APPENDIX 1: RAPID EVIDENCE REVIEW

GATSBY

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1. EXECUTIVE SUMMARY

RECOMMENDATIONS

1. There is a clear need for more high-quality studies of practical work that have a tightly-defined focus and a rigorous methodological approach. We are confident that this finding would persist in a more extended review than a Rapid Evidence Assessment (REA), which is necessarily limited in scope.

2. We would not recommend conducting a more in-depth, more traditional systematic review at this stage. There is a wealth of commentary on the purpose and usefulness of practical science, but very few robust studies. A more extensive search encompassing the grey literature would undoubtedly identify more studies, but they are unlikely to add significantly to the current knowledge base. This REA has highlighted the need for more evaluations of practical science in its various guises. There is a requirement for research that is clear in its aims, focus and definitions; has a sound methodology with adequate sample sizes and appropriate outcome measures; and is designed to shed light on the usefulness of practical science work across different contexts and for different purposes.

3. Drawing from the literature, the report identifies five main purposes of practical science. These are to enhance student performance in conceptual understanding; practical skills; non-subject specific intellectual and personal attributes; attitudes towards science; and understanding of how science and scientists work. There is currently a much greater evidence base around practical work improving physical skills and dexterity compared with the other four purposes of practical work defined in this report.

THE REVIEW PROCESS

4. There were two strands to the REA. Firstly, national curricula and other policy-related documents for each of the top ten performing countries in the PISA 2012 science assessment were examined. This was to establish the purposes of practical science work in high-achieving countries. The same analysis was conducted for the four countries of the United Kingdom (England, Scotland, Wales and Northern Ireland). The situation in some developing and post-conflict countries was also examined by way of contrast. Secondly, a literature search, focused on two electronic databases (ERIC and Google Scholar) and a contents search of some key science education journals (IJSE, JRST and Science Education), was undertaken to identify any international comparisons of practical work and studies of what makes practical work good. The focus was on research among 11–18 year olds.

5. For this study, science practical work has been defined as hands-on activities using scientific techniques and procedures, and scientific enquiries and investigations. Passive learning experiences, such as teacher demonstrations not involving the students, and drama/enactment activities were excluded. Few studies had to be rejected because they were outside this definition. More limiting was the exclusion from the qualifying criteria of studies relating to engineering or computer science.

CURRICULUM ANALYSIS

6. Most of the top PISA 2012 countries have elements of all five over-arching purposes in their curricula. In several cases, practical science carries weighty expectations, particularly as regards the category of intellectual attributes and characteristics that are not directly related to science. It is anticipated that practical work can have a wider societal impact either by creating more engaged and conscientious citizens (Singapore, Poland, South Korea), or cultivating character traits such as perseverance (Hong Kong) and reduced passivity (Vietnam). Additional, more in-depth analysis of the documentation from these countries would be necessary to establish how the expectations for practical work compare with expectations for other aspects of the science curriculum.

7. England, Wales and Northern Ireland all stress developing the understanding of the nature of science and acquiring practical, technical skills. In the Northern Ireland curriculum, social and collaborative skills also feature prominently. Scotland has a different profile. It operates a different curricular model and practical work appears to focus on the understanding of scientific ideas.

STUDIES OF PRACTICAL SCIENCE

8. The literature provided scant evidence that any of these purposes had been achieved. This was primarily due to a lack of studies with a well-defined focus and appropriate research design. Because there are many types of practical science covering a broad range of purposes, it is important to define what aspects and types of practical work and which outcomes a study is intending to measure. Studies seldom make this clear, leading to vague over-generalisations regarding practical work as a whole. However, considering the scope of the term, it is more logical to discuss the particular activities and their outcomes in practical work. This finding fits into the context of science education research more widely, which tends to lack rigour compared with fields such as literacy and numeracy (Slavin, 2014). One issue is the absence of easily-administered, age-appropriate and standardised science outcome measures.

9. Among the small number of studies that provide data to support their claims, there is some direction in terms of best practice. Teaching structures for practical work that encourage every student to participate and provide opportunity for discussion and reflection (especially through working in small groups) have been shown to have positive results (Taraban et al., 2007; Freedman, 1997). Other studies have either been very specific or over-general in their focus, and few are methodologically robust.

10. The broader aspirations for practical science around developing societal conscience and personal characteristics that featured in several of the national curricula are not reflected in the research studies, which are often concerned instead with the impact on students' conceptual understanding. One possible reason for this might be the problems related to the measurement of those ambitions.

11. The level of a country's development is a factor that also impacts the success of practical science. The least developed, conflict-affected and fragile states often lack the capacity, facilities and teacher training levels to implement practical work effectively. Moreover, the priorities of science education are different in these countries. Rather than facilitating discovery and cutting-edge exploration, the aim is to adopt and build capacity in the existing body of science through conceptual understanding and skill development.

12. A large majority of the research studies reported here have been conducted in the US and the UK, and (to a lesser extent) Australia. These were accessible to our review because they have been published in English. None of these countries feature in the PISA 2012 top ten for science.

2. INTRODUCTION

The Institute for Effective Education was funded by the Gatsby Charitable Foundation to carry out a short small-scale systematic review of the literature and policy documentation around practical science work. The purpose of the review was to inform the science practical work programme that Gatsby has been running for several years. In particular the review was timed to provide background to Gatsby's forthcoming international benchmarking project, designed to answer the question:

What does practical work in secondary school science look like when it is good?

The review had four main aims:

1. To locate any international comparisons of practical work in different countries.
2. To explore the purposes of practical work, as exemplified in curricula and in the research literature.
3. To find studies of what makes good practical work.
4. To make recommendations about whether a more in-depth and systematic review would be justified.

As far as possible, aims (2) and (3) were international in scope.

The team carried out a Rapid Evidence Assessment (REA), based on the toolkit developed by the Government Social Research Service (GSR) to "provide a balanced assessment of what is already known about a policy or practice issue, by using systematic review methods to search and critically appraise existing research" ("Rapid Evidence Assessment Toolkit index," 2013). REAs maintain the rigour and quality of systematic reviews but are more limited in scope. Boundaries have to be drawn in all reviews, and the trade-off with a more rapid and less costly review is that it is less inclusive, while still avoiding bias. The REA approach is less flexible than a larger-scale systematic review, with reduced opportunity for interim changes and last-minute inclusion of reports.

REAs follow a less comprehensive process than full systematic reviews, for instance by limiting the scope of the mapping stage and simplifying the quality appraisal.

Definitions were agreed at the beginning of the REA. Science was defined to include biology, chemistry, physics, earth sciences and astronomy but to exclude engineering, computer science/IT and geography. Practical science was defined as in a Scientific Community Representing Education (SCORE) statement, which reads:

> Practical work in science is a 'hands-on' experience that prompts thinking about the world in which we live. It is made up of a core of two activity types:
>
> - Scientific techniques and procedures, both in the laboratory or the field.
> - Scientific enquiries and investigations.
>
> Each of these core activities not only supports the physical development of skills but also helps shape the understanding of scientific concepts and phenomena. The hands-on approach offered by practical work often challenges students' preconceived ideas and as a result deepens their scientific understanding ("Getting Practical: A framework for practical science in schools," 2014).

For the purposes of this review, practical work included student experiments in laboratories, field studies, the manipulation of natural objects and so on. Passive learning experiences, such as teacher demonstrations with no student interaction or visits to places of scientific interest where no fieldwork or hands-on learning took place, were excluded. Theatrical work and enactment activities, such as the acting out by students of a chemical reaction, also fell outside the scope of this review. Only a few studies concerning these areas were found and had to be rejected, implying either they do not exist in great number or they were missed because the search strings, deliberately, did not target them (see Appendix 1B).

We defined practical work as purposeful activities with distinct learning outcomes and good practical work as practical work that achieves its purposes.

In this report, we link the intended purposes of practical work to five outputs derived from the published literature:

– Enhancement of student understanding of key concepts, which can be variously linked to conceptual learning and increase in achievement.
– Improvement of student physical abilities and manual dexterity, including the measurement, observation and precise manipulation of objects.
– Improvement of student intellectual and personal attributes distinct from those specifically related to the nature of science.
– Increase of student motivation, improvement of engagement and encouragement of post-compulsory study of science.
– Engagement of students with the nature and processes of science, to help them to understand how science and scientists work.

There are two strands to the REA: a cross-country policy focus based primarily on national documentation, and a report on relevant studies about practical work identified from a trawl of the literature.

The countries selected for the policy review were the top ten performers in the 2012 PISA rankings for science[1] in addition to the four countries of the United Kingdom (England, Scotland, Wales and Northern Ireland).

Our inclusion criteria for selecting literature for the review were:

1. Studies had to be relevant to our definition of practical work and science.
2. Studies could use qualitative, quantitative, or mixed methods.
3. Studies evaluated practical science work that took place at least partly among 11–18 year olds.
4. Schools/institutions in the studies could be state or private, including fee paying.
5. Studies could have taken place in any country, but the findings had to be available in English.
6. The date of publication had to be 1995 or later. Older studies that offered important insights or that were the basis of significant future work could be included.

The search included electronic databases, books, journals, websites, conference proceedings and governmental documents. Our main focus was on the Education Resources Information Centre (ERIC) database, Google Scholar and individual journals (International Journal of Science Education, Science Education and Journal of Research in Science Teaching).

We assessed studies for quality of methodology and design, and relevance of the research question and the internal and external validity of the studies. The details of our quality criteria varied according to the type of design used (qualitative or quantitative). Reviewers used their professional judgement of quality based

[1] The Organisation for Economic Co-operation and Development (OECD)'s Programme for International Student Assessment (PISA) evaluates education systems worldwide by testing 15-year-olds in key subjects. Students take a test that lasts two hours. It is a mixture of open-ended and multiple-choice questions organised in groups based on a passage setting out a real-life situation. PISA is a triennial survey so countries and economies participating in successive surveys can compare students' performance over time and assess the impact of education policy decisions.

on their critical appraisal of:

- Sample:
  - Size.
  - Representativeness.
  - Recruitment (eg how selected).
- Data:
  - How collected (eg who, where).
  - Measures/instruments used (eg test, topic guide, survey).
  - Analysis approach (eg statistics used, coding/thematic analysis).
- Rigour:
  - Reporting (justification for methods and analysis).
  - Researcher (objectivity).
  - Credibility of evidence (triangulation, statistical power for quantitative, multi-analysts and respondent validation for qualitative).
  - Generalisability.

Best practice recommends that all papers are screened for inclusion by two people. In this study, after consultation with Gatsby and to ensure completion within the tight timeframe, three reviewers assessed one paper to ensure consistent judgements. Then a single reviewer screened each paper unless there were issues that required consultation.

The report sections are as follows:

- Executive summary.
- Introduction.
- Existing theories about the purposes of practical science.
- What does best practice look like in practical science?
- The purposes of practical science in different curricula.
- The limitations to best practice in science practical work.
- Implementing good practical work in developing and conflict-affected countries.
- Conclusions and recommendations.

The appendices contain short case studies of those countries and curricula that we examined in detail for the report and details of the literature search process. A full list of references is provided at the end of this report and a spreadsheet containing further information about all the qualifying studies, including hyperlinks, is available at www.gatsby.org.uk/GoodPracticalScience

The review team consisted of Dr Mutlu Cukurova and Dr Alexandra Lewis, led by Dr Pam Hanley.

3. EXISTING THEORIES ABOUT THE PURPOSES OF PRACTICAL SCIENCE

In the science education literature, practical work is widely recognised as an essential aspect of the discipline, although there is little agreement on how it should be used in school science teaching or what its main purposes are. Kirschner and Meester state that: "[practical] work is intrinsic to science in general and to the scientist in particular. But how this … can best be used in the instruction of future scientists is still an unanswered and, sometimes hotly disputed, question" (1988, p. 83). Since these words were published almost thirty years ago, the situation does not seem to have neared a resolution. The reality remains that: "Too few attempts have been made so far to uncover the complex cognitive processes that take place during students' engagement in lab work: what happens and why as they carry out laboratory procedures" (Psillos & Niedderer, 2002, p. 3).

Many studies into the effectiveness of practical work lacked clarity and specificity when describing its purposes. White (1996) claims that practical work can be thought to support nearly any aim of teaching science, declaring: "laboratories are so embedded in the practice of science teaching it is difficult to imagine doing without them. Yet their purpose is not universally agreed, and evidence of their effect is equivocal" (p. 761). Practical work can be taken as a proxy for science more widely, as argued by Hofstein and Lunetta: "often the goals articulated for learning in the laboratory have been almost synonymous with those articulated for learning science more generally" (2004, p. 38).

Authors have ascribed numerous purposes to practical work. For Layton (1990), its main purpose is to train students in scientific method, whereas Johnstone and Lettou (1989) see it as increasing manual dexterity. Woolnough (1991) argues that, since the main aim of teaching science is to help students understand its principles and theories, this should also be the main purpose of practical work. Similarly, Millar concludes that: "The aim of science education is to help students develop an understanding of the natural world: what it contains, how it works, and how we can explain and predict its behaviour. So, in teaching science, we build upon students' everyday knowledge of the world around them – and augment this by providing carefully designed activities in which students observe and interact with real objects and materials" (2002, p. 9).

Some scholars have attempted to categorise and catalogue the purposes of practical work, as suggested by other researchers and teachers. For instance, Shulman and Tamir (1973) created five categories to cover all its purposes:

- Skills.
- Concepts.
- Cognitive abilities.
- Understanding the nature of science.
- Attitudes.

Kirschner and Meester (1988) argue that there is a lack of an exhaustive explication of the purposes of practical work in science teaching. Analysing the literature, they catalogued more than 120 objectives for practical work. They claim that: "the stated objectives [of practical work] are either so *detailed* that they can only be of used in specific laboratories in specific disciplines or are so *general* that they can include almost anything one can think of" (p. 87). In summary, they suggest eight general purposes of practical work:

- To formulate hypotheses.
- To solve problems.
- To use knowledge and skills in unfamiliar situations.
- To design experiments to test hypotheses.
- To use laboratory skills in performing experiments.
- To interpret experimental data.
- To describe an experiment clearly.
- To remember the central idea of an experiment across a long time span.

In an attempt to define the goals of practical work in teaching Physics, the American Association of Physics Teachers (AAPT) published a report (AAPT, 1998), prepared by members of the AAPT Committee on Laboratories, along with the Apparatus Committee, the Two-Year College Committee and the Committee on Physics in Undergraduate Education. It is important to clarify here that this publication was not the outcome of a Delphi study of the expert community, but it was rather the outcome of discussions held among the members of the committees involved in the official meeting. The report suggests five categories for the purposes of practical work (for which it prefers the term "laboratory") in physics teaching:

- The art of experimentation: the introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations.
- Experimental and analytical skills: the laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis.
- Conceptual learning: the laboratory should help students master basic physics concepts.
- Understanding the basis of knowledge in physics: the laboratory should help students understand the role of direct observation in physics and to distinguish between inferences based on theory and on the outcomes of experiments.
- Developing collaborative learning skills: the laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavours.

AAPT suggests that practical work activities should be designed with these five fundamental goals in mind.

Hofstein and Lunetta (2004) report that practical work has traditionally been regarded as promoting student improvement and progress in five main categories:

- Understanding of key concepts.
- Interest and motivation in science subjects.
- Scientific practical skills and problem-solving abilities.
- Scientific habits of mind.
- Understanding of the nature of science.

In a more recent study, Nivalainen, Asikainen and Hirvonen (2013) examined research articles related to the purposes of practical work in science teaching and also proposed five categories, which they assert encompass almost all the main objectives of practical work formulated by different scholars and teachers:

- Developing practical or experimental skills.
- Developing an understanding of science content and conceptual understanding.
- Fostering motivation.
- Developing an understanding of the nature of science and of scientific process.
- Enhancing social and learning skills.

There are several commonalities among those studies that aim to categorise the purposes of practical work. By examining the overlaps and key features we have put forward a five-way classification of the purposes, which can be used as a framework for structuring this review. The five groups can be summarised as: enhancing conceptual understanding; improving practical skills; improving non-science-specific abilities; enhancing engagement with the subject of science (improving attitudes being linked with likelihood to continue studying science) and engaging with the scientific method and process. Further details are outlined in Table 1.

Table 1: Five categories of practical work

Primary purpose of practical work	Examples from the curricula
The enhancement of student understanding of key concepts, which can be variously linked to conceptual learning and increase in achievement.	To increase students' understanding of the properties of ionic bonding. To improve students' understanding of how catalysts work in chemical reactions. To help students access conceptually difficult areas of the sciences.
The improvement of student physical abilities and manual dexterity, including measurement, observation and precise manipulation of objects.	To improve students' ability to measure correctly on different scales. To contribute to students' practical skills. To improve students' ability to handle a burette during titration.
The improvement of student intellectual and personal attributes distinct from those specifically related to the nature of science.	To improve students' creativity. To improve students' ability to ask questions. To improve character traits, such as perseverance and initiative.
The increase of student motivation, the improvement of engagement and the encouragement of post-compulsory study of science.	To increase students' motivation to study science subjects. To foster positive attitudes towards science and scientists. To increase students' motivation and engagement in science subjects.
The engagement of students with the nature and processes of science, to help them to understand how science and scientists work.	To be able to identify benefits and limitations of using scientific modelling. To increase students' understanding of the difference between correlation and causation. To develop skills of scientific inquiry and investigation.

4. WHAT DOES BEST PRACTICE LOOK LIKE IN PRACTICAL SCIENCE?

Bearing in mind the wide variety of purposes ascribed to practical work in science, it is important to explore what best practice might look like. This requires a definition of "good practical work". We adopt the position that good practical work is that which meets its purposes. This view is in line with Richard Kraut's philosophy that "good" is that which is productive or that which forms part of the "maturation and exercise of certain cognitive, social, affective, and physical skills" (2007, p. 141). There is an overlap between the categories of the purposes of science proposed in Section 3 (namely, *conceptual understanding, practical skills, non-science-specific attributes, engagement with subject,* and *the nature of science*) and the skills that would mature and be exercised if something is 'good' according to Kraut.

In this section we put forward some examples to illustrate good practical work, as drawn from the literature that met our inclusion criteria. Ideally these examples would come from studies in which a purpose of practical science was clearly stated and tested and in which the results show that the purpose was achieved. However, we found a shortage of research that was clear about which purposes of practical work it was investigating. Other studies could be identified with one of the five purposes in our framework, such as improving students' understanding of key concepts, but the research quality was inadequate. More detail about what was identified within the scope of this limited Rapid Evidence Assessment can be found in the annex to this report.

It is important to note that, as much of the research on the impact of practical science on students and society has been conducted in the US and other affluent, English-speaking countries, we cannot assume that it is generalisable to other nations. The simple reality is that many "findings may not apply to low-income countries; for that matter, a technique found successful in Panama may fail in Chile or Nigeria" (Walberg, 1991, p. 26).

The quality criteria for inclusion in this report were deliberately not restrictive (for instance, we did not specify rigorous experimental or quasi-experimental studies only) and the professional judgement of the reviewers underpinned decisions. Existing literature suggested that there were only a limited number of the highest quality studies and, as befits an exploratory review of the field, our criteria were relaxed accordingly. However, we have commented on the quality of the studies to allow judgement of reliability of the findings. Some we excluded because they were not generalisable (eg Bleicher, 1996, was a case study of one student) and others for being restricted and/or not adopting a systematic approach (eg the literature review in Jokiranta, 2014).

In all, 38 studies were initially identified, ten of which were later excluded mainly because they did not fall within the definition of practical work or did not focus sufficiently on this element. Publications were distributed fairly evenly across the time period examined. The 28 qualifying studies emanated mainly from the UK (7), the US (6), and Australia (4). It was not always easy to ascertain the main aim of some of the studies (see Mulopo & Fowler, 1987, for instance). Where their aims could be identified and aligned to the five purposes defined in this report, nine measured understanding and achievement; six focused on the nature of science; two on attitudes; and two on practical skills. Two studies discussed effects on behaviour, linking with the purpose of developing non-science-specific personal and intellectual attributes. The REA process also identified 18 reviews, reducing to 14 after four were excluded – three because of inadequate coverage of practical science and one for insufficiently rigorous methods. Ten opinion pieces or policy papers were found although two were excluded because they were too general.

The review uncovered very few examples of research that featured international comparisons. Those that existed tended to focus on just two or three countries (eg Swain, Monk & Johnson comparing Egyptian, Korean and UK teachers' attitudes in 1999; Watson, Prieto & Dillon investigating the effect of practical experience on understanding in both England and Spain, 1995). The variety of contexts and methodologies used in different studies makes post-hoc comparison difficult, and designing bespoke international studies is a costly and specialist exercise. In the developing world, research is limited to regional reports by the World Bank, UNESCO and UNICEF, such as the Ottevanger, Akker and Feiter study on Developing Science, Mathematics, and ICT Education in Sub-Saharan Africa (2007). These are policy overviews that aim to strategise new pathways in education, rather than investigations of the impact of existing teaching methods on the ground. In other contexts, comparisons are either limited to two or three case studies, due to the capacity and time limitations of researchers, or are made on a very general level. Sunee Klainin's 1988 publication "Practical work and science education" is a good example of this. She overviews approaches to practical science found in different countries, but turns to the existing academic literature for limitations and implications. This means that practical work is assessed and evaluated in different contexts through different methods by different researchers, leaving an absence of comparable data that could be used to draw out international findings.

It was clear that claims made about practical science in published studies need to be closely examined to ensure they are justified by the evidence. For instance, Haslam and Hamilton (2010) wrote that: "research has found that practical work can improve student achievement in science (Gardner & Gauld, 1990; Lock, 1992)" (p. 1715). However, further investigation of the references reveals that Gardner and Gauld (1990) are discussing the link between laboratory work and attitudes without any direct reference to student achievement in their research study. Lock's (1992) study looks at the gender differences in performance of 18 boys and 18 girls on four problem-solving tasks set in science contexts without any direct reference to students' science achievement.

In one of the rare examples of research that did investigate the impact of practical science on students' achievement in science, Freedman (1997) found that students who had regular (weekly) practical science instruction scored significantly higher ($p<.01$) in the examination of achievement in scientific knowledge than those who had none. The students were randomised to intervention or control conditions and the intervention lasted for 36 weeks. However, the study involved only one school and teachers were allowed to opt into the control condition if they wished. There was no pre-test. The intervention required students to interact with materials and equipment to observe and record phenomena, and the activities were performed cooperatively by small groups. That meant that students were asked to discuss and work together during the practical work, which is also part of many other instruction models: "The model of instruction in which a laboratory influences a change in … [students'] achievement in science knowledge in a ninth-grade physical science course contains many of the elements of other accepted instructional models" (p. 353). These findings are in line with other science education experts' opinions. For instance, Millar (2004) argues that much of the learning from practical science activities often takes place in the discussion that follows the practical activity. He maintains that discussions and practical science activities themselves are very closely related, so that it does not make sense to separate them.

Gunstone and Champagne (1990) argue that the generation of links between activity and teaching by the learners has vital importance to the acquisition of knowledge and understanding and this needs to involve time for interaction and reflection. They suggest that discussions that "allow students to evaluate their own beliefs, observations and interpretations" can promote "appropriate consideration of the nature of their beliefs, observations, interpretations, and ways in which these link with other ideas" (p. 179) and this is a necessary condition for conceptual change.

Even though its emphasis in the literature is clear, the significance of allowing students enough time for discussions and reflection before, during and after practical work appears to be underestimated in the curricula of many of the countries investigated in this review.

Moeed (2011) believes that practical work should be undertaken in meaningful contexts in order to be effective, and that it needs to be followed up with discussions to achieve an increase in students' knowledge and understanding of key concepts in science. She continues her argument by stating that appropriate contexts are a necessity to keep students interested in practical work. She reports findings from two open-ended questions, administered to one year group in one school, that asked for examples of practical work engaged in over the previous year and what the students felt they had learnt from it. This self-reported information, in common with similar large-scale surveys of school science practical work carried out in the UK, could be criticised as being more about the rhetoric of practical work than the reality (Abrahams & Millar, 2008).

Haslam and Hamilton (2010) concluded that text and science equipment in practical science activities should use integrated illustrations (multimedia instructional messages containing pictures and text). Using integrated illustrations in practical science activities, they asserted, decreases the cognitive load and increases the positive effect of practical science on students' knowledge and understanding. Haslam and Hamilton compared the impact of integrated text and illustrations against the impact of traditional practical science activities for one specific activity. It is unclear how the students, who attended two different schools, were assigned to treatment. Those who received integrated instructions scored better, not only for practical science performance, but also knowledge of, and understanding about, science content tests than did peers who received traditional instructions. This result indicates that students' understanding was facilitated to a higher degree with integrated illustrations compared to the traditional conditions and is in line with the idea that integrated illustrations make instructions easier to understand (Marcus, Cooper, & Sweller, 1996; Mayer & Moreno, 1998).

Palmer (2009) designed a study to investigate "situational interest", a short-term form of motivation initiated by a specific situation, during a science lesson. Small groups of participants attended the researcher-led lesson, which was delivered to the same basic structure on each occasion. Students were asked to rate their interest in different sections of the lesson. Palmer found that situations with a "wow factor" were highly-rated and concluded that novelty is students' main source of interest in practical science. According to Palmer: "novelty is closely related to learning because when one learns something, one is learning something new. Novelty is therefore always present in the learning process" (p. 158).

Taraban et al. (2007) evaluated the use of hands-on, inquiry-oriented practical work incorporating real-life contexts and cooperative learning in comparison with business-as-usual control conditions where teachers continued with their usual methods. Teacher survey responses suggested the control conditions were more dependent on lecturing and textbooks and featured considerably less (but not zero) hands-on activities. The study was designed to measure gains related to content knowledge, process skills and attitudes towards science. A cross-over design was used (each of the six teachers taught two topics, one using the intervention approach and one in their traditional manner) and 408 students participated. Written science tests showed that students had gained significantly more content knowledge and knowledge of process skills from the intervention approach than through more conventional teaching. Additionally, students expressed a preference for the active-learning practical science environment in post-intervention questionnaires.

Keys et al. (1999) introduced a science writing heuristic as a framework for guiding practical work to achieve learning. It consisted of a teacher template to help teachers plan the stages of a practical activity, and a student template with prompt questions to guide student thinking. One element of implementation was that students worked in small groups to discuss and develop concept maps. The results of this study suggested the tool helped students to generate meaning from data; make connections among procedures, data, evidence, and claims; and engage in metacognition. However, the study was confined to two classes of students and there was no comparison group.

Abrahams and Millar (2008) conducted a study of 11-16 year olds in England, which suggested that the practical work they experienced was more effective at improving practical skills than enhancing understanding or reflection. However, this research was very small scale and there were no details about how the eight schools involved were chosen, nor how they selected which lessons to observe, or which teachers and students to interview.

The evidence presented above suggests that a key feature of good practical science for enhancing understanding is that it should give students sufficient time and space for discussions, interaction and reflection. However, this does not seem to reflect the essence of many secondary school practical science activities in the countries in this review, including the UK (Abrahams & Millar, 2008).

There is more published research suggesting that practical work improves practical and technical skills than evidence for achieving the other four purposes (especially improving conceptual understanding). However, the absence of large studies with good research designs makes it impossible to determine whether or not practical work across the spectrum is effective in achieving its ends (where these are articulated) or not.

5. THE PURPOSES OF PRACTICAL SCIENCE IN DIFFERENT CURRICULA

In the book based on the European project "Labwork in science education", Dimitris Psillos and Hand Niedderer declare (in accordance with our preceding sections): "policy-makers worldwide are convinced of the value of labwork" (2002, p. 21). According to Jerry Wellington: "We have experienced over 100 years of school science practical work and witnessed the coming (and sometimes going) of the heuristic approach, discovery methods, the 'Nuffield philosophy', investigational work, the process movement and the 'problem-solving' approach, to mention but a few" (Wellington, 1998). He maintains that the implementation of practical work changes over time in relation to various phases and fashions at the policy level. For example, in the US, from the 1960s the inquiry-based approach to learning, which includes the encouragement of students to draw "upon their scientific knowledge to ask scientifically oriented questions, collect and analyze evidence from scientific investigations, develop explanations of scientific phenomena, and communicate those explanations with their teacher and peers" (Furtak, Seidel, Iverson & Briggs 2012, p. 301), was prioritised in science teaching. This approach was subsequently adopted in other countries (Abd-El-Khalick et al., 2004). More recently, a similar trend has been seen with the focus on scientific literacy and the nature of science (Lederman, 2006). However, for Wellington, practical work persists as a constant in secondary education, with the Bunsen burner as its symbol. Although writing primarily about practical science in England, his position is widely applicable in the developed world as demonstrated by the following comparative analysis of secondary school science in high-performing PISA 2012 countries.

The five main purposes of practical science education as categorised in Table 1 relate to *conceptual understanding, practical skills, non-science-specific attributes, engagement with subject (attitudes)*, and *the nature of science*. Looking at the top 10 ranking countries in the PISA 2012 index, it is evident that these purposes are reflected not only in the academic literature, but also in national curricula. The learning objectives for practical science in each country are summarised in Table 2 and mapped onto the relevant purposes. These were often implicit in the curriculum and required careful analysis and interpretation to unpack. One, two or even three key purposes emerged from the curricula (or substitute literature) for each country based on an analysis of mentions. The relevant sections of documentation have been paraphrased while maintaining key country-specific terminology. The case study countries are described in more detail in Appendix 1A.

All five purposes are represented to varying degrees in the curricula we surveyed, apart from Shanghai-China, the highest performer in science on the PISA 2012 Index. Here, the focus of practical science seems to be more grounded in achievable, measurable outputs focusing on practical skills, such as observation, experimentation and scientific investigation, to the exclusion of other purposes.

Each of the four countries of the UK also referenced these five purposes to some degree. The science curriculum in England relates practical science to developing all aspects of inquiry skills, running from appropriate planning, the practicalities of conducting an experiment (eg observation and measurement), classifying and comparing data, through to reporting scientific evidence. Students are encouraged to develop their scientific thinking, consider the nature of theories, and – albeit to a lesser extent than in the previous iteration of the curriculum – to reflect on wider social and ethical issues around science investigations. Likewise in Wales there is an emphasis on using practical work to improve inquiry, along with problem-solving and technical skills. It is seen as a way of helping students to study the relationship between data, evidence, theories and explanations.

There are similarities between the Northern Ireland curriculum and those of England and Wales in the emphasis on investigative skills. Inquiry-based and problem-centred investigations are seen as a means to foster more critical and creative thinking as well as improving physical abilities.

In Scotland, the architecture of the curriculum is very different to the other countries considered here: it is not categorised by topic or stage. This makes it harder to unpack the purposes of practical science. The stress is on understanding and attitudes towards science. Hands-on work and the associated discussion are perceived as stimulating students' interest and engagement in science more broadly, improving knowledge and leading to increased achievement.

Contextualised structure of practical work is mentioned in the national science curricula of all countries included in this review. Practical work in Singapore aims to guide students in acquiring knowledge with understanding for application in their daily lives. To do so, students are motivated to learn science through contextual hands-on learning.

However, the most commonly recurring purpose across the top 10 PISA 2012 countries is the development of intellectual attributes that are not specific to science. These personal characteristics include confidence, the ability to work independently or as part of a team, ingenuity and perseverance. In countries that are high performing for scientific education, practical science is generally but not universally intended to help in the development of well-rounded individuals with diverse abilities, enabling students to appreciate and engage with the broader world around them. In Vietnam, this entails the encouragement of personal characteristics such as activeness (a willingness and confidence to engage actively with daily challenges), voluntariness (exercising free will), initiative and creativity. These attributes are key characteristics of proactive individuals, in which case it may be surmised that the purposes of practical science in Vietnam are to do with discouraging passivity in Vietnamese citizens. In Hong Kong, the stated aim of similar curricular designs is to encourage ingenuity and perseverance in students.

For Singapore, South Korea and Poland, ambitions appear to be loftier still. For Singapore, practical science is intended to help students to become concerned citizens and active contributors to the world, adaptable to changeability and capable of acting in a socially responsible manner. For South Korea, practical science promotes positive interactions with the natural world for students, thereby producing individuals capable of living environmentally sustainable lifestyles. For Poland, practical science builds the capacity of students to act as reasonable citizens in everyday life.

This purpose is less evident in the UK context. The exception is Northern Ireland, where practical science is viewed as an opportunity to nurture collaborative behaviour, important in the broader context of the "mutual understanding" thread that runs through some of that country's other subject curricula.

The widespread curricular emphasis on these broader intellectual aspects, with implications beyond the narrow subject-specificity of science, contrasts with the tendency of the research studies to focus on the effects of practical work on improving students' understanding of key scientific concepts.

Table 2: Purposes of practical work in high performing PISA 2012 countries

PISA 2012 Ranking (Science)	Country	Stated purpose of practical work	Purposes most emphasised
1	Shanghai-China	Experimental skills training: improving students' skills of measuring, observing or interpreting the effects of a planned intervention in the material world to test a prediction.	Practical skills
2	Hong Kong	To allow students to show their interest, ingenuity and perseverance in science classrooms.	Intellectual attributes Attitudes
3	Singapore	To prepare students to be confident, self-directed learners who are concerned citizens and active contributors in a world where change is the only constant.	Intellectual attributes Practical skills
4	Japan	To enable students to learn observational and experimental skills, to develop the ability to give consideration to the results of observations and experiments, and to develop and express their own ideas. At the same time, to enable students to understand familiar physical phenomena.	Understanding Practical skills Intellectual attributes
5	Finland	To contribute to students' understanding of the significance of experimentation and theoretical speculation in the formation of knowledge in science, and how knowledge is built up in science through experimentation and related modelling.	Nature of science
6	Estonia	To improve students' knowledge acquisition and understanding of concepts related to specific science topics. To improve students' ability to analyse and interpret directly perceived phenomena, as well as phenomena imperceptible to our senses at the micro, macro and mega levels. To appreciate the role of models and their limitations in describing such phenomena.	Understanding Nature of science
7	South Korea	To build confidence in the implementation of manual research methods. To promote enthusiasm for the sciences. To promote positive interactions with the natural world and create individuals capable of living environmentally sustainable lifestyles.	Practical skills Intellectual attributes Attitudes
8	Vietnam	To develop personal characteristics, including: activeness, voluntariness, initiative and creativity. To develop critical thinking. To generate enthusiasm for the sciences.	Intellectual attributes Attitudes
9	Poland	To develop scientific thinking. To improve critical reasoning. To develop students' abilities to use research methods. To build capacity of students to act as reasonable citizens in everyday life.	Intellectual attributes
10	Canada	Practical science is intended to help students to develop four sets of skills of scientific investigation: initiating and planning, performing and recording, analysing and interpreting, and communicating.	Practical skills

Table 2: Purposes of practical work in high performing PISA 2012 countries

PISA 2012 Ranking (Science)	Country	Stated purpose of practical work	Purposes most emphasised
18	England	Practical work is strongly related to students' inquiry skills including their ability to ask questions, make careful observations, identify, classify, compare, and report scientific evidence.	Practical Skills Nature of Science
22	Scotland	Practical work should act as a motivation for progressively developing skills, knowledge, understanding and attitudes, and so maximise achievement.	Attitudes Understanding
24	N. Ireland	Practical work is considered to serve as a means to increase students' investigation skills. To improve students' physical skills as well as their collaboration and social skills. To increase motivation.	Practical Skills Intellectual Attributes Nature of Science
36	Wales	Practical work is seen as an opportunity for students to consider the relationship between data, evidence, theories and explanations. To develop practical, problem-solving, and inquiry skills.	Practical Skills Nature of Science

6. THE LIMITATIONS ON BEST PRACTICE IN SCIENCE PRACTICAL WORK

We have seen in previous sections of this report that practical work in the sciences is taught for a range of ambitious purposes, from increasing student comprehension to igniting enthusiasm for scientific study and enabling students to engage with the methods and nature of scientific inquiry. With such lofty aspirations, it is not surprising that practical work has not always delivered on all its goals. This can be for a variety of reasons: teachers may lack the training and capacity to implement it effectively; not every student shares a passion for hands-on learning activities; and learning outcomes may not be linked effectively to experiment processes (Abrahams and Millar, 2008; Dillon, 2008; Hodson, 1991). Such shortcomings have fuelled a wealth of critical engagement with practical work, in which limitations are associated with each of the purposes of practical work outlined in preceding sections. Table 3 summarises the main limitations identified for each of the five purposes along with references to the relevant studies.

Central to the debate, as Clackson and Wright summarise, is the notion that: "Although practical work is commonly considered to be invaluable in science teaching, research shows that it is not necessarily so valuable in science learning" (1992, p. 40). The true impact of practical work on students has been difficult to determine and even more difficult to demonstrate. It has been almost impossible to prove any definitive connection between hands-on learning and increased conceptual understanding of key scientific phenomena among students. For example, in a small-scale study comparing traditional teaching with discovery learning in Zambia, Mulopo & Fowler (1987) found that the control group, who had been taught traditionally, outperformed the discovery learning group, although there was some indication that the latter group might have benefited more in terms of improved attitudes and appreciation of the nature of science. More recently, in a large pre/post-test design, Pine et al. (2006) compared hands-on and textbook curricula and found no significant curricular effect on students' science inquiry abilities. Watson, Prieto and Dillon (1995) probed the difference in students' understanding of combustion reactions in two different countries, Spain and England. They found that, although the responses of English and Spanish students are significantly different, the more extensive use of practical work in English schools has only a marginal effect on students' understanding of combustion.

There is very little robust research evidence to support or reject the claims made by policy makers and educators, and inherent in many science curricula, regarding the benefits of practical work. It could be, as Jonathan Osborne argues, that practical work "only has a strictly limited role to play in learning science and that much of it is of little educational value" (1998, p. 156). If this is the case, then the positioning of practical work as a central component of science education may not be universally productive, particularly considering the additional costs of implementing practical work for schools. However, the research base is weak so equally there is no conclusive evidence that practical work has no impact on students.

One intended purpose of good practical work, as defined in preceding sections, is to increase student comprehension of the material covered in class, i.e. aid conceptual understanding (Gunstone & Champagne, 1990). Yet research on the use of practical work in South Korea (the 7th highest performing country on the PISA 2012 index), indicates that, in reality, teachers rarely use practical-based teaching to improve student understanding, and practical science is generally associated with "concept confirmation" rather than "concept comprehension"(Shim, Moon, Kil, & Kim, 2014, p. 2). Justin Dillon (2008) confirms that much of the critical literature indicates that theory and practice are not always linked effectively in classroom learning. Studies in Zambia have also shown little or no correlation between student understanding and practical work (Mulopo & Fowler, 1987). In general: "research has failed to show simple relationships between experiences in the laboratory and student learning" (Hofstein & Mamlok-Naaman, 2007, p. 2).

Derek Hodson (one of the most frequently cited authorities on the subject) claims that practical work in the sciences should only be used among students who are already familiar and happy with relevant scientific concepts (1991), otherwise practical work simply becomes too confusing and unproductive, with no clear linkages between activities and learning (1993). In a similar vein, Sweller, Kirschner and Clark (2007) suggested that students should be carefully guided towards accurate constructions, understandings and solutions during practical work.

Strict guidance during practical work undermines one of the stated goals of practical work, which is to build intellectual attributes such as creativity and independent thinking. The danger is that leaving students on their own to discover solutions is very unlikely to lead to scientifically accurate learning (Taber, 2011) and might lead to an increase in the number of student misunderstandings (Cukurova, 2014). Because practical work in the sciences takes place in a classroom environment with little opportunity for long-term research, it is by nature prescriptive and leaves little room for innovation or the kind of experimentation that is at the heart of scientific progress (Abrahams & Reiss, 2012). The inevitable constraints introduced by fitting an activity into a lesson slot of perhaps less than an hour can lead to unforeseen compromises. For instance, Jordan, Ruibal-Villasenor, Hmelo-Silver and Etkina (2011) found that providing students with laboratory equipment before they plan and consider different experimental approaches can limit their ideas and encourage tool-focused solutions to experimental design tasks.

Robin Millar argues that criticisms directed at practical science stem from the conflation of all practical activities into one category: "If we are interested in the effectiveness of practical work, we really have to consider specific practical activities that we use, or plan to use", because "practical activities differ considerably in what they ask students to do and what they are trying to teach" (2009, p.3). According to Millar, practical work can be divided into two categories: one that allows students to see and remember an observable event; and one that enables students to develop their understanding of specific scientific ideas. Referring to the second category, Millar writes that it is "unreasonable to expect durable long-term learning of a scientific idea or concept to result from a single, relatively brief, practical activity" (p. 5) leading to limitations in what can be realistically accomplished at the school level.

Table 3: Limitations of practical work as identified by classroom studies

Purpose of practical work	Identified limitations	Relevant sources
The enhancement of student understanding of key concepts, which can be variously linked to conceptual learning and increase in achievement.	Theory and practice are not always linked effectively in classroom learning. It has been very difficult to prove any connection between hands-on learning and increased conceptual understanding. Practical science is about 'concept confirmation', not 'concept comprehension'.	(Dillon, 2008) (Mulopo & Fowler, 1987) (Shim, K.C.; Moon, S.H.; Kil, J.H., & Kim, K., 2014)
The improvement of student physical abilities and manual dexterity, including measurement, observation and precise manipulation of objects.	The evidence of practical work building transferrable skills related to the manipulation of objects and observation of phenomena among students is limited.	(Lave, 1998)
The improvement of student intellectual attributes distinct from those specifically related to the nature of science.	Practical work in the sciences is often about following procedures and replicating specific results: there is little room for creativity and innovation.	(Abrahams & Reiss, 2012)
The increase of student motivation, the improvement of engagement and the encouragement of post-compulsory study of science.	Research that is admittedly dated and conducted in the developed world indicates that practical work has only limited success in generating increased interest in the sciences, particularly among girls.	(Qualter, 1993)
The engagement of students with the nature and processes of science, to help them to understand how science and scientists work.	Due to pedagogical limitations and the reality that most science classes are less than two hours long, in-class practical work commonly follows a set recipe that has little in common with professional scientific research.	(Abrahams & Reiss, 2012)

7. IMPLEMENTING GOOD PRACTICAL WORK IN DEVELOPING AND CONFLICT-AFFECTED COUNTRIES

The review has shown that the purposes and methods of teaching science practical work vary from country to country, and this is particularly apparent between high- and low-income countries. As Keith Lewin writes, the orthodox view – adopted by policymakers and education practitioners in countries evidencing best practice in the developed world – is that science education should stress the "importance of discovery, invention and understandings of the natural world over application, improvement of already existing technologies, and the development of scientific knowledge related to the needs of the poor and marginalised" (2000, p. 1).
In developing, fragile and conflict-affected countries, science education needs not only to generate intrigue and curiosity in scientific phenomena among students but also spur development and peacebuilding, while also compensating for a national-level phenomenon of brain drain in the scientific community (occurring as scientific minds are lost to economic or labour migration, displacement, trauma, permanent injury, or death (Docquier, Lohest, & Marfouq, 2007).

Educational and scientific capacity is linked to economic recovery (Barclay, 2002, p. 42). When educational attainment levels in the sciences increase, developing countries gain the capacity to build essential infrastructure in key development sectors, including healthcare, agriculture, mining and other resource extraction, and production. Science education is not only about the pursuit of knowledge; it is also about playing catch up with the developed world.

Research on practical science is primarily conducted in the developed world and findings may be less relevant to low income countries (Walberg, 1991, p. 26). Indeed, Lewin (2000) argues that there is a contrast between the emphasis of science education in the developed world, which highlights scientific discoveries and the development of cutting edge science, and the developing world, where the need to adopt and adapt pre-existing knowledge to new contexts demands the prioritisation of conceptual understanding and skill development over creativity. Criticisms directed at practical science in the developed world – that in its implementation it encourages students to replicate rather than comprehend results and allows them only to practice lower level skills (Lunetta, Hofstein, & Clough, 2007, p. 403) – may not apply where the purpose of practical science education is to create students capable of reproducing, rather than innovating, scientific progress.

The primary restriction to effective practical science provision in developing countries is capacity, both in terms of the availability of qualified teaching staff, and of the capacity of teaching facilities to provide safe and appropriately-equipped environments for hands-on learning. Moreover, teachers may struggle to make the aims and content accessible to students from a wide range of ability and prior educational experience, especially where schooling has been disrupted by war or natural disaster (Ottevanger, Akker, & Feiter, 2007, p. 13).
There is a long history of secondary science being taught poorly by underqualified teachers struggling with curricula that are either urban-biased, or founded on international textbooks based on unfamiliar and inaccessible examples, philosophies and moralities (Lewin, 1989, p. 674). Laboratories and teaching equipment have been under-utilised in cases where teaching staff have lacked the confidence to perform practical activities (Psacharopoulos & Woodhall, 1985). Innovation is often limited by a donor emphasis on reproducing accepted international norms and ideals in developing countries and states recovering from conflict, encouraging them to implement curricula based on British A levels, for instance, among other systems (Ottevanger et al., 2007, p. 13).

The general trend in education design and provision in developing countries, as evidenced by ten countries surveyed in sub-Saharan Africa,[2] is "away from the restrictive, expensive, fixed-service bench laboratories toward the more flexible – and cheaper – option of a serviced room", encouraging simple and easily-replicable experiments (Ottevanger et al., 2007, p. xiii). Mobile laboratories touring from city to city (Agatsya International Foundation, 2008), lab-in-a-box ("Lab in a Box (LIB)", 2014) and fab labs (Mandavilli, 2006) are examples of the programmes intended to engage children in experiments, hands-on learning and fieldwork. The evidence suggests that the introduction of practical science to communities that previously did not have access to hands-on learning opportunities in formalised education settings has led to increased rates of student retention in the sciences, re-enrolment by students that had previously left school prior to completion (Raghavan, 2006), and increased participation by girls in the sciences (Dlodlo & Beyers, 2014). However, this evidence is limited, being drawn primarily from reports by vested interests, rather than from rigorous evaluations. Broad country comparisons are lacking, particularly in fragile and conflict-affected states, where it is difficult to conduct research.

In a similar attempt to introduce low-cost practical science in less affluent settings, UNESCO has funded the development of microscale chemistry (Bradley, 2001). A Malaysian study (Abdullah et al., 2009) claimed that an individualised, microscale approach can increase students' understanding of chemistry concepts. Although the evaluation had an experimental design, it was very small-scale (three control classes from one school and three intervention classes from another, comprising 170 students in total).

[2] Countries surveyed were Botswana, Burkina Faso, Ghana, Namibia, Nigeria, Senegal, South Africa, Uganda, Tanzania and Zimbabwe.

8. CONCLUSIONS AND RECOMMENDATIONS

Many different purposes for practical work in science education have been identified in the literature. We have rationalised these into a five-way categorisation to form a working framework for this review. These over-arching purposes are to:

- Develop an understanding of key concepts, which can manifest as conceptual learning and increase in achievement.
- Improve the ability of a student to undertake practical work, for example manual dexterity and observation skills.
- Enhance intellectual capacities that are not specific to science, such as creativity, critical thinking and questioning.
- Increase student motivation and engagement with science.
- Involve students with the nature of science: to understand scientific processes and how scientists work.

An examination of the curricula of the top performing countries in the PISA 2012 science rankings found that most of their national curricula feature all of these purposes to different extents. The most prevalent is the category of building intellectual capacity that is not specific to science. With the exception of Shanghai-China, there is an expectation that practical science will develop intellectual attributes and qualities that are generalisable far beyond the scientific discipline. Practical science is seen as a way of producing involved citizens (Singapore, Poland) and enabling people to live in an environmentally sustainable manner (South Korea). It is also credited with the power to influence character traits such as fostering perseverance (Hong Kong), creating confident and self-directed in learners (Singapore) and reducing passivity (Vietnam). However, some key purposes are more closely related to the practical nature of the activities, including improving experimental skills (Shanghai-China) and appreciating the role of experimentation in knowledge building (Finland).

Within the UK, the development of inquiry and practical skills tends to dominate, especially in England, Wales and Northern Ireland. In Scotland, more prominence is given to the potential of practical science to engage and motivate students as well as directly improving knowledge and understanding. The building of intellectual capacity not specific to science features most strongly in Northern Ireland, where collaborative skills promoted in group work are valued as a way of building mutual understanding. To a lesser degree, the Scottish curriculum also links practical science with collaborative working.

The picture is very different in the least developed countries. Here, state capacity to deliver practical work in the sciences is diminished. Interrupted schooling leaves teachers struggling to accommodate students from diverse backgrounds, age groups and levels of pre-existing knowledge, often within only a handful of classes. The schools that teachers work in can be ill-equipped, without proper laboratory facilities. Furthermore, teachers themselves may lack training in practical skills and scientific methods, and consequently may lack the confidence and the ability to teach these processes effectively. Within such contexts, countries set goals that are easier to meet than the lofty goals espoused by high-performers in the PISA index. Rather than prioritising the ability of students to innovate, an emphasis is placed upon helping students to replicate existing procedures and technologies.

It might be expected that researchers would struggle to furnish evidence for some of the more idealistic and long-term aims of practical science, such as creating more engaged citizens. The reality is that there is very little evidence available about whether practical science is adequately delivering on any of the diverse range of expectations. This is compounded in developing countries by a lack of any systematic research on existing science programmes and curricula.

We searched the literature for international studies where the purpose of practical science was clearly stated; where the research was well designed and had used appropriate measures; and where the results showed whether or not the purpose had been achieved. Few published articles met these criteria, and experimental studies using randomised or matched control groups were rare. This lack of rigorous experimental studies is not confined to practical science; it is a wider issue within science education (Cheung, Slavin, Lake & Kim, 2015). The outcome measures in the studies were also problematic, with widespread use of surveys and self-report or teacher report. As a result, there was little convincing evidence of a link between participation in science practical work and improvements in achievement.

Practices that encourage every student to participate and provide space and structure for them to discuss and reflect on their learning emerge as those with most promise for enhancing knowledge and conceptual understanding through practical science. Often these approaches are delivered through some form of collaborative or co-operative learning, with students working in small groups (Freedman, 1997; Taraban et al., 2007). This accords with other reviews that have concluded that, in the science classroom, the effectiveness of the teaching has more impact than the materials used (Cheung et al, 2015).

There were one-off studies for other specific aspects of practical work, but most of these were of tangential relevance or were too methodologically weak to generate meaningful conclusions.

Findings are limited in their impact by an absence of cross-country comparisons of practical work. There have been few attempts to compare practical work across multiple case studies.

It would be possible to conduct an in-depth, systematic review to uncover more studies. However, the incremental benefit of this is questionable. The studies are likely to be in a similar vein to the ones identified in this report: too generalised and not rigorous enough to add usefully to the body of knowledge about practical science. Currently, there are insufficient evidence-based studies to determine whether expectations for practical science have been set too high. At this stage, it is unlikely that more reviews would help the situation. The real need is for more focused and robust studies.

APPENDIX 1A: CASE STUDY CURRICULA

SHANGHAI-CHINA

Table 4: Practical work in Shanghai-China

2012 PISA ranking	1
Definition of practical work	Teaching methods that require students' direct interaction with observable measures through experimental activities.
Purposes of practical work	To improve students' skills when measuring, observing or interpreting the effects of a planned intervention in the material world to test a prediction.

Shanghai-China, ranked 1st in science in PISA 2012, was possibly the hardest country to review in this assessment, due to a lack of legal documents translated into English. Hence, in this review, specifically for Shanghai-China, we used publications related to the country's curriculum and personal communications with science education scholars from the country.

In Shanghai-China, in secondary schools, the overall science curriculum is divided into physics, biology, earth science, and chemistry (similar to many other curricula reviewed in this report), which each have an independent curriculum. All are published in Chinese-based languages and, to the best of our knowledge, English versions do not exist. There are national standards for those independent curricula (Zhaoning, pers. comm., 21 February 2015) but these are also in Chinese, which makes the investigation of this country's legal documents very hard for researchers who cannot read the relevant Chinese language.

In a 2001 curriculum reform, the first National Curriculum Standard of Science Education for grades 7–9 was issued by the ministry of Education in Shanghai-China. According to documents related to the reform in 2001, practical work is seen as an opportunity to do "experimental skills training". Purposes of practical work in science curricula were often associated with purposes of experiments in science in general rather than practical activities of students in science classrooms. Stated purposes of practical work in science teaching included improving students' skills of measuring, observing or interpreting the effects of a planned intervention in the material world to test a prediction.

HONG KONG

Table 5: Practical work in Hong Kong

2012 PISA ranking	2
Definition of practical work	Practical work and scientific investigations are defined as common teaching activities that give students 'hands-on' experience of exploring.
Purposes of practical work	To improve students' practical skills. To give students personal experience of doing and finding out things. To develop students' understanding of scientific concepts and principles as well as their ability to handle and interpret data obtained in investigations.

In Hong Kong-China, ranked 2nd in science in PISA 2012, all science curricula for secondary schools have versions in English and other languages. In national curricula, practical work and scientific investigations are defined as common activities in the learning and teaching of science subjects. They are seen as an opportunity to give students hands-on experience of exploring. Practical work can be used, as stated in the national curriculum for science, to enable students "to show their interest, ingenuity and perseverance" in science classrooms.

Numerous purposes for using practical work in teaching science are stated (explicitly and implicitly) in national science curricula for Hong Kong-China. One purpose of practical work particularly emphasised in the curricula is to improve students' practical skills related to scientific investigations such as the "ability to design experiments and to do careful and accurate measurements". It is seen as essential for students to gain personal experience of science through doing and discovering things.

Another, less emphasised, objective of practical work is its likely contribution to students' understanding of scientific concepts and principles, and their ability to handle and interpret data obtained in investigations. These curricula mention practical work many times. Practical work was associated with various terms including students' attitudes, values, knowledge, understanding and skills including problem-solving skills, critical thinking skills, creativity, strategies for learning how to learn, and ability to define problems. However, those purposes are related to science teaching in general rather than exclusively or explicitly to practical work.

It is worth mentioning here that throughout the curricula there is a clear emphasise on the importance of scaffolding during practical work in order to be able to achieve its purposes.

SINGAPORE

Table 6: Practical work in Singapore

2012 PISA ranking	3
Definition of practical work	Practical activities in which students are asked to interact with the material world.
Purposes of practical work	To generate confident, self-directed learners. To increase students' ability to select and organise techniques, apparatus and materials for scientific experiments; handle experimental data and observations; interpret and evaluate experimental results.

Singapore was ranked 3rd in science in PISA 2012. The National Curriculum for Lower and Upper Secondary Schools states: "Scientific subjects are, by their nature, experimental. It is therefore important that the candidates carry out appropriate practical work to facilitate the learning of this subject". The national curriculum was revised in 2013 and puts great emphasis on the 21st Century Competencies Framework. This framework aims "to prepare students to be confident, self-directed learners who are concerned citizens and active contributors of a world where change is the only constant". Most of the stated purposes of practical work relate to students' practical skills improvement. It is expected that students can improve various skills through practical work, including "the ability to select and organise techniques, apparatus and materials for scientific experiments; take readings accurately; handle experimental data and observations; and interpret and evaluate experimental results".

JAPAN

Table 7: Practical work in Japan

2012 PISA ranking	4
Definition of practical work	Hands-on activities used in science teaching to facilitate the learning of the subject.
Purposes of practical work	To enable students to learn observational and experimental skills. To develop the ability to give consideration to the results of observations and experiments. To develop and express students' own ideas, and at the same time, to enable students to understand familiar physical phenomena.

In Japan, ranked 4th in science in PISA 2012, the national curricula for both upper and lower secondary school science have certain objectives, which are more abstract than the ones stated in other countries' science curricula reviewed in this assessment. For instance, one of the overall objectives of science teaching borders on spiritual: "Nurturing hearts and minds that are filled with an affection for the natural world". Similar themes can be observed throughout the curricula and are reflected in the purposes of practical work in science teaching in Japan. In national curricula, when referring to practical work, "hands-on" activities (possibly a more general term) are preferred.

For the lower secondary level the purposes of practical work are stated as: "To enable students to learn observational and experimental skills; to develop the ability to give consideration to the results of observations and experiments; and to develop and express their own ideas, and at the same time, to enable students to understand familiar physical phenomena".

For upper secondary schools, stated purposes of practical work involve: "Enhancing students' interest in nature and sense of inquiry; enabling them to carry out observations and experiments; developing attitudes and abilities to investigate scientifically, and at the same time, deepening their understanding of natural events and phenomena and developing scientific views of nature". It becomes clear in national curricula of science in Japan that "improving students' understanding" is, perhaps to a greater extent than other countries, presented as a purpose of using practical work in science teaching.

One further important difference in the national science curricula of Japan compared with other countries investigated is that there are explicit references to discovery-based learning in practical work activities. Practical work is seen as an opportunity for students to investigate concrete examples and improve their understanding of those examples with the help of discovery-based learning strategies.

FINLAND

Table 8: Practical work in Finland

2012 PISA ranking	5
Definition of practical work	Activities through which students acquire information based on observation and experimentation.
Purposes of practical work	To improve students' science process skills. To increase students' understanding of the significance of experimentation and theoretical speculation in the formation of knowledge in science. To develop students' ability to interpret, assess, present and discuss information.

Finland was ranked 5th in science in PISA 2012. According to the National Core Curriculum for Upper Secondary Schools published by the Finnish National Board of Education in 2003, science subjects are "characterised by the acquisition of information based on observation and experimentation". The curriculum has numerous references to practical work activities and often uses the word "experimentation" instead of practical work.

Stated purposes for doing practical work in school science in the national curriculum are often related to science process skills, such as making observations and measurements or creating models for use in explaining natural phenomena. Practical work is expected to contribute to students' understanding of "the significance of experimentation and theoretical speculation in the formation of knowledge in science" and "how knowledge is built up in science through experimentation and related modelling". It is claimed that students can learn "how to plan and carry out experiments concerning different phenomena, taking safety considerations into account" through practical work.

Practical work is associated with a possible improvement in students' ability to interpret, assess, present and discuss information acquired through experimentation and with students' aptitude for scientific work, team behaviour and their ability to use different sources of scientific information and assess information critically.

ESTONIA

Table 9: Practical work in Estonia

2012 PISA ranking	6
Definition of practical work	Hands-on learning activities applied in schools to facilitate students' learning.
Purposes of practical work	To improve students' knowledge acquisition and understanding of concepts. To improve students' ability to analyse and interpret directly perceived phenomena. To increase students' skills at investigating problems, framing hypotheses, controlling variables, collecting data/evidence through observations or experimentation, analysing and interpreting results.

Estonia was ranked 6th in science in PISA 2012. National curricula for secondary school science (last revised in 2011) include syllabuses, which incorporate specific practical work activities and related learning outcomes for each topic within every natural science subject. These learning outcomes mainly focus on students' knowledge acquisition and understanding of concepts related to specific science topics.

Secondary science curricula include purposes general to all practical activities suggested in the syllabuses. One of those purposes is related to improve students' ability "to analyse and interpret directly perceived phenomena, as well as phenomena imperceptible to our senses at the micro, macro and mega levels, and appreciate the role of models and their limitations in describing such phenomena". Another purpose of practical work in Estonian science teaching is to increase students' "skills at investigating problems, framing hypotheses, controlling variables, collecting data/evidence through observations or experimentation, analysing and interpreting results and presenting conclusions indicating the solution to the scientific problem as well as limitations and sources of error involved".

In the national science curricula there is an emphasis on improving students' ability to find and use appropriate sources of scientific and technological information presented at the verbal, numerical or symbolic level and their ability to critically evaluate and appreciate such information from both a personal and social viewpoint. This aspect of practical work (that there are many practical work examples in which students were asked to search information from other sources such as the Internet and libraries) is emphasised more in Estonia than in other case study countries.

SOUTH KOREA

Table 10: Practical work in South Korea

2012 PISA ranking	7
Definition of practical work	The use of practical methods and hands-on learning activities, including investigations and laboratory work.
Purposes of practical work	To build confidence in the implementation of manual research methods. To promote enthusiasm for the sciences. To promote positive interactions with the natural world and create individuals capable of living environmentally sustainable lifestyles.

South Korea is ranked 7th among the highest performing countries on the PISA 2012 framework. South Korean secondary education is provided to students aged 15–19 in high schools.

School curricula for South Korea are not available online in English. Information for this review has been taken from:

1. Kim, Fisher and Fraser, Classroom Environment and Teacher Interpersonal Behaviour in Secondary Science Classes in Korea (2010).
2. Kang, Scharmann and Noh, Examining students' views on the nature of science: results from Korean 6th, 8th, and 10th graders (2005).
3. Seo and Chang's Analysis of Korean and Israeli Science Curricula for Junior and Senior High School (2004).

The purposes of science education in South Korea are to "understand knowledge systems of science, to have an interest and curiosity in natural phenomena, to be able to use the inquiry method, and to have a positive attitude toward nature". These goals are promoted through the use of practical methods and hands-on learning activities, including investigations and laboratory work.

VIETNAM

Table 11: Practical work in Vietnam

2012 PISA ranking	8
Definition of practical work	Practical work includes fieldwork, laboratory work and experimental work.
Purposes of practical work	To develop personal characteristics, including: – Activeness – Voluntariness – Initiative – Creativity To develop critical thinking. To generate enthusiasm for the sciences.

Vietnam is ranked 8th among the highest performing countries on the PISA 2012 framework. In Vietnam, students enrolled in secondary education are aged 11–15 and those enrolled in high school are aged 15–18.

School curricula for Vietnam are not available online in English, so we used:

1. Kieu and Chau, Education in Vietnam (2000).
2. Ng and Nguyen, Investigating the Integration of Everyday Phenomena and Practical Work in Physics Teaching in Vietnamese High Schools (2006).
3. The United Nations Educational, Scientific and Cultural Organisation's (UNESCO's) World Data on Education: Vietnam ("World Data on Education: Vietnam," 2011).
4. UNESCO report on Vietnam and its national curriculum ("Vietnam," 2015).
5. World Bank Education in Vietnam: Development History, Challenges and Solutions ("Education in Vietnam: Development History, Challenges and Solutions," 2011).

In Vietnam, science is seen as a subject that is inherently practical. As such, it fosters teamwork and promotes skills of observation and deductive reasoning.

Practical science work in Vietnamese secondary and high schools is centred on developing essential life qualities in students, centred around changing their attitudes to include characteristics such as activeness (i.e. being proactive rather than passive), voluntariness (exercising free will), initiative and creativity (Ng & Nguyen, 2006). These characteristics are developed alongside student capacities to work independently, to apply learned knowledge to practical activities and critical reasoning. Practical work in the sciences is intended to generate enthusiasm for taught material and encourage continued studies in the sciences.

POLAND

Table 12: Practical work in Poland

2012 PISA ranking	9
Definition of practical work	Practical actions that include observations, experiments and measurements.
Purposes of practical work	To develop scientific thinking. Improve critical reasoning. Develop students' abilities to use research methods. Build capacity of students to act as reasonable citizens in everyday life.

Poland is ranked 9th among the highest performing countries on the PISA 2012 framework. In Poland, students enrolled in secondary education are aged 13–19 and divided between Stage 3 (lower secondary) and Stage 4 (upper secondary) schools.

School curricula for Poland are not available online in English, so information for this review has been taken from:

1. Polish EURYDICE Unit Report, The System of Education in Poland ("The System of Education in Poland," 2012).
2. Grajkowski, Ostrowska and Poziomek, Core Curriculum for Science Subjects in Selected Countries (2014).
3. UNESCO World Data on Education: Poland ("World Data on Education: Poland," 2012).

Student study of science has a strong emphasis on practical work including observation, experimentation and measurement. These activities are intended to help students to learn about scientific processes and phenomena.

On completion of a secondary education in science, students are expected to be able to demonstrate scientific thinking, defined as: "The ability to use scientific knowledge in order to identify and solve problems, and the ability to formulate conclusions based on empirical observation related to nature and society" ("The System of Education in Poland", 2012). Students are expected to deepen their own reasoning skills. Practical work in the sciences is also intended to help students improve their ability to use various research methods: "Perceiving and understanding the relations between empirical evidence and scientific theories, not only in the area of science, but also in everyday life of a responsible citizen" (Grajkowski et al., 2014).

CANADA

Table 13: Practical work in Canada

2012 PISA ranking	10
Definition of practical work	Investigations involving scientific inquiry and independent research.
Purposes of practical work	Practical science is intended to help students to develop four sets of skills of scientific investigation: – Initiating and planning. – Performing and recording. – Analysing and interpreting. – Communicating.

Canada is ranked 10th among the highest performing countries on the PISA 2012 framework. Education in Canada is generally divided into primary education followed by secondary education and post-secondary. Students in secondary education are aged 14–18. In the later years of secondary education (Grade 9 to 10), science courses are divided between academic and applied programmes. Academic courses develop students' knowledge and skills through the study of theory and abstract problems; practical applications of the sciences are also included as appropriate. Applied courses focus on essential concepts only, and develop students' knowledge and skills through practical applications and examples.

In both academic and applied programmes, the heart of studying the sciences in Canada lies in practical work that takes the form of investigations. Students plan and conduct their own research based on consultations with their teachers. They practise using various inquiry and research skills and learn how to determine the most appropriate methods for their specific research activities.

Practical science is intended to help students to develop skills of scientific investigation, such as initiating and planning, performing and recording, analysing and interpreting, and communicating ("The Ontario Curriculum – Grades 9 Through 10 – Science," 2008).

Schools, teachers and students are encouraged to engage in co-operative education and other forms of experiential learning. Such activities include, but are not limited to, job shadowing, field trips and work experience that are intended to enable students to apply the skills that they develop in the classroom to real-life activities in the world of science and innovation.

ENGLAND [3]

Table 14: Practical work in England

2012 PISA ranking	18
Definition of practical work	There is no stated definition, yet practical work appears in national curricula as a combination of scientific methods, processes and skills, which are used to observe and act on the world in which we live.
Purposes of practical work	To develop scientific thinking. To develop experimental skills and strategies. To improve the ability to plan different types of scientific inquiries to answer questions.

Practical work has traditionally been strongly emphasised in science teaching in England, and students spend relatively more time on practical work in England compared to many other countries (see TIMSS results for an international comparison). As stated in the primary national curriculum: "Most of the learning about science should be done through the use of first-hand practical experiences" (2013).

In the primary-level national curriculum, practical work is strongly related to students' inquiry skills including their ability to ask questions, apply careful observations, identify, classify, compare, and report scientific evidence. Inquiry skills are also emphasised in the secondary level national curriculum. Also covered is the non-dogmatic nature of scientific theories; the economic, societal and ethical issues related to scientific investigations; and the evaluation of risks in wider contexts. In addition, the focus of practical work extends towards developing scientific thinking and acquiring practical skills.

Overall, the most emphasised objectives of practical work appear to be strongly related to the engagement of students with the nature and processes of science. Another, less prominent, objective of practical work is its possible contribution to students' physical abilities and manual dexterity, including measurement, observation and precise manipulation of objects.

[3] NB England, Scotland, Wales and Northern Ireland are usually reported together as the UK (amalgamated ranking for science is 20=). The separate scores are found in the UK Country Note, p. 3 (accessed September 2017 at www.oecd.org/pisa/keyfindings/PISA-2012-results-UK.pdf).

SCOTLAND

Table 15: Practical work in Scotland

2012 PISA ranking	22
Definition of practical work	Practical work is a hands-on learning experience used in developing attributes and capabilities and in achieving active engagement, motivation and depth of learning.
Purposes of practical work	To increase students' motivation and engagement in science subjects. To improve students' conceptual understanding. To develop skills of scientific inquiry and investigation. To increase students' ability to work collaboratively.

Scotland has an idiosyncratic way of approaching the design of the school curriculum. Instead of a national curriculum categorised by subject and age group, there is a Curriculum for Excellence. This aims to provide a coherent and more flexible curriculum for children and young people (from 3 to 18). It was introduced in August 2010 and it does not provide a prescriptive list of topics to be taught nor does it advise at what stage topics should be covered.

This situation makes the interpretation of the main purposes of practical work in Scotland more challenging. To reduce ambiguity we have referred to two outputs of the Scottish government as key documents: "The sciences 3–18: Good practice examples" and "Curriculum for excellence: Sciences principles and practice". The "Sciences: principles and practices" document sets out the purposes of learning within the curriculum area and describes how the experiences are organised as well as offering guidance on variety of aspects including learning and teaching, assessment, progression and connections with other areas of the curriculum. "The sciences 3–18: Good practice examples" document provides practitioners with a compilation of good practice in the sciences. Documents are both written by Education Scotland, which is the national body in Scotland for supporting quality and improvement in learning and teaching.

The most often mentioned purpose of practical work in those documents was related to the increase of student motivation, engagement and interest in the living, material and physical world. It was also argued that practical work can "act as a motivation for progressively developing skills, knowledge, understanding and attitudes, and so maximise achievement" (Sciences: principles and practice, p. 2).

It was reported in the good practice examples document: "Learners show high levels of motivation and enjoyment engaging with practical work" (The sciences 3–18, p.12).

Another purpose of practical work mentioned was related to the enhancement of students' understanding of key concepts, the aim being that hands-on practical activities – and, importantly, the discussion thereof - would help students access conceptually difficult areas of the sciences. There were also (albeit less often) explicit references to the possible contribution of practical work to students' collaborative skills.

NORTHERN IRELAND

Table 16: Practical work in Northern Ireland

2012 PISA ranking	24
Definition of practical work	Practical work is a type of active engagement when students are doing something with their hands (or bodies) with the materials.
Purposes of practical work	To develop students' thinking skills and personal capabilities, including collaborative learning. To develop skills in accurately measuring and recording information. To increase students' motivation.

Within the Northern Ireland Curriculum, there is an emphasis on learning with understanding, consolidating pupils' knowledge and enabling pupils to make connections between science and the real world. However, even greater attention is paid to skills and capabilities that can be developed through practical work. Practical work is considered a means to increase students' investigation skills including planning, observation, data collection, data analysis and synthesis as well as evaluation. It is recommended that practical work activities should adopt a more inquiry-based and problem-centred approach to improve pupils' critical and creative thinking. This will encourage them to ask more questions to develop and evaluate explanations of phenomena and events in the world around them.

Science is considered to be a practical subject; hence it is extensively promoted in the national curriculum. It is stated that another purpose of practical work should be improving students' physical skills including accurately measuring, recording information and safely using scientific equipment.

Practical work activities are also seen as opportunities for pupils to be challenged about individual and collective social and environmental responsibilities. It is argued that group work during practical activities can improve students' collaborative skills and feed into mutual respect and co-operation.

WALES

Table 17: Practical work in Wales

2012 PISA ranking	36
Definition of practical work	Student activities that require active participation and manipulation of real world objects.
Purposes of practical work	To contribute to students' practical skills. To improve students' ability in inquiry: asking the right questions and searching for answers. To increase students' problem-solving and creative thinking abilities.

In Wales, practical work is seen as an opportunity for students to consider the relationship between data, evidence, theories and explanations. According to the national curriculum, during practical work students "develop practical, problem-solving and inquiry skills, working both individually and in groups" (p. 27).

The most often mentioned purpose of practical work was to improve students' inquiry abilities. It was stated that practical work activities should allow students to evaluate their methods and conclusions both qualitatively and quantitatively, and communicate their ideas with clarity and precision. Planning, collecting data and incorporating evaluation methods as part of the ability to set up an inquiry are all stressed as the purpose of practical work.

Another stated purpose of practical work is to improve students' practical skills related to working accurately and safely while collecting first-hand data. Practical work activities are seen as an opportunity to study the work of scientists and to help students recognise the role of experimental data, creative thinking and values in scientists' work while developing scientific ideas.

ANNEX TO APPENDIX 1A: STUDIES MAPPED TO PURPOSES

This Annex was compiled in March 2017. Some of the studies listed were published post-2014, after the literature search for the REA was completed and consequently are not discussed in the main text. The studies have been mapped to the five purposes outlined in the Good Practical Science final report, not those in the REA. Although there are many similarities between the two sets of purposes, the set in the REA was constructed from the available literature and does not reflect subsequent developments in thinking.

Please note the caveat as in the original REA: few of these studies are methodologically robust and many are relatively small-scale.

A. TO TEACH THE PRINCIPLES OF SCIENTIFIC INQUIRY

Positive effect

Abrahams, I., & Reiss, M. J. (2012). *Practical Work: Its Effectiveness in Primary and Secondary Schools in England*. Journal of Research in Science Teaching, 49(8), 1035–1055.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). *Improving science inquiry with elementary students of diverse backgrounds.* Journal of Research in Science Teaching, 42(3), 337–357.

Hart, C., Mulhall, P., Berry, A., Loughran, J., & Gunstone, R. (2000). *What is the purpose of this experiment? Or can students learn something from doing experiments?* Journal of Research in Science Teaching, 37, 655–675.

Hofstein, A., Navon, O., Kipnis, M., & Mamlok-Naaman, R. (2005). *Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories*. Journal of Research in Science Teaching, 42(7), 791–806.

Taraban, R., Box, C., Myers, R., Pollard, R., & Bowen, C. W. (2007). *Effects of active-learning experiences on achievement, attitudes, and behaviors in high school biology.* Journal of Research in Science Teaching, 44(7), 960–979.

No effect

Abrahams, I., & Millar, R. (2008). *Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science*. International Journal of Science Education, 30(14), 1945-1969.

B. TO IMPROVE UNDERSTANDING OF THEORY THROUGH PRACTICAL EXPERIENCE

Positive effect

Abdullah, M., Mohamed, N., & Ismail, Z. H. (2009). *The effect of an individualized laboratory approach through microscale chemistry experimentation on students' understanding of chemistry concepts, motivation and attitudes*. Chemistry Education Research and Practice, 10, 53–61.

Freedman, M. P. (1997). *Relationship among laboratory instruction, attitude towards science, and achievement in science knowledge.* Journal of Research in Science Teaching, 34(4), 343–357.

Hart, C., Mulhall, P., Berry, A., Loughran, J., & Gunstone, R. (2000). *What is the purpose of this experiment? Or can students learn something from doing experiments?* Journal of Research in Science Teaching, 37, 655–675.

Martindill, D., & Wilson, E. (2015). R*hetoric or reality? A case study into how, if at all, practical work supports learning in the classroom*. International Journal for Lesson and Learning Studies, 4(1), 39–55.

Moeed, A. (2011). *Successful science learning from practical work*. School Science Review, 93(343), 121–126.

No effect

Abrahams, I., & Millar, R. (2008). *Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science*. International Journal of Science Education, 30(14), 1945–1969.

Abrahams, I., & Reiss, M. J. (2012). *Practical Work: Its Effectiveness in Primary and Secondary Schools in England*. Journal of Research in Science Teaching, 49(8), 1035–1055.

Martin, M. O., Mullis, I. V. S., Foy, P., & Hooper, M. (2016). *TIMSS 2015 International Results in Science*. Retrieved from Boston College, TIMSS & PIRLS International Study Center website: timssandpirls.bc.edu/timss2015/international-results/ (accessed September 2017).

Pine, J., Aschbacher, P., Roth, E., Jones, M., McPhee, C., Martin, C.,... Foley, B. (2006). *Fifth graders' science inquiry abilities: A comparative study of students in hands-on and textbook curricula*. Journal of Research in Science Teaching, 43, 467–484.

Shim, K. C., Moon, S. H., Kil, J. H., & Kim, K. (2014). *Secondary Science Teachers' Views about Purposes of Practical Works in School Science*. International Journal of Social, Education, Economics and Management Engineering, 8(7), 2131–2134.

Negative effect

OECD (2016). *PISA 2015 Results (Volume II): Policies and Practices for Successful Schools*. Retrieved from www.oecd.org/publications/pisa-2015-results-volume-ii-9789264267510-en.htm (accessed September 2017).

C. TO TEACH SPECIFIC PRACTICAL SKILLS, SUCH AS ASPECTS OF MEASUREMENT AND OBSERVATION, THAT MAY BE USEFUL IN FUTURE STUDY OR EMPLOYMENT

Positive effect

[V weak evidence – Teacher survey question suggested that teachers used practical work to improve "observing, measuring, classifying": Shim, K. C., Moon, S. H., Kil, J. H., & Kim, K. (2014). *Secondary Science Teachers' Views about Purposes of Practical Works in School Science*. International Journal of Social, Education, Economics and Management Engineering, 8(7), 2131–2134.)]

D. TO MOTIVATE AND ENGAGE STUDENTS.

Positive effect

Freedman, M. P. (1997). *Relationship among laboratory instruction, attitude towards science, and achievement in science knowledge*. Journal of Research in Science Teaching, 34(4), 343–357.

Hart, C., Mulhall, P., Berry, A., Loughran, J., & Gunstone, R. (2000). *What is the purpose of this experiment? Or can students learn something from doing experiments?* Journal of Research in Science Teaching, 37, 655–675.

Palmer, D. H. (2009). *Students' interest generated during an inquiry skills lesson*. Journal of Research in Science Teaching, 46(2), 147–165.

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Royal Society of Biology (2017). Post 16 Biology Survey. Retrieved from: www.rsb.org.uk/education/teaching-resources/secondary-schools/post-16-survey (accessed September 2017).

E. TO DEVELOP HIGHER LEVEL SKILLS AND ATTRIBUTES SUCH AS COMMUNICATION, TEAMWORK AND PERSEVERANCE

Positive effect

Martindill, D., & Wilson, E. (2015). *Rhetoric or reality? A case study into how, if at all, practical work supports learning in the classroom*. International Journal for Lesson and Learning Studies, 4(1), 39–55.

APPENDIX 1B: SEARCH DETAILS

Sources searched:

Databases:	ERIC
	Google Scholar
Journals:	IJSE
	JRST
	Science & Education

Search strings used in database searches:

science +

practical
experiment
investigat*
inquiry
enquiry
hands-on
lab/laboratory
field* (pick up fieldwork and field studies)

+

classroom
secondary school
school
learning
assessment

(* represents any other characters after that stem)

See annex for details of studies.

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