the care being taken by students the measurements took longer than Mr B had expected but the whole class voluntarily stayed after the lesson for up to 15 mins to finish taking measurements, showing the care students took in their work.

Students did all the work; Mr B did not touch equipment once the practical work began. He discussed individual mistakes with specific groups for example when one group was holding metre rules end to end to measure 4 metres.

It is clear that students took the measurements seriously and took a lot of care. Although this led to a lot of time being spent it was good to see a class where all students took practical work very seriously. It is clear this is the product of an effort by Mr B to share his passion for practical work.

Analysing: This lesson covered several aspects of the baseline test and actually covered two lessons. I needed to go through the criteria for drawing a graph to an A level Physics standard and how to use the graph to calculate the wavelength, the baseline test suggested that students had some prior knowledge of both of these so they took up a smaller part of the lesson. This left the bulk of the lesson to using error bars and lines of worst fit to give an uncertainty to the wavelength values which students had almost no prior knowledge about. The objectives were:

i) To be able to draw a suitable graph of the results

ii) To calculate from the graph a value of wavelength

iii) To explain why the gradient was approximately wavelength over slit separation.

iv) To draw appropriate error bars on the graph

v) To draw a worst acceptable line of best fit to determine the uncertainty in wavelength.

The starter of was for students to match descriptions of common graph mistakes (see fig 11) to their visual equivalent and then explain why these are mistakes. It was clear that students understood these criteria quickly and they then moved on - using criteria to avoid these mistakes in their own graphs. There was then a brief teacher explanation on how to find the wavelength which students managed to complete with their own results. The lesson then slowed down to cover error bars, lines of worst fit and using this to establish the uncertainty in wavelength, something the baseline test suggested was an area they knew little about. It was clear that this was needed and the topic went back to the basic ideas of measurement and uncertainty with students given a step by step example of what to do and asked to explain back why we did each

Common Graph mistakes

- Joining point to point
- Insufficiently precise line
- Unclear or imprecise curve
- Too many points above line
- Forced through origin
- Last pointed plotted off the area of graph
- Gradient found using data points not on line of best fit
- Gradient triangle used is to small
- Too many large squares with no label
- Awkward scale on x axis
- Non-linear scale on x axis

Fig 11 – descriptions of common graph mistakes

step. Due to time constraints this was completed at home, all students achieved a suitable value of wavelength and its uncertainty.

Evaluation: I wanted to focus on Q7, 8 and 10 from the baseline test to finish the projects – all of these students had struggled with so I knew it would take some time and several lessons. There objectives were:

i) To be able to use the terms precision and accuracy correctly

ii) To be able to use a comparison between percentage uncertainty and percentage difference to comment on the experiment

iii) To be able to calculate the y intercept from a graph with a broken scale

iv) To be able to evaluate the experiment and back this up with quantitative data.

v) To identify the largest sources of uncertainty and suggest and explain relevant improvements to the method.

The students did a starter considering some fabricated realistic data and commenting on its accuracy and precision, this was used, through discussion and questioning, to elicit a rule to compare percentage uncertainty and percentage difference. This was used to help students consider if they had accounted for the major sources of error. We then looked at y intercepts, although not very relevant to this experiment, students were asked to compare their y intercept value and its uncertainty to the expected value and to use this to back up their comments about the precision and accuracy of the experiment. With support they were able to work this out for themselves so I took it to mean that they understood the initial idea. In the second lesson we began with a hypothetical set of experiment data, 3 variables with different uncertainties were given and a series of questions and

discussion was used to get across the idea that it is important that improvements to the experiment focus on the largest source of uncertainty. Students were then given a structure to follow for their evaluations; their efforts were peer assessed for immediate feedback before being teacher assessed.

A final standalone lesson was done on error calculations and error propagation which did not fit in with the projects but the baseline assessment suggested was needed. This began with students being given a starter to recap terminology, formula and rules. I then reinforced by the teacher with the emphasis on error propagation. Next I went through an example, initially using upper and lower bounds, a concept students are familiar with from GCSE maths, comparing this to percentage uncertainties and discussing the merits of each approach. Students were then required to complete a number of example problems of increasing difficulty and periodically stopped to go through common misunderstandings or receive individual help. A couple of exam paper examples were used as a plenary which suggested students had reached the required standard.

Students then completed an assessment to see how much progress they made. It was structured similarly to the baseline test to allow for an easy comparison and marked on the same 1-3 scale. This time in a new context was used to see if they had made progress and if they were able to transfer the skills to a different but familiar experiment.

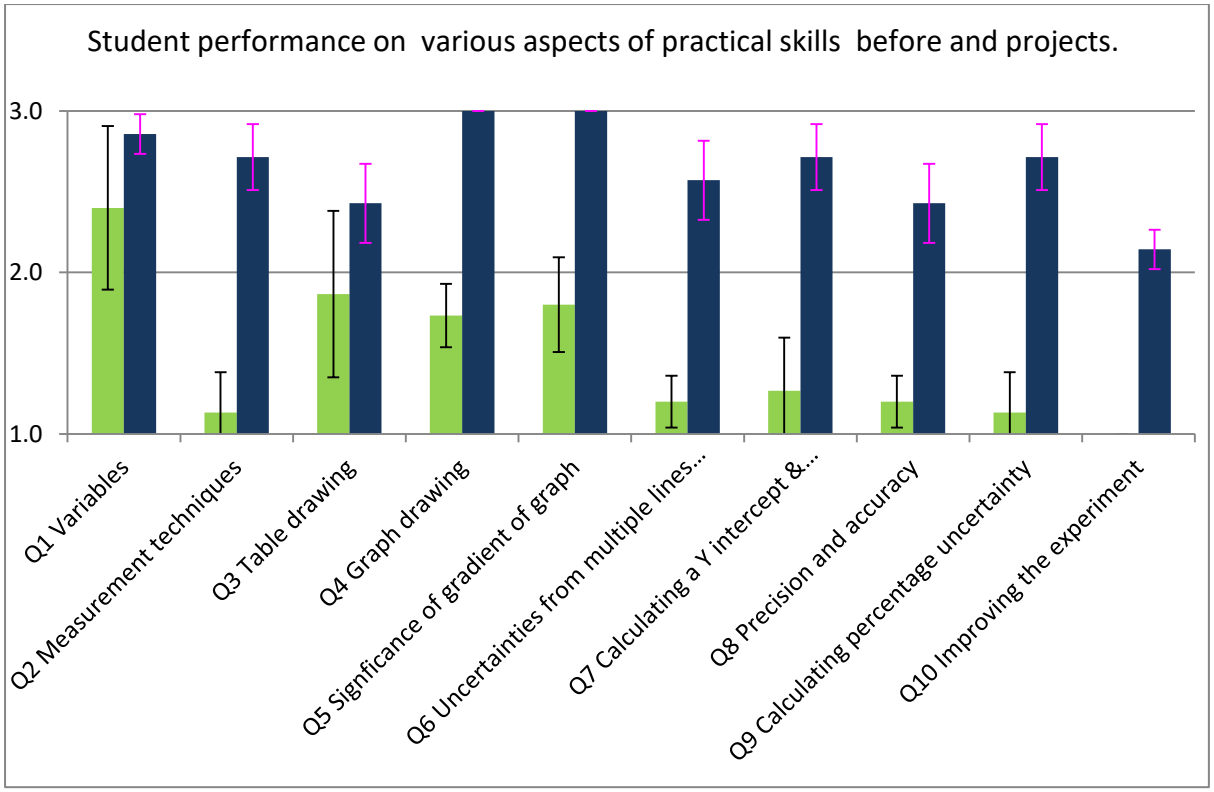


Fig 12 – this graph shows the difference between the baseline test (green) and the end of project test (purple). As before the error bars show the variance.

This graph shows that students have made progress in each of the 10 categories. After the project the lowest performing categories are Q10 and Q3. Q3, table drawing was to do with students not identifying an error in the number of decimal places data was recorded to. This is disappointing as it is not a difficult idea but sometimes students don't recognise its importance. It is clear that more understanding and practice on this is needed: fortunately table drawing is a skill required in the majority of practicals so there are opportunities to improve. Q10 has the disadvantage of being at the end of the test and although students were given as much time as they needed, the compulsion to finish may have lead them to rush this question. It is also a question that requires extended written answers, something some students don't like to give. It is clear further work needs to be done on this and it will be included in the upcoming core practicals.

To see which parts of the project were most impactful the progress (difference between starting and finishing attainment need to be considered. As the starting attainment was different in each skill I have considered how much improvement was made as a proportion of the maximum possible improvement (with maximum possible improvement being every student scoring three out of three). For example on Q1(variables) the starting attainment was 2.4 out of 3 meaning the maximum improvement was only 0.6 whereas on Q10 the maximum improvement was 3, this makes a direct comparison misleading.

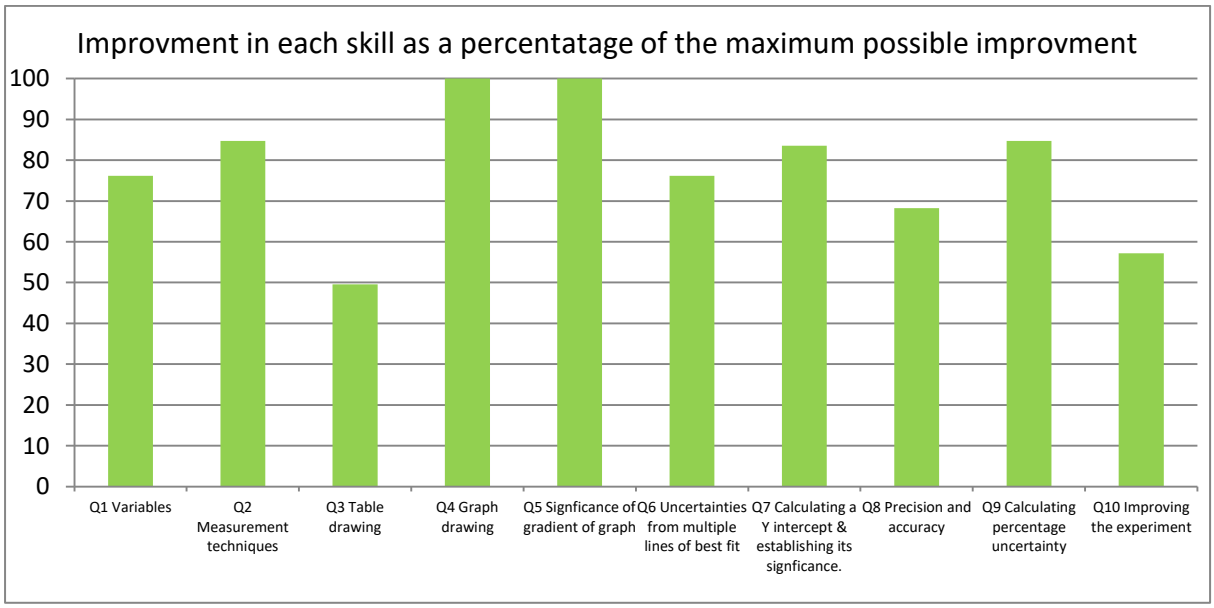


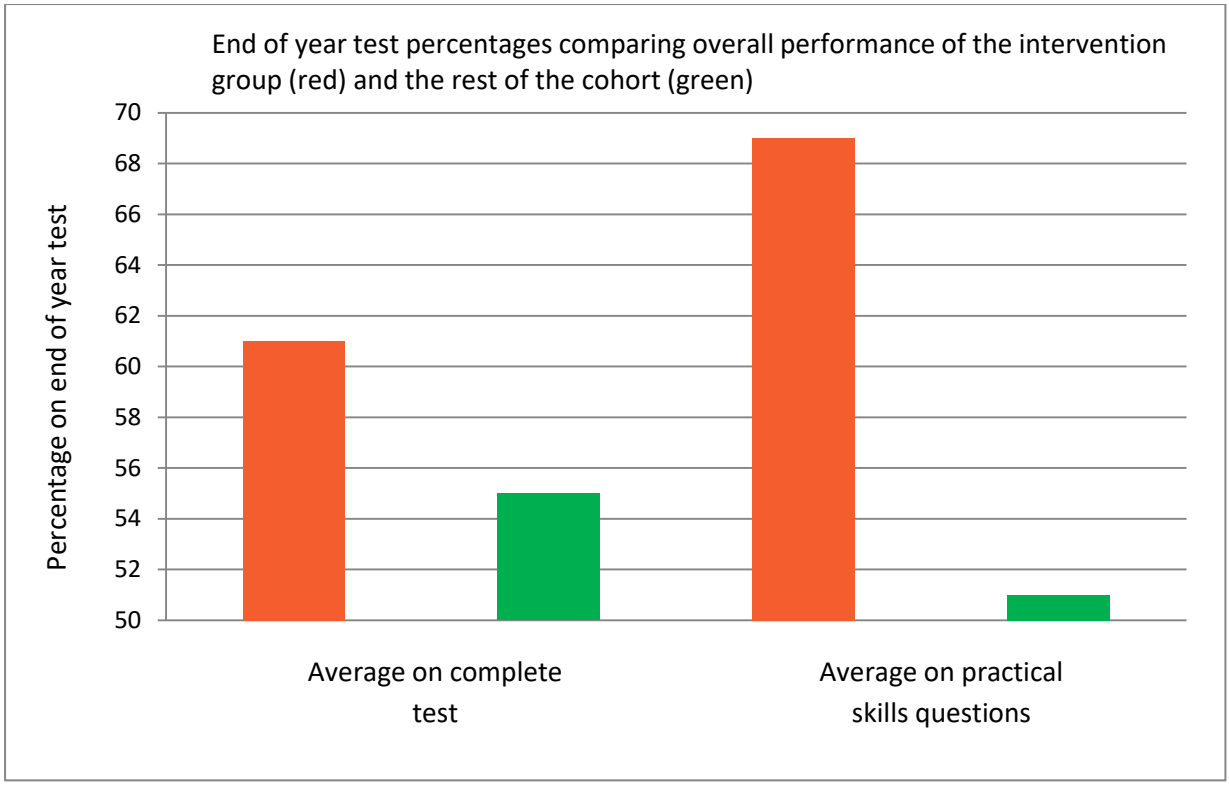
Fig 13 – this graph shows the progress made between the baseline test and the end of project test.

Again Q3 and Q10 score lowest. When teaching the skill needed for Q3 I went through it at a fast pace, thinking students had some initial knowledge (as indicated by the baseline test), but it is clear more time needed to be spent. Interestingly I took a similar approach with graphs and students made the maximum progress on this, although a similar amount of time was spent on each of these

aspects the activities used for graph drawing were effective but table drawing was mostly just a teacher explanation with questions. The activities used to embed graph drawing criteria can be easily adapted to be used for tables and it seems this would be a useful activity.

End of year exams

The end of year exams allow for students who completed the new, focused practical skills programme compared to those who learnt practical skills throughout the year in range of experiments. The classes are not set, students are assigned classes largely randomly at enrolment. Completely randomly if they are doing subjects with more than one class, there are 6 Physics classes for Y12, the only factor that limits what class a student would be in is if they are doing another subject which only exists in one on option block. The class I trialled the new project withwere timetabled to block A, the only unique subject in block A is Spanish meaning if a student wanted to do Physics and Spanish they would have to be in one of the other 5 Physics classes, this only affected two students. The common subjects studied with Physics (Further Maths, Maths, Chemistry and Biology) have a large number of classes making the process random. I feel this allows classes to be compared fairly. The end of year exam was 110 marks of questions with 15 marks categorised as practical skills.



There is a clear discrepancy between the intervention group and the rest of the cohort both on the overall mark and on the practical skills questions. The discrepancy in the overall mark is not fully accounted for by the higher practical skills mark, the overall discrepancy is an average of 6.6 marks with the practical skills accounting for just 2.7 marks. This suggests the intervention group are higher attaining (although this was not apparent in assessments early in the year). However the discrepancy per mark available is far higher on the practical skills paper, 2.7 marks out of a possible 15 means that students in the intervention group scored on average 0.18 marks per mark available higher compared to an extra 0.04 marks per mark available on the remaining 95 marks. This suggests that the new program is significantly more effective than the system it is trying to replace.

Findings and discussion

Limitations: The work I have done ended up being primarily with one class (initially the aim was to work with two but due to timetable changes this became difficult). This makes the sample size small and therefore any conclusions drawn from the work with the students need to be treated cautiously as they may be specific to the group of students sampled or contexts relating to the class, teacher school or local area. The teacher interviews involved 3 Physics teachers, and while they have expressed some similar ideas, disagreeing with some aspects of the literature; this is also too small a sample to challenge widely held views. The consistency of opinion among the teachers may relate to their experience at this school (aside from a small amount of unqualified teaching and initial teacher training none have worked at other schools). The context of the school is also somewhat atypical (sixth form only, new school with limited budget for practical resources) so it should not be surprising that this atypical experience leads to some views which differ from the norm. While the sample of 3 is very limited when considering the wider issues it means that all the department were involved in my work and therefore I feel this gave me as good as possible understanding of the issues specific to the school context; conclusions based in these ideas are therefore as robust as can be expected.

Although both quantitative and qualitative methods have been used, a detailed analysis of the statistical significance of findings has not been completed. This means that no individual piece of evidence should be considered as a robust finding, however the consistency across the findings does allow meaningful conclusions to be drawn, indicating that further questions raised warrant meaningful consideration. There are some issues with the method of data collection, use of student self-assessment is subjective and what one student considers a good understanding may not match the grading of another student. Additionally there is a question of the power relationship between myself and the students. It is possible that some students felt obliged to answer in a way that they

thought I wanted to hear or conversely that the anonymity empowered students to give negative answers free from fear of recourse (although the data does not suggest that either of these problems occurred). With staff a similar issue could have occurred. Although all seemed to participate keenly and willingly as the Head of Science there is a power imbalance and many of the way things are done in the department is because that is how I set them up in the past. Although this year a head of Physics was appointed and this has lead to some changes it is certainly possible that staff held back on some issues to avoid disagreeing with what they felt my view to be.

Further, much of the literature which informed my approach is very 'applied' - I could not find literature directly about the teaching of practical skills for an exam-based assessment for A level students (which is quite a specific problem). Therefore I had to look at research in a number of areas which had overlap with my situation (practical science, assessing practical skills, modes of assessment, student motivation for practical work, reformed A levels etc.) and apply findings in these studies to my problem. I may have mis-applied the literature in that findings I have applied to my problem may not be transferable, meaning the rationale behind decisions I made is flawed.

For these reasons, any attempt to implement conclusions of this work more broadly would need to consider the similarities and differences in context and ensure that changes implemented were carefully monitored.

Discussion, in relation to the research questions.

1. **What are teachers' and students' attitudes towards practical work and its assessment?**

While some of the literature from interest groups (SCORE, Welcome Trust, Gatsby) suggests that practical work will inspire and motivate students it was clear from the research that this was not universally the case at my school. Although some students enjoyed practical work it varied a lot

between different students and some students engaged less well with practical work than theoretical lessons. It was not generally important in students choosing to study Physics A level or motivating them to take specific university courses. This somewhat undermines the commonly asserted view that practical work is important in inspiring students to continue to study Science. Students do not always understand the importance of practical work as part of their learning, either in terms of their development as physicists or in relation to A level assessments. Generally it is taken most seriously when doing the core practicals, but some students develop assessment anxiety and others are unable to learn optimally while being assessed. Both of these are issues raised in the literature which relates to the impact of assessment on learning, e.g. Black and Wiliam (1998).

Teachers have a very clear view that practical work is important to doing and learning Physics. They highlighted 3 of the 4 reasons given in the House of commons review on practical science in 2011 to do practical work including helping students understand theoretical concepts, improving practical skills and to engage students. In lessons there are some concerns about how much students learn in practical work especially in relation to getting the balance between supporting students and giving them independence. There are also concerns about having sufficient time, and conducting practicals at the appropriate point in a learning sequence. In addition, teachers were concerned about making sure students understand the importance of practical work. In many ways these all link back to the idea of having clear learning objectives for practical lessons which the literature highlights as a common issue with practical work in schools (put in some references). Lunetta (1998, 2007) talks about how students struggle to link practical examples to theoretical concepts without teacher support. Studies, including the one by Abrahams and Millar (2008) discussed above highlight how students are often busy doing but not busy learning, this is sometimes raised as the idea of recipe science – thoughtlessly going through a series of instructions.

2. What effects does a sequence of lessons on practical skills have on students' learning?

One of the ideas raised in the literature is the range of reasons to do practical work. In the classroom this can result in practical activities which don't have clear and concise objectives Hodson 1994, Abrams and Millar 2008. In my school some students focus on the theoretical context rather than the practical skills or don't take practical work sufficiently seriously, often not identifying the specific ideas that they needed to learn. The advantage to delivering the practical skills as a standalone sequence of lessons is that it has given the students clarity on what it is they need to know and allowed them to piece similar ideas together, developing a deeper understanding and to see practical skills as at least equal to any other topic studied in Physics. From the teacher perspective it makes it easier to develop and deliver clearer concise objectives and focus on exactly what needs to be learnt. This allows for more relevant assessment and in turn better informed teaching. This greater clarity about the aim of a practical activity allows teachers to be better informed when deciding to extend an activity or knowing when to support and when to let students work it out for themselves. This reduces problems with students doing but not learning.

3. **What effects does a sequence of lessons on practical skills have on students' attitudes and motivation?**

In my study, the students engaged well with the sequence of lesson on practical skills, in the view of an observing colleague significantly better than in normal practical work, to the point where the class willingly stayed after school to complete experimental work. This meant that modifications to improve engagement were not needed. Had it been required the literature is somewhat split with several arguing that practical motivates students eg Woodley, 2009; Hampden-Thomson and Bennet 2013. Others argue that motivation alone is not a reason to do practical work Abrahams 2008, Adey 1997. Other studies point to students enjoying some aspects of practical work more than others, eg Kohnle et all 2012 finds that the level of control students have over their work. Some of these ideas were built into the sequence of lessons, with students given (at least the impression of) high

independence may be why students engaged well. There was a clear improvement on student engagement during the sequence of lessons compared to previous approaches.

Conclusion: The aim of my work was primarily to improve how my department prepares students for the exam assessed practical skills. In doing this I have looked at the role of practical work in learning science, specifically A level Physics. The literature was clear that practical work was an important part of learning science but it has a several different purposes and different forms of practical work can support these to greater and lesser extents. There is also some concern over the effectiveness of some school practical work. One significant issue raised is that students struggle to link practical work to theoretical concepts and that practical lessons don't sufficiently emphasize this. Another is that in practical lessons students spend a lot of time doing but are not necessarily learning. This can be due to recipe style experiments but also that students are more likely to be confused about what it is they need to learn than in 'theory' lessons. Finally there is difficulty in assessing practical skills meaningfully, the A level course has resorted to two methods, the PE and the exam.

Teachers raised a number of concerns about students' motivation in practical work, which contradicted some of what was said in the literature, and the impact of the practical endorsement assessment on learning, which was broadly backed up by the literature. The observations with an experienced colleague show that many of that the motivation issues have been avoided, with students engaging well in the practical skills lesson sequence. These observations, and my own reflections on the changes and comparisons with previous cohorts, show that using the PE to embed the practical skills through practise and application to new contexts rather than to support theory has been a positive change. This has allowed students to focus on the learning of the practical skills and avoided confusion over the purposes of the practical work, an issue raised both in the literature and by teachers (although not fully backed up by student surveys). Teachers also highlighted a range

of other organisational problems that the new system has resolved such as where to fit practical skills into the scheme of work, the use of mock exam style practical skills assessments, setting a standardised approach for all teachers to follow and a clearer guidance in between meeting core practical requirements and ensuring learning happens.

The new method of delivering practical skills shows consistent improvement. Although none of the individual pieces of evidence are robust due to the small sample size, the consistency of the findings suggests that the developed approach can be considered an improvement.

Next steps: Upon completing this project work I took key data and discussed my experiences with colleagues. It was agreed that I should use my experiences to write a sequence of lessons for year 12 to develop practical skills that would be delivered to all classes next year. It would be taught at the end of the first theoretical unit (electricity) and based around a project to determine the material of an unknown wire through accurate measurement of its resistivity. To go with this I was asked to develop an improved system for the core practicals which would focus on using them to reinforce and practise applications of practical skills. It was agreed by the head of Physics and rest of the department that I should complete this work guided by the following principles (based on conclusions of the research:

- That learning practical skills in a block, as a set of linked ideas, is an effective approach.
- That learning practical skills in one simple and familiar context allows the focus to be on learning to be on the practical skills rather than the theoretical concepts which link to the practical context.
- The initial learning of practical skills should not be done during the core practicals but these should be used to enable students to practise applying practical skills previously learnt to a new context.

Furthermore it was agreed that:

- The department needs a consistent message to frame how students approach the practical endorsement. The Head of Physics will discuss with the Heads of Chemistry and Biology how they approach this and if there are any merits in a consistent approach across the sciences
- I would use my experiences with Y12 to develop and deliver modified versions for Y13 as a 'revision of' practical skills.
- That teacher-led demonstrations should be used to engage students and explain the links theoretical concepts to observable phenomena.
- That student attitudes to practical work are mixed, practical work should not be done purely to motivate students

Further work: The expansion of the project from one class this year to all classes next year is a big challenge. I have modified my resources in a way which allows a multiple teachers to use them and written a sow to accompany them. The topic has changed from waves to electricity, to fit with a change in sequence on the scheme of work. These changes mean the new lessons will need to be evaluated and likely further modified after their first use. Under our new system the significance of the practical endorsement has been somewhat diminished. We are using it to support learning practical skills and trying to break the view that it is an assessment. In doing this we have to ensure that regulations surrounding the practical endorsement are upheld and that students meet the required standard in the non-exam assessed skills. It would be worth seeing how this is treated in other schools. I also feel there is an interesting question in to what extent the implementation of the practical endorsement meets its initial aims.

Appendix 1 – OCR Practical skills (OCR 2016, p12)

1.2.1 Practical skills

(a) apply investigative approaches and methods to practical work Including how to solve problems in a practical context.
(b) safely and correctly use a range of practical equipment and materials See Section 5h.
(c) follow written instructions
(d) make and record observations/measurements
(e) keep appropriate records of experimental activities
(f) present information and data in a scientific way
(g) use appropriate software and tools to process data, carry out research and report findings
(h) use online and offline research skills including websites, textbooks and other printed scientific sources of information
(i) correctly cite sources of information
(j) use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification.

1.2.2 Use of apparatus and techniques

(a) use of appropriate analogue apparatus to record a range of measurements (to include length/ distance, temperature, pressure, force, angles and volume) and to interpolate between scale markings
(b) use of appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance and mass)
(c) use of methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line
(d) use of a stopwatch or light gates for timing
(e) use of calipers and micrometres for small distances, using digital or Vernier scales
(f) correctly constructing circuits from circuit diagrams using DC power supplies, cells, and a range of circuit components, including those where polarity is important
(g) designing, constructing and checking circuits using DC power supplies, cells, and a range of circuit components
(h) use of a signal generator and oscilloscope, including volts/division and time-base
(i) generating and measuring waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave/radio wave source
(j) use of a laser or light source to investigate characteristics of light, including interference and diffraction
(k) use of ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data
(l) use of ionising radiation, including detectors.

Appendix 2 – Letter to headteacher with return form

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Director Professor Jo-Anne Baird

Dear James

I am writing to enquire about conducting research in school this academic year. As you know, I am studying for the Master's in Learning and Teaching at Oxford University, supervised by Dr Judith Hillier. In my final research project, I will be looking at the role practical work plays in learning science particularly in the context of A-level Physics. This will involve researching techniques that are reported as effective, trialling them in my lessons and evaluating their effectiveness. My expectation is that by adopting a more purposeful approach to practical work we will be more effective at preparing students for the practical skills part of their A level. The research will involve 2 year 12 Physics classes which I teach.

I hope to conduct this research between January and July 2018. It will involve designing typical lesson activities which will be evaluated through collection of data such as; summative assessment of practical skills, student self assessment of understanding, lesson observations (as part of the paired lesson observation CPD), and analysis of results. The data collected will be in line with normal classroom practice, not sensitive nor including any details on individual students. I also plan to interview some colleagues if they are willing to be involved in the study, I will write to them seperatly.

Oxford University has strict ethical procedures on conducting ethical research with teachers and young people, consistent with current British Educational Research Association guidelines. As practitioner research however, the University recognises that schools have the highest ethical standards in any event. Therefore only your consent is necessary, and not that of parents. Throughout the research, students and other teachers will be able to refuse to participate in any research activities at any time.

All participants, including students, teacher and the school, would be made anonymous in all research reports. The data collected would be kept strictly confidential, available only to my supervisor and myself, and not used other than specified without further consent. The raw data

collected would be kept on Harrisnet and only processed, anonymised data would be shared beyond the participants.

If you feel you would like to take part in the study, or need more information about what is involved, please contact me.

I look forward to hearing from you.

Yours sincerely,

Jon Burland

Investigating the changes to practical work in A level Physics.

University of Oxford,Department of Education

Harris Westminster 6th Form

Tothill Street, London, SW1H 9LH

James Handscombe

- ☐ We do not wish to participate in this project.
- ☐ We would like to find out more about this project.
- ☐ We would like to take part in this project.

If you would like further information, please contact me, or my supervisor. If you require clarification of the ethical approval, process please contact Chair of Department of Education Research Ethics Committee, Dr Liam Gearon.

Supervisor email:*judith.hillier*@education.ox.ac.uk

Chair of Department of Education Research Ethics Committee, Dr Liam Gearon email: liam.gearon@education.ox.ac.uk

Please return this form to me.

Thank you for your help.

Appendix 3 – Teacher consent for interview

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Director Professor Jo-Anne Baird



January 2018

Dear

Thank you for considering taking part in my investigation into the role of practical work in learning Physics. I am interested in asking you a few questions about how you feel practical work helps students learn and the challenges you feel affect practical lessons.

Your thoughts will inform the conclusions of my thesis but will not be attributed to you, a teacher at HWSF or even within Harris federation. If it is acceptable to you I would like to record the audio of interview for ease of data collection. As said your comments would be anonymous and heard only by myself and possibly my supervisor Dr Judith Hillier.

Thanks for your time

Jon

PARTICIPANT CONSENT FORM

Investigating the changes to practical work in A level Physics

Purpose of Study: To investigate classroom practice to support students' understanding of Physics through the use of practical work

		Please initial each box
1	I confirm that I have read and understand the information sheet version_____dated _____ for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, and without any adverse consequences or academic penalty.	☐
3	I understand that research data collected during the study may be looked at by designated individuals from the University of Oxford where it is relevant to my taking part in this study. I give permission for these individuals to access my data.	☐
4	I understand that this project has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee.	☐
5	I understand who will have access to personal data provided, how the data will be stored and what will happen to the data at the end of the project.	☐
6	I understand how this research will be written up and published.	☐
7	I understand how to raise a concern or make a complaint.	☐
8	I consent to being audio recorded	☐
9	I understand how audio recordings will be used in research outputs	☐
10	I agree to take part in the study[1]	☐

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of person taking consent	Date	Signature

_____

Appendix 4: Teacher interview questions

1)To what extent do you feel it is important students do practical work when learning A level Physics?

2) What are the challenges you face when doing practical work?

3) What are the aspects of practical work which most challenge students?

4) In what ways do you approach assessed practicals differently to other practical work?

5) In what ways do students approach assessed practical differently to normal practical?

6) To what extent do you feel practical work affects student motivation?

7) How do you ensure that students are learning practical skills required for the exam when doing practical work?

8) How do you ensure that students are able to understand how the practical work links to theory they have learn?

9) How do you check students have learnt what you wanted them to learn when doing practical work?

Appendix 5 – Student practical work attitudes self-assessment

Please indicate with a 1,2,3 or 4 the extent to which you agree with the following statements.

1 – disagree strongly, 2 disagree, 3 agree, 4 agree strongly

a) I enjoy doing practical work

b) The opportunity to do practical work was a reason for me choosing a level Physics

c) The opportunity to do practical work would make me more likely to choose a subject at university

d) Practical work helps me understand theory I have learnt in class

e) We have done too little practical work so far in Physics a level

f) Practical work is time consuming and not a good us of class time

g) I learn something new when doing practical work in class

Preparedness for practical skills

Please indicate with a 1,2,3 or 4 the extent to which you agree with the following statements.

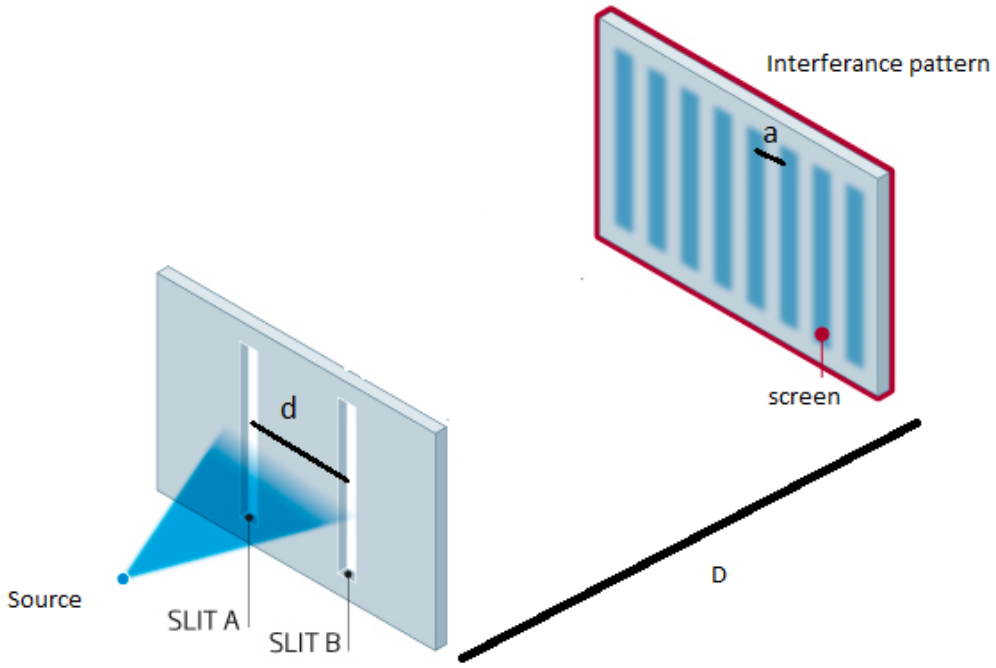
1 – disagree strongly, 2 disagree, 3 agree, 4 agree strongly

a) I have been taught practical skills in some of the experiments I have done this year

b) I understand what the practical endorsement is

c) I am aware of how practical skills are assessed in A level Physics exams

Appendix 6- Practical skills baseline assessment



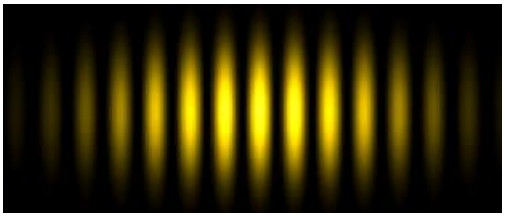
This question is about an experiment involving two slit interference patterns. The waves diffract as they pass through both slits A and B, as waves from one slit meet waves from the other an interference pattern forms, made visible by the screen. The equation λ=ad/D describes the situation to a close approximation, λ is the wavelength, a is the distance between adjacent maxima (fringe spcacing), d is the slit separation and D is the distance from the slit to the screen. To determine the wavelength of monochromatic light a student measures the fringe spacing after changing D while using the same slits.

1. State the:
   i) Independent variable

   ii) Dependent variable

   iii) Control variable

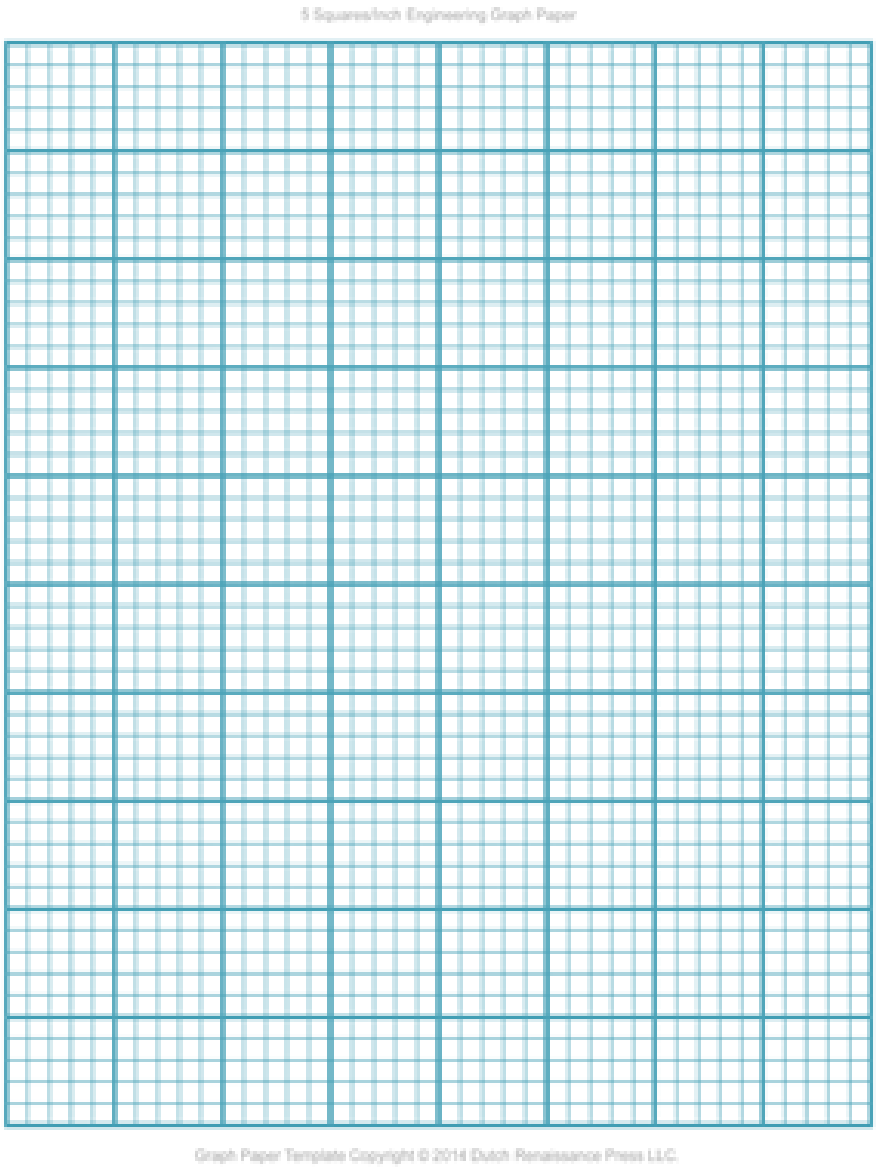
2. The student passes monochromatic light through slits of separation 0.0001 meters (you may assume negligible uncertainty) and records measurements in the table below. The final value of a is missing, use the photo of interference pattern to fill in the final row of the table, show your measurement on the diagram.



a (m) ± 0.0001 (m)	D (m) ± 0.005 (m)
	0.7
0.0052	0.8
0.0059	0.9
0.0065	1
0.0072	1.1
0.0078	1.2
0.0085	1.3

3. State and explain a mistake with the table

4. Draw a graph of a (y axis) against D (x axis), include appropriate error bars.



5. Explain why the gradient of the graph is equal to λ/d

6. Use your graph and the value of d to calculate a value and uncertainty for λ

λ = ……..……...m ± ……..……m

7. Calculate the y intercept and its uncertainty

c = ……..…….. ± ……..……

8. Use the value of your y intercept to comment on the precision of your experiment

9. Another student attempts to find λ by taking a measurements and using the formula. She finds that for a slit to screen distance of 1.1m the fringe separation was 0.0070. Calculate a value and uncertainty for λ (you may assume the errors are the same as in the experiment above).

λ = ……..……..m ± ……..……m

10. The student wants to try and make the experiment more accurate. Suggest and explain changes that they could make to the experiment.

Appendix 7 – Self assessment of practical skills

Examples of practical techniques you need to know

Below are some examples of practical skills you could be tested on in your exam. To what extent do you feel confident you can do the following statements, please rate your confidence on a 1-4 scale

1 – very little confidence to 4 – very confident

a) I know how to identify the uncertainty in common apparatus

b) I know how to take measurements from an oscilloscope

c) I know how to take measurements using a Vernier calliper

d) I know how to set up an oscilloscope

e) I know how to draw a graph that meets the expectations for an a level physics student

f) I can record data in an appropriate table

g) I know how to calculate percentage errors

h) I can use an appropriate number of decimal places /significant figures when doing practical work

i) I can find the gradient of a curve

j) I can evaluate an experimental method that I have done this year and explain how it could be improved to get more accurate results.

k) I can put equations in the form y = mx + c to evaluate the significance of a gradient or y intercept

l) I can explain the importance of recognising the largest source of uncertainty in an experiment

m) I can use the term resolution correctly

n) I can use the term systematic error correctly

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