Royal Academy of Engineering

UNIVERSITY OF WINCHESTER
CENTRE FOR REAL-WORLD LEARNING

Reimagining practical learning in secondary schools: A review of the evidence

Bill Lucas and Janet Hanson

October 2021

Acknowledgements

The authors would like to thank:

The education team at the Royal Academy of Engineering, Dr Rhys Morgan and Thomas Gunter, for their continued support of our work.

Professor Tim Ibell FREng, the lead Fellow assigned to this project by the Royal Academy of Engineering, for his advice and encouragement throughout the project.

The Comino Foundation for its continuing support of the Centre for Real-World Learning's (CRL) work in developing young people's personal and practical capabilities and its particular support of this research. We were pleased to have the opportunity in this report to showcase some of the outcomes from other initiatives supported by Comino in which the practical creativity and innovation of young people were celebrated.

Members of our Advisory Panel who generously gave their time to offer their expertise and guidance on practical learning.

Colleagues at the Royal Society, Peter Finegold and David Montagu, for engaging with us in thought-provoking discussions about practical learning.

Our colleagues at the CRL, in particular Carole Johnson, who produced the interactive map of schools used in this report.

About the Centre for Real-World Learning at the University of Winchester (CRL)

CRL is an applied research centre focusing on the teaching of learning dispositions. Its ground-breaking work in identifying creative habits of mind has been influential in the decision by the Organisation for Economic Development (OECD) to introduce the 2021 PISA Test of Creative Thinking. Since 2014 CRL has been undertaking research into engineering habits of mind (EHoM) on behalf of the Royal Academy of Engineering.

ISBN: 978-1-909327-54-2

URL here: www.raeng.org.uk/publications/other/reimagining-practical-learning-in-secondary-school

Suggested citation for this report:

Lucas, B. and Hanson, J. (2021). *Reimagining practical learning in secondary schools: A review of the evidence*. London: Royal Academy of Engineering.

Contents

Executive summary

This report, commissioned by the Royal Academy of Engineering, seeks to reimagine practical learning. It reaches beyond unhelpful binary stereotypes of academic versus practical, theoretical versus applied, and traditional versus progressive to reimagine practical learning in secondary schools as something to be desired by the whole education system.

Why practical learning?

Practical learning in secondary schools forms part of every subject on the school curriculum. However, except when it is specifically referred to in a small number of subjects, such as the practical in science, the project in design and technology or fieldwork in geography, practical learning remains largely invisible for many teachers: they do not see it as an aspect of learning to be understood, valued and explicitly taught. Despite growing recognition of its contribution to the development of key dispositions for learning such as problem-solving, to important aspects of character like resilience and to employability in general, practical learning still tends to be seen as the poor relative of academic learning.

When it does appear explicitly in schools, practical learning mainly occurs within three specific approaches to pedagogy – project-based, inquiry-based and problem-based learning.

But these three approaches have become mini educational brands and tend to divide the teaching profession. One group applauds them for their empowerment of students and real-world relevance while another considers them to be imprecise and ineffective ways of teaching students to acquire necessary disciplinary knowledge.

These divisions are unhelpful since engineering and young people more broadly need access to the advantages afforded by practical learning. As the role of the engineer expands and evolves, effective interpersonal skills and creativity have joined the more traditional skillset of problem-solving. Organisations such as the OECD, the CBI and many others suggest that successful young people not only need disciplinary knowledge but also creativity, problem-solving, social, and practical skills. Research by neuroscientists into embodied cognition is also pointing towards the fallacy of a belief in teaching that attempts to separate mind from body.

For this report, practical learning in schools has been defined as: "learning that is whole, involving head, heart and hand working in harmony. In schools this requires teachers to use carefully chosen strategies that encourage students to experience and navigate real-world challenges and acquire and apply their knowledge in a range of settings as they explicitly seek to develop a set of wider dispositions for learning for life."

In this report we seek to reimagine practical learning in the light of a synthesis of the evidence from quantitative and qualitative reviews, exploring what it looks like when it is well done and how it impacts on learners at school and beyond.

The aim of this research is to understand how a more informed realisation of the value of practical learning in schools might drive innovation in pedagogy and so, ultimately, inspire young people to want to become engineers. The research has four objectives:

- to understand the benefits of practical learning in secondary schools
- to describe the features of high-quality practical teaching
- to create a map of secondary schools in England that are investing significantly in practical learning
- to explore the ways in which high-quality experiences of practical learning are, or could be, being used in education for engineering in secondary schools.

The approach

The overarching approach to this research has been theory-based, developing a theory of change (TOC) to articulate a different approach to understanding practical learning in schools. We designed a research strategy to combine a rigorous review of recent high-quality research into practical learning (focusing on project-based, inquiry-based and problem-based learning) alongside a search of grey literature published by a wide range of national and international organisations. An analysis of information derived from publicly available reports and websites of a small number of promising school examples was used to illustrate the features of practical learning in action.

After describing the key features of these three selected approaches to practical learning, their impact on a range of student outcomes including knowledge acquisition and the development of various habits of mind for success beyond school were reviewed. The factors necessary for achieving high-quality practical teaching in schools were also identified and were used to interpret the school data.

The findings

The research suggests that when well done the three approaches are as effective in supporting learning as more traditional methods of teaching. In addition, the evidence suggests that they develop a range of other desirable capabilities in learners such as better problem-solving, enhanced creativity, more effective communication, and improved collaboration.

The authors offer insights into the essence of excellent practical learning and suggest some promising secondary school examples of these practices.

Given concerns about the lack of students choosing to study engineering beyond school and become working engineers, the report's conclusions offer insights for all those who care about engineering and who want to see an education system that seeks to make learning whole again, deliberately reintegrating practical learning into all aspects of the school curriculum.

Conclusions

In summary the research concludes that:

- practical learning is complex, valuable and an integral part of almost all learning
- without paying explicit attention to creating opportunities for practical learning, it is likely to be overlooked, ignored or undervalued in secondary schools, which, in England are largely measured by success at GCSE and A levels
- the three methods we have explored in particular – project-based, inquiry-based and problem-based learning – generate unhelpful responses in some school leaders and teachers, at least in part because they are only known by their media hype and not examined with a more critical lens
- there are several practical steps now needed to take our reimagining of practical learning in secondary schools to the next stage.

Recommendations

In the light of this research, we suggest that:

- further qualitative research is undertaken to describe excellent practical learning in schools to produce detailed secondary school case studies so that the field can be better understood and practices that might make engineering more visible to young people can be better evaluated
- the Academy uses examples of schools that have embedded high-quality practical learning to understand more about the potential of such approaches for attracting young people to learn about engineering and consider engineering as a career
- the Academy considers further investigation into the role of embodied cognition in continuing to build a better understanding the field of practical learning
- the Academy, through initiatives such as This is Engineering, and with partner bodies such as the Crafts Council, the Royal Society and the Comino Foundation, acts as a catalyst for wider inquiry into the role of practical learning in schools to continue reimagining practical learning so that it is valued and offered explicitly in all secondary schools.

1. Introduction

> **The prevailing educational philosophies regrettably continue to emphasise and value conceptual, intellectual and verbal knowledge over the tacit and non-conceptual wisdom of our embodied processes.**
>
> Pallasmaa, J. (2009) *The Thinking Hand*. Chichester: John Wiley & Sons (p.22)

When we talk of practical learning in schools, our first thoughts tend to be of experiments, fieldwork, school trips, rehearsals, performances, displays, exhibitions, and projects. Such examples of practical learning happen in school spaces such as laboratories, studios, workshops, theatres, school grounds, and the places that schools may take their students to visit.

Or sometimes practical is used in conjunction with the term vocational, indicating a more explicit interest in learning that relates to employment. So, a student might learn about food preparation in a training restaurant in a further education college, or engineering in an automobile workshop in schools like university technical colleges (UTCs), which offer both a vocational and core academic education.

As psychologist Kurt Lewin says, 'there is nothing so practical as a good theory' (Lewin, 1951, p.169). In this regard it is very easy to make over-simplifying remarks about school subjects such as, for example, that mathematics is theoretical and physical education (PE) is practical. While it may be possible that the balance of activities in school makes one subject seem more or less practical, all subjects

contain theory and practice; mathematics can invite us to solve real-world engineering structural problems and PE requires at least a tacit knowledge of the laws of motion.

Indeed, it is easy to overlook practical learning in schools. In English, for example, the act of making a poem, often assumed to be an 'academic' task, is essentially practical. While you may be learning about different poetic forms, the craft of interleaving words and phrases is a practical one. In the Social Market Foundation's report *Practice Makes Perfect*, Richard Pring (2017, p.85) goes further. He highlights the areas of speaking and listening as practical skills that risk neglect in a world that finds it easier to codify and assess reading and writing skills; a world that undervalues the practical and overstates 'literacy' at the expense of 'oracy' because of its apparent importance to the academic endeavour (p. 81). This reminds us that there is a whole world of 'skills' that need to be included in any concept of practical learning including activities such as argumentation, experimentation, sketching, and measuring.

However, all too often young people are positioned as being either practical or theoretical learners and are channelled into educational pathways that can exclude them from career options (Mian et al., 2018). This research report seeks to explore whether a better understanding of the value of practical learning might help us understand its important role in many subjects, not just those traditionally thought of as 'practical', and improve the engagement of young people and teachers in education for engineering.

A core element of this study is to develop a more nuanced definition of practical learning than the binary positions described earlier, by focusing on three of the more commonly used approaches in schools: project-based learning (PBL), inquiry-based learning (IBL) and problem-based learning (PrBL).

This research aims to understand how a more informed realisation of practical learning's value in schools might drive innovation in pedagogy and so, ultimately, inspire young people to want to become engineers.

The research has four objectives:

- to understand the benefits of practical learning in secondary schools
- to describe the features of high-quality practical teaching
- to create a map of secondary schools in England that are investing significantly in practical learning
- to explore the ways in which high-quality experiences of practical learning are or could be being used in education for engineering in secondary schools.

1.1 What is practical learning?

To understand practical learning, this research has sought to understand practical not as the antithesis of academic or theoretical learning but rather as an aspect of what good or effective learning looks like in schools.

The Ancient Greeks had a word for practical intelligence, *φρόνησῐς* (phronesis), which loosely translates as 'practical wisdom'. It suggested a kind of wisdom necessary for any practical action that might be guided by good judgement, good character and good habits of mind. The word helpfully reminds us of how the academic and practical need not be unhelpfully pitted against each other in terms of 'abstract' versus 'concrete' or 'theoretical' versus 'hands-on', which is often depicted in everyday definitions of practical such as 'relating to experience, real situations, or actions rather than ideas or imagination' (Cambridge Dictionary, 2020).

So how have knowledge and subjects that are 'abstract' widely become seen as more intelligent, more complex and better than those that are concrete or practical in schools? To take an example, mathematics, especially algebraic symbols and abstract computations, is seen as somehow more academic and less practical than many subjects and the sciences are esteemed in order of their proximity to mathematics – physics, then chemistry, and lastly biology.

To understand how this dualist, binary reading of the role of practical learning came about, we need to go back to the early 17th century. In a time before the modern medical and psychological sciences were born, philosopher René Descartes suggested that mind and body were entirely separate, with mind being the more important of the two. This, Descartes argued, was because one's personal experiences are first conceptualised through thought and subsequent practice is informed by intelligent theorising (Entwistle, 1969).

Descartes' dualism profoundly influenced Western educational thinking for centuries, giving rise in England to the public and grammar school systems where the idea that mind was better than body and that subjects that could be considered academic were more valued than those that were deemed practical have dominated the curriculum (Macedonia, 2019).

This dualist perspective was challenged by philosophers such as Ryle (1949) and Polanyi (1958) who used different explanations to raise the status of practical knowledge. Ryle's 'intelligent performance' and Polanyi's 'tacit knowing' repositioned the place of theory in a learner's ability to act or perform skillfully. Ryle argued that 'intelligent performance' was the exercise of individual knowledge in action, or knowing how, that was equal to and not subservient to theoretical knowledge (Stolz, 2013).

Polanyi explained tacit knowledge as having the ability to act skillfully because we know how to, drawing on our propositional knowledge, or 'knowing that', despite not being able to explicitly explain why the performance was skilled (Allen, 1978). However, the lack of an explicit language with which to describe 'tacit knowledge' imbued it with a sense mystery that still tended to downplay the role of theory in practical learning (Entwistle, 1969). But although these challenges informed debates about learning, dualism between mind and body remains a dominant force in education even as the learning sciences have demonstrated the many ways in which this is an unhelpful over-simplification (Sawyer, 2006).

Recently, however, neuroscientists have been helping us understand that 'our body plays a crucial role in our cognitive processes' (Howard-Jones, 2014, p.25) and have begun to consider the ways in which a growing understanding of embodied cognition might affect the way we organise learning. 'Descartes' error', as neuroscientist Antonio Damasio (1995) has called it, has been shown be just that: a misunderstanding of the evidence. Indeed, as embodied cognition has demonstrated, an intimate relationship exists between mind and body. Body and mind, it turns out, are mutually dependent.

While there is no single theory of embodied cognition, it suggests that 'information is grounded in both perception and action, and that cognition is deeply dependent upon features of the physical body of an agent' (Fugate et al., 2019, p.274). In other words that, far from the body and practical activity being passively present, their active engagement at the point of initial learning improves the learning process: 'the more nuanced the encoding (including the more the senses and the body are involved, as well as the more instances of encoding), the better the recall and use of that information' (ibid, p.283). So, for example, research on language learning has found that bodily movement can positively influence learning. Words associated with forward and backward movement are more readily learned when associated with the relevant physical movement. The symbols involved in this learning are encoded in the same part of the brain involved in bodily movement (Shapiro and Stolz, 2019).

That said, it may be some time before we see research into embodied learning having any significant impact on education, since the predominant thinking currently influencing the English curriculum gives preference to the study of academic disciplines, rooted in the purpose of schools being about passing on knowledge to the next generation (Spielman, 2017). The principle of enabling all children to acquire and engage with a knowledge-rich curriculum, expressed through specialised subject-based teaching, is important in underpinning social equity, since such knowledge gives young people the power to think beyond their own experiences and envisage alternatives (Young, 2018). Entwistle (1969) points out that having to research information every time one needs it would hugely limit participation in the world and suggests that, like financial assets, some of one's cognitive assets should remain 'liquid' (p.128).

However important the aim of social equity is, this focus on disciplinary knowledge has weakened the position of some 'practical' subjects in the curriculum. Most notable is design and technology (D&T), which, having evolved over time from a craft to a design orientation, appeared to lack a strong and definable knowledge base, leading to its demotion in the curriculum (McLain et al., 2019).

Furthermore, the implementation of a knowledge-rich curriculum can have unintended consequences, as Ofsted's research found (Spielman, 2018). When well-implemented, schools espousing a knowledge-led curriculum stress the importance of the subject as a discipline, engage pupils with subject-specific vocabulary, and consider the local context and pupil needs when designing the curriculum. However, in schools where knowledge-led is less well understood, the concept can lead to a narrowing of the curriculum for disadvantaged pupils, greater use of transmission teaching and 'teaching to the test' (Spielman, 2018).

Ofsted's research informed the revised Ofsted Education Inspection Framework (2019), which emphasises the need for a school's curriculum to 'give all learners … the knowledge and cultural capital they need to succeed in life' and also for the curriculum to be 'coherently planned and sequenced towards cumulatively sufficient knowledge and skills for future learning and employment' (p.9).

Although the implementation of a knowledge-rich curriculum unfortunately tends to be associated with more transmissive styles of teaching, or teacher-led 'telling' strategies, it is important to note that these are not the same as the approach known as explicit instruction, which can be a valuable teaching method when done well. Hodgen et al.'s (2020) systematic review of approaches to teaching mathematics to low attaining pupils in secondary education demonstrated this clearly. Explicit instruction is the use of carefully structured, often scripted, explanations followed by structured practice leading to mastery, which should be used alongside other approaches such as problem-solving and collaborative work (ibid, 2020).

The acknowledgement that knowledge and skills are both seen as important for a high-quality curriculum is welcome, but, as we will learn in the next section, both must adapt and keep pace with change to maintain their relevance. This nod to skills is also a far cry from education for the whole person where embodied learning facilitates a synthesis of thinking, feeling and acting (Stolz, 2015).

A few schools have raised the status of practical learning through a specific focus on education through 'head, heart and hand', notably Bedales, a well-known independent school in Hampshire, England. Bedales' founder John Badley laid the foundations for the school's current emphasis on inquiry, doing and making with students undertaking richly challenging projects. A similar philosophy has been adopted by School 21 in London, which invests significantly in practical learning to provide its students with an 'education for the head, heart and hand' (Hyman, 2019, p.47.)

We were attracted by the idea of 'head, heart and hand' in our initial thinking about practical learning but, as our research progressed, decided that even this helpful attempt at expanding our horizons still suggests a divided, segmented approach to learning. So we also took inspiration from Harvard researcher David Perkins' *Making Learning Whole* (2009). Perkins argues for a version of learning that integrates theory and practice, work in progress and final 'product', individual components and the whole experience.

Perkins makes some compelling arguments as to why teachers sometimes take decisions that lead to learning that is fragmented and unsatisfying. He starts from the premise that much of learning is complex and that the danger is that we either make it wholly abstract and teach the theory of it (he calls this 'aboutitis') or we breakdown complexity into meaningless repetitive exercises ('elementitis'). Perkins uses the idea of a football match as an example. In this case the temptation he suggests either to teach about famous football matches (who did what and the tactics of the two teams, for example) or to focus exclusively on skills such as dribbling and passing and never to play an actual game. Wherever possible, Perkins argues, it is both more satisfying and more effective if you find a way of playing the 'whole game'.

Perkins is not saying that we do not need abstractions or that breaking down the learning of a complex task into its component parts is a bad idea. Instead, he is arguing that teachers should enable their students to play the whole game of learning whenever they can to ensure they understand the big questions that drive learning and have time to work through challenging problems with support. It's a bit like playing Junior Scrabble, which manages to maintain appropriate complexity but with more structure as a preparation for the 'real' game of Scrabble.

In our research into education for engineering in schools thus far we have sought a similar balance, trying to make explicit the theoretical foundations that can strengthen efforts to improve learning and to provide practitioners, particularly teachers and school leaders, with an understanding of the 'structures, behaviours, processes and contextual features that will be needed to achieve the aims and actions of the intervention' (Davidoff et al., 2015, p.230). Being an engineer (like being a surgeon or an orchestral conductor, for example) requires a powerful blend of mind and body working in harmony and it seems sensible that education provides this integrated outcome.

1.2 Why does practical learning matter?

There are several reasons why practical learning in schools deserves greater attention. Even before the 2020 COVID-19 pandemic, scenarios of the not-too-distant future were imagining a quite different economic and social environment from the present. By 2030 it is envisaged that as work adjusts to environmental, economic and social changes, individuals will need to be comfortable operating in cross-disciplinary environments, continuously adapting to learning new skills and be willing to take on more responsibility for their own development. Employees will require strong self-organisation and analytical skills to work in digital, project-based and collaborative working modes (Störmer et al., 2014).

Individuals will also need a capacity for problem-solving and be open to trying different solutions, which, as the World Economic Forum (WEF) points out, should lead to the recognition of the importance of the connection between body and brain for learning and the need to re-appraise the position of practical problem-based learning in the curriculum, both in schools (WEF, 2020) and in higher education (Puri, 2018).

The OECD's Learning Compass 2030 shows how learning a combination of knowledge, skills and attitudes can prepare young people for exercising agency over their futures. Disciplinary knowledge is still important, but students will also need a 'broad range of skills, including cognitive and meta-cognitive skills (e.g. critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g. empathy, self-efficacy and collaboration); and practical and physical skills' to apply their knowledge and mediate their actions (OECD, 2018, p.5). Specialised disciplinary knowledge is likely to remain the core of the curriculum but the ability to make connections between disciplines is important for solving complex problems. Project-based learning can facilitate developing this interconnectedness (OECD, 2019a).

Digital technologies have transformed industries and the importance of individuals gaining and maintaining digital skills, often considered practical, has been noted for many years (Edge, 2019a). Although much of the commentary focuses on the risks to jobs associated with automation, there are many opportunities for job creation (Bakhshi et al., 2017). However, as the impact of robotics and artificial intelligence in all spheres of life grows, it is human capabilities such as creativity and empathy that are going to help individuals flourish in this future (OECD, 2019b, 2019c).

Vast amounts of data can be processed by machines but the ability to question algorithmic decisions and make ethical judgements about matters that have an impact on the medical, financial or privacy concerns of individuals is essentially a human skill (Economist, 2019, p.12). These abilities are remarkably similar to those associated with demonstrating creativity, such as 'thinking beyond traditional norms; seeing things from different points of view; thinking laterally; making unexpected connections and identifying relationships; and thinking or making something new' (Durham Commission on Creativity in Education (DCCE), 2019, p.29).

Employers represented by the CBI agree, noting that although automation threatens to displace people from jobs it is 'those skills that make us uniquely human, such as creativity, originality, problem-solving and the ability to learn, [that] give people the advantage over machines. They may be the hardest to teach and learn, but it is vital that the education and skill system develops ways for people to master these skills' (CBI/Pearson, 2019, p.6).

Indeed, in the last 20 years in the UK several commissions, inquiries, manifestos, and reports (Appendix 1) that appear to have some bearing on the role of practical learning have argued for the education system to change to meet the demands of this future environment.

The lack of creative and practical skills in the existing workforce has been noted and an inherent prejudice against practical learning, touched on in the section above, has been blamed for the failure to develop an adequate technical and vocational education in England (Independent Panel on Technical Education, 2016; Leitch, 2006; Parliamentary Skills Group, 2011; Wolf, 2011).

In the school system it is also feared that prejudice against practical learning leaves gaps in learning that will render young people unable to meet the challenges of the so called Fourth Industrial Revolution and the potentially disruptive impacts of new technologies. There are calls for schools to offer more practically based and interdisciplinary subjects at primary and secondary levels to enable young people to master not only core subjects but also skills and attitudes such as problem-solving and collaboration that support innovation in the workplace (All-Party Parliamentary Group for Education, 2017; CBI, 2012; Huynh, 2019; Störmer et al., 2014).

Most recently, the Durham Commission on Creativity in Education (DCCE) argued that all schools should be teaching for creativity; not just in the subjects traditionally thought of as creative, such as art and design, music, and drama but in all subjects including science and mathematics. The authors also asserted that academic rigour was not at odds with creativity, in fact, a rich knowledge base was an essential pre-condition for creative thinking, but there also have to be opportunities for learners to develop the skills to apply their knowledge, which include: 'exploring; experimenting; trying and reworking; making and re-making; engaging with difference; overcoming obstacles; and developing and applying knowledge and understanding' (DCCE, 2019, p.14.). The commission echoes earlier demands for schools to enhance opportunities for 'making' activities to promote creativity (Crafts Council, 2014; NACCE, 1999).

These kinds of shifts in thinking about education are well captured in *The Problem Solvers* (Leadbeater, 2018):

'The core purpose of education needs to shift – from teaching students to follow instructions to preparing students to identify and solve problems … To make that shift, education systems need to provide dynamic experiences for young people through which they can learn in practice how to deploy knowledge in action, to work with others and to develop critical personal strengths such as persistence and resilience, to learn from feedback and overcome setbacks. Providing a dynamic mix of theory and practice will require more than adding courses in entrepreneurship to our current systems of academic instruction' (p.5).

The notion of a dynamic blend of theory and practice seems likely to be at the heart of a more nuanced understanding of practical learning.

1.3 Why does practical learning matter now?

As we have suggested, practical learning is not well enough understood. All too frequently it is seen as a lower status alternative to, and separated from, academic learning. Mind and body are somehow unconnected in school life and, therefore, from the real world where, of course, they merge effortlessly.

Understanding the complexity of practical learning is of particular relevance to one discipline and career pathway: engineering. Engineers are practical people. They make things that work and make things work better. They move effortlessly between conceptual and practical, theoretical and applied. They are practical learners and practical doers. But as the field of engineering evolves it is becoming clear that education systems globally are not keeping pace with the need to produce engineers who have the right engineering mindset as well as the right skill set (Royal Academy of Engineering, 2020, p.9).

This is evident in the UK where there is a shortage of engineers. *Engineering UK 2018: The state of engineering* suggests several factors accounting for the shortage including:

- the engineering outdated identity problem
- education, especially the decline in apprenticeships
- an ageing workforce
- economic factors reducing the number of entry level positions
- employer brands struggling to compete
- an inflexible approach to talent acquisition.

While the lack of apprenticeships is undoubtedly an issue in reducing the availability of high-quality applied learning, the educational element of the problem needs more careful scrutiny. In particular, the perception that there is an increasing lack of opportunity for practical work in schools needs attention. What if a major challenge for would-be engineers in schools is that they simply do not have enough opportunities to experience high-quality practical learning?

One possible reason for the invisibility of engineering in secondary schools and the lack of young people being engaged in engineering-related activities within the formal curriculum is an undervaluing of practical, problem-based learning in schools (Kehoe, 2007). This was partially confirmed by the All-Party Parliamentary Group (APPG) on Diversity and Inclusion in STEM that found that disadvantaged pupils with low science capital became less interested in STEM subjects when they contain less practical work or have fewer links to real-world applications (APPG, 2020).

In addition to the calls from national and international sources for education to afford greater value to practical learning cited in Section 1.2, UK engineering bodies have been making the same point for many years in response to the predicted shortfall of engineers. In the Academy's report *Engineering skills for the future: The 2013 Perkins Review revisited* it is suggested that greater contextualising of the curriculum to promote engineering to all young people is needed in order to nurture practical skills and creativity, complex problem-solving and critical thinking (Royal Academy of Engineering, 2019, p.6),

Section 1.1 noted the importance of the 'knowledge-rich' curriculum in England and the emphasis on disciplinary knowledge and suggested that this appeared to be detrimental to the position of subjects like D&T. The impact of this undervaluing of practical and creative subjects becomes evident when the qualifications achieved by young people are considered. While the current generation of young people have never been more highly qualified on leaving education (Mann and Huddleston, 2017), a steady decline in secondary students' participation in creative arts and crafts subjects has been charted since 2007/8, with falling entries to GCSEs in art and design, D&T, drama, dance, and music (Edge Foundation, 22 August 2019a; Pooley and Rowell, 2016). These subjects are not included as core academic subjects in the English Baccalaureate (EBacc), one of the accountability measures for schools in England and it is suggested that this has led schools to change their curriculum to accommodate more EBacc subjects and restrict access to non-EBacc subjects (Richmond, 2019).

Over a similar period, entries for GCSE history and geography have increased, perhaps because these humanities subjects are included within the EBacc while arts subjects are not (Cultural Learning Alliance, 2019). This is of concern considering the call from employers to the government to broaden the EBacc to be more inclusive of creative subjects (CBI/Pearson, 2019).

The inconsistencies in understanding of 'academic' and 'practical' have led to the undervaluing of practical intelligence involved in 'doing' and 'making' and an increased emphasis on assessment by 'writing about doing' rather than practical forms of assessment (Pring, 2007).

The National Endowment for Science, Technology and the Arts (NESTA) calls for more collaborative problem-solving to be developed in schools (Luckin et al., 2017), arguing that knowledge and a thorough understanding of the subject is important, but students must be able to apply the knowledge and use it to solve problems.

Unfortunately, pressure from awarding bodies frequently leads to greater emphasis placed on the use of external assessment methods, often individual examinations, rather than on assessments that focus on teamwork and project-based learning (Millard et al., 2018).

One positive factor that might begin to redress the balance between practical and academic learning is the growing evidence from embodied cognition of the importance of both mind and body to learning. The relevance of embodied cognition for STEM learning could be significant 'because STEM disciplines rely on representation systems that require sensory encoding (for example, visualisations of data and information including maps, blueprints, graphs, charts), and are nevertheless dependent on highly abstract, formalised symbol systems (for example, those used in math or chemistry)' (Weisberg and Newcombe, 2017, p.1/6.).

So, something as apparently simple as a teacher's hand gestures when teaching mathematics can have a significant impact on students' ability to understand mathematical concepts and to work harder on a task, because the gestures work in combination with the spoken information to shift the cognitive load (how much memory processing is required) of the task from verbal to visuospatial memory stores (Alibali and Nathan, 2012).

Principles of embodied cognition can also inform the teaching of one central but difficult to teach principle in STEM subjects: spatial thinking. Although long considered to be an innate ability rather than a developed skill, teaching spatial ability is now being aligned with embodied learning environments to articulate some specific design principles and teaching interventions (DeSutter and Stieff, 2017).

There are encouraging signs that more young people have a better understanding of engineering and are more attracted to it as a career, although this insight is often achieved through outreach activities rather than innovation taking place within the curriculum (Engineering UK, 2019; Institution of Engineering and Technology, 2019).

While STEM outreach activities support an increase in young people's interest in science and engineering careers, they only reach a small percentage of school-age children (Engineering UK, 2019) and there is doubt as to whether they actually have a significant long-term impact on uptake of STEM subjects (Banerjee, 2017; Ozis et al., 2018).

Nor do extra-curricular activities necessarily lead to young people equipped with a secure foundation of knowledge, skills and attributes needed to thrive in the evolving engineering programmes in higher education, where the need for collaboration skills and problem-based learning are increasing (Hitt, 2020; Mitchell et al., 2021).

The subjective wellbeing of British children has suffered through lack of access to creative and active pursuits and children's wellbeing scores have been shown to decline from Key Stage 3 to Key Stage 4 (McLellan et al., 2012). Furthermore, children from more vulnerable communities may be particularly affected by lack of access to non-formal learning through outdoor activities and social action programmes, as secondary students on free school meals (FSM) are notably less likely to take part in such activities than other students (Birdwell et al., 2015).

1.4 In summary

Practical learning is more complex than it is often considered to be. It can easily be overlooked and undervalued. Schools under pressure to achieve results can too easily opt for more theoretical, text-based approaches, which can be quicker and easier to manage. Yet there are many indications of practical learning's value beyond school. National and international educational and employer organisations are presenting arguments in support of enhancing the value and teaching of practical learning in schools.

There are indications from existing research that practical learning can contribute to several desirable outcomes for learners, schools and wider society including:

- fostering dispositions for learning such as persistence, creative thinking and problem-solving
- building agency
- enhancing employability and career flexibility.

We continue to face a shortage of engineers at a time when schools, especially secondaries, are offering fewer opportunities for practical learning. While these two events are not directly connected, we suggest that they are linked conceptually. If there are few chances to experience rigorous and engaging practical learning at school at the same time as a reducing number of engineering apprenticeships (Foley, 2020) then perhaps some of the solutions to the engineering recruitment issue may lie in changing the nature of learning experienced in too many schools.

2. Our approach to the research

In the art of inquiry, the conduct of thought goes along with, and continually answers to, the fluxes and flows or the materials with which we work. These materials think in us, as we through them. Here every work is an experiment: not in the natural scientific sense of testing a preconceived hypothesis, or of engineering a confrontation between ideas 'in the head' and 'facts' on the ground, but in the sense of prising an opening and flowing where it leads.

Ingold, T. (2013) *Making: Anthropology, Archaeology, Art and Architecture.* Abingdon: Routledge (p.6–7)

Despite growing national and international recognition that practical learning in schools is important for a range of economic, social and cultural reasons (Edge Foundation, 2018; OECD, 2019d; World Economic Forum, 2020), research into practical learning in secondary education appears to have reached a position of stalemate. The most commonly asked research question of practical learning is 'does it increase attainment when compared with more traditional methods of instruction?' and the response from research has frequently been that it is equal to, but no better than, traditional instructional methods (Condliffe et al., 2017; Jerzembek and Murphy, 2013). However, recent research is more polarised; using a meta-analysis Chen and Yang (2019) reported that project-based

learning had a medium to large positive effect on students' academic achievement while Mostafa et al.'s (2019) analysis of 2015 PISA data found that inquiry-based science teaching can be associated with poorer science attainment under some circumstances.

The now predictably contradictory answer to a question that seeks to compare one method with another is that it dramatically reduces the incentive for exploring the impact of practical learning in terms of the *wider* learning outcomes that might accrue for individuals and society. In particular, it hinders an exploration of whether experiences of high-quality practical learning might enhance student engagement in engineering.

The question as typically posed is also unhelpfully binary. It invites us to conclude that one method is better than another and that, once the better method is discovered, it should be the method of choice.

In a review of vocational learning (Lucas et al., 2012) we concluded that any consideration of teaching and learning methods required us to consider not either/or choices but the degree to which a particular desired outcome suggests a particular method (see **Figure 1**).

A quick glance at the first and last of these dimensions illustrates the folly of oversimplifying the decisions that teachers need to take as they decide which methods to use. At the extremes of each continuum, didactic and directed are pitted against facilitative and self-managing. But it almost never as clear-cut as this.

The pedagogical 'sweet spot' in teaching tends to be found when the outcomes desired from any lesson/session can be shown, by a process of reverse-engineering, to lead to well-judged choices about pedagogy, each informed by the level of knowledge, skill and motivation present in any group of learners.

Given all these factors, we have chosen a research strategy designed to combine a rigorous review of recent high-quality research into practical learning (focusing on PBL, IBL and PrBL initially), alongside a search of material from less formal sources such as websites and other online documents, and an

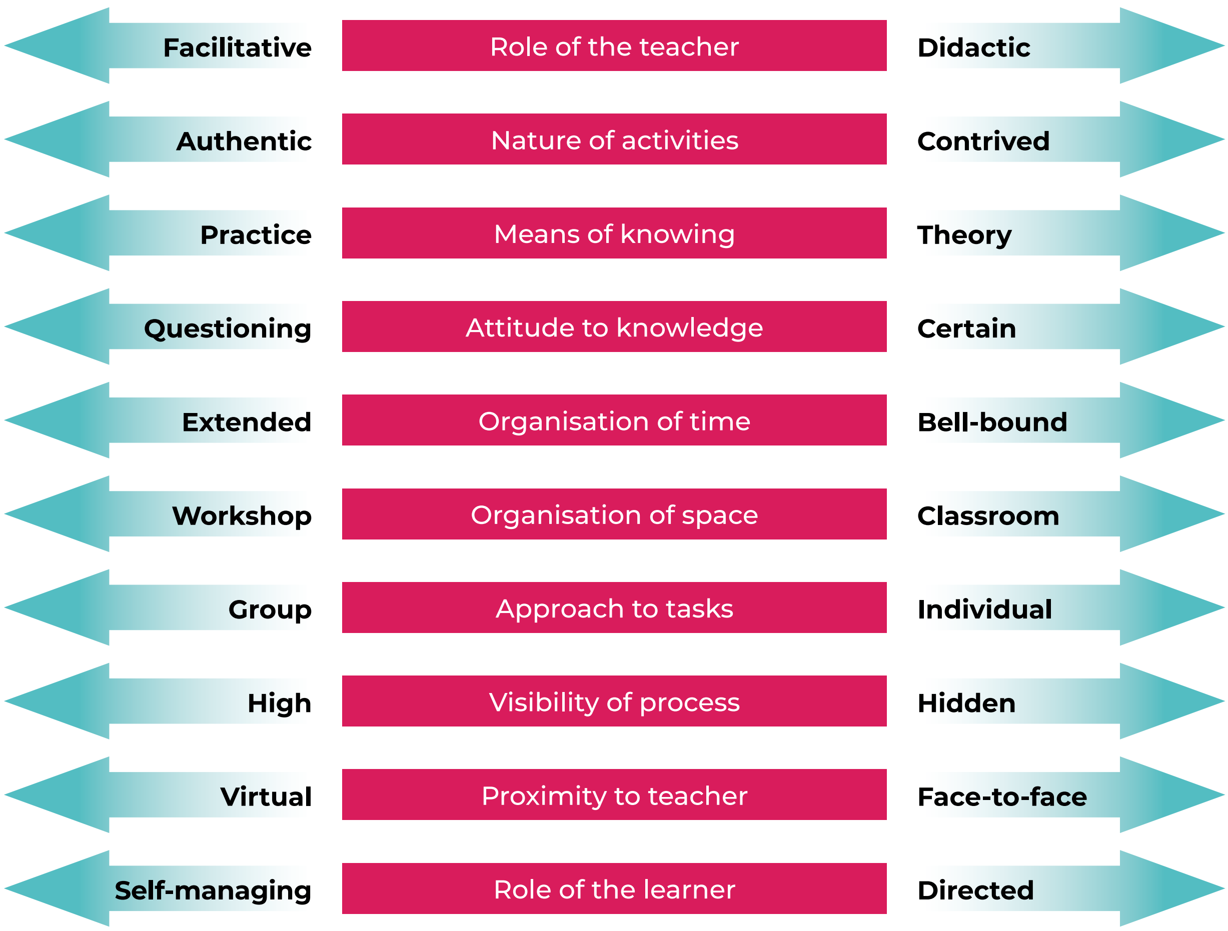


Figure 1:
Ten dimensions of decision-making for vocational pedagogy (Lucas et al, 2012)

analysis of a relatively small number of promising school examples of practical learning in practice.

In earlier research (Lucas et al., 2014), we argued that if we want to locate engineering more effectively in schools then it may help if engineering is reframed as a series of engineering habits of mind (EHoM) rather than being defined through subjects on the timetable such as physics, mathematics or design and technology. If we do this then we are better able to specify the kinds of pedagogies that might develop potential engineers. The approach we adopted has been widely cited and was commended in *Big Ideas: the future of engineering in schools* (Finegold and Jones, 2016).

The hypothesis guiding this research is similarly radical. It starts from the premise that for too long advocates of types of practical learning such as PrBL have not found adequate high-quality evidence of its efficacy as a method when compared to more didactic forms of teaching in schools. Many have therefore concluded that PrBL should not be used.

But in fact, researchers have been asking the wrong question. Rather than asking whether PrBL is better than traditional methods, it would be more helpful to ask three different questions:

- Is PrBL, when done well, *as* effective as more traditional/didactic methods in gaining examination results?

And:

- What other benefits do methods like PrBL confer on learners?

And specifically:

- Might engagement with high-quality forms of practical learning encourage potential engineers and their teachers to value it more at school?

This section outlines our approach to the research.

2.1 Our research questions

Five research questions have guided this study:

- What is practical learning?
- What positive outcomes for learners can be cultivated through practical learning, as defined in this project?
- What are the key features of high-quality practical teaching?
- Which secondary schools in England are investing significantly in practical learning?
- How might high-quality experiences of practical learning be used to foster engagement with engineering in secondary schools?

2.2 A theory-based approach

For the reasons articulated thus far, our understanding of the various forms of practical learning found in schools is not yet advanced or comprehensive enough to rely solely on a conventional systematic review. Definitions of practical learning vary too much and the majority of high-quality studies focus on attainment rather than on other benefits.

Our overarching approach to this research has, therefore, been theory-based, developing a theory of change (TOC) to articulate a different approach to understanding practical learning in schools (see 2.2.2).

A TOC is 'a systematic and cumulative study of the links between activities, outcomes and context' (Fullbright-Anderson, Kubisch and Connell, 1998, p.16). TOC is a process of reverse-engineering in which desired outcomes are articulated and the necessary stages to achieve these are mapped backwards. A TOC provides a robust hypothesis against which evidence can be tested. In this case our desired outcomes combine identifying teaching methods for practical learning that:

1. develop a broad range of learning habits of mind likely to cultivate would-be engineers (see **Figure 2**), and
2. which are at least as effective in terms of students' achievement as more 'traditional' methods of teaching that focus on individual subject disciplines.

Typically, three methods are used to develop a TOC (Laing and Todd, 2015):

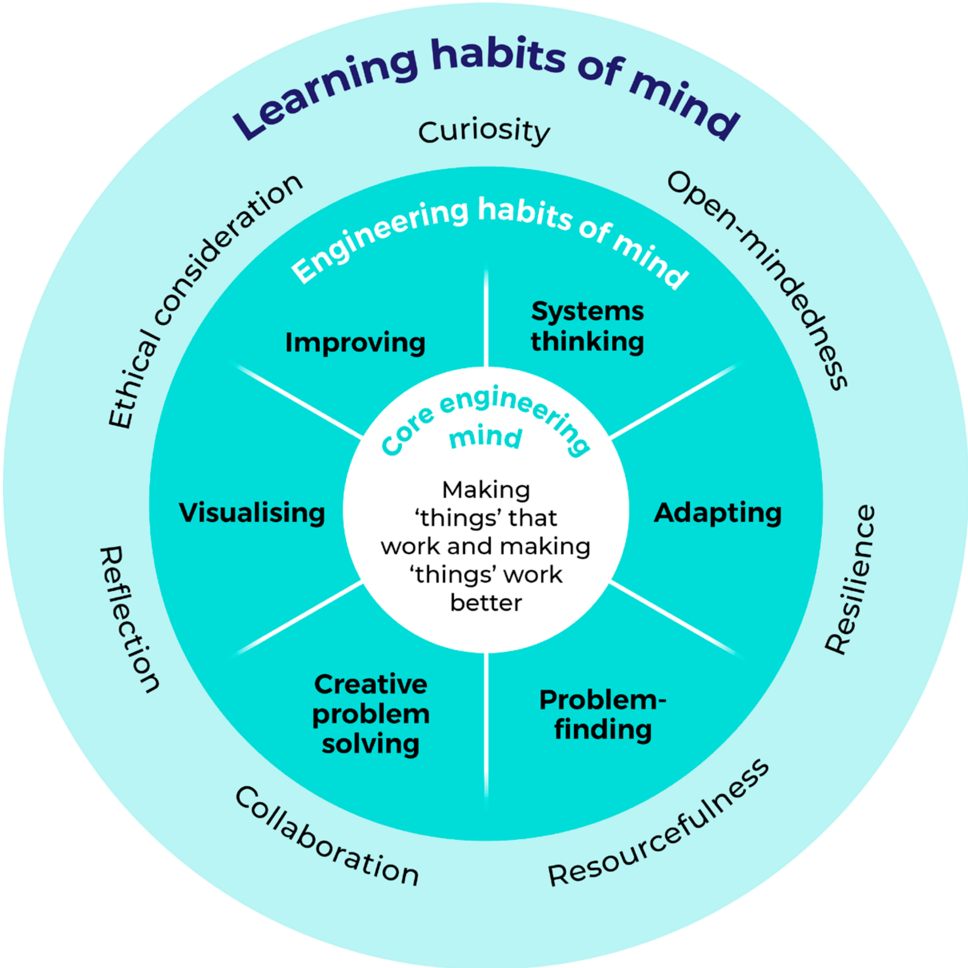
- collating evidence from existing research and knowledge of what works (working deductively)
- building theory from observed phenomena rather than relying on what is already known or assumed about how it works (working inductively)
- working with stakeholders (privileging the knowledge and experience of those who have their own ideas about how things work).

The scope of this review did not allow time to work directly with stakeholders, apart from those who were members of our expert Advisory Panel (Appendix 2), but we have assembled a list of schools with promising practices in practical learning for a later stage (see Section 5).

2.2.1 Collating existing evidence

In collating evidence of what works we used a scoping review method (Arksey and O'Malley, 2005) to locate and analyse relevant high-quality studies of

Figure 2:
Engineering habits of mind (EHoM) (Lucas, Hanson and Claxton, 2014)



some forms of practical learning in schools. Our initial definition of practical learning was:

"Practical learning involves head, heart and hand working in harmony. In schools this means using approaches such project-based, problem-based and inquiry-based learning, which encourage students to explore real-world challenges and offer learners opportunities to work with resources of many kinds to make things that work or make things work better."

A scoping review approach

A scoping review is a process of reviewing the existing literature or evidence base to clarify definitions related to the research questions and to understand the way these are conceptualised in existing literature, and to identify gaps and uncertainties (Arksey and O'Malley, 2005). The search strategy for a scoping review is typically broad and comprehensive, encompassing published literature and less formal literature and resources, often referred to as grey material (Adams et al., 2016). A scoping study also enabled us to include and disseminate findings from a range of different research methods and study designs (Arksey and O'Malley, 2005).

Given the range of this field, we narrowed our focus down to three specific practical learning approaches associated with effective pedagogies for engineering learning – undertaking authentic projects, using a process of rigorous inquiry and solving problems (Lucas and Hanson, 2016). Expressed as teaching methods these are PBL, IBL and PrBL. We also limited our selection of high-quality studies for review to peer-reviewed meta-reviews, 20 of which were included at this stage. Further details about our search strategy and criteria for inclusion can be found in Appendix 2.

Our approach to grey literature

Grey literature is information produced by many organisations in electronic and print formats where publishing is not the primary activity of the producing body. This literature typically takes the form of, for example, reports, policy statements,

Table 1:
Categories and number of organisations searched for grey literature

Category of organisation	Number searched from Royal Academy of Engineering list	Number of additional organisations	Totals
Charitable trusts and foundations/ research organisations/think-tanks	14	16	30
STEM subject community organisations/teacher support/ activity providers AND some general teacher support bodies	12	9	21
Engineering bodies	4	0	4
STEM policy bodies	3	0	3
Community interest company	1	0	1
Government and agencies	2	0	2
Awarding bodies	2	0	2
Employers' organisations	1	0	1
International regional or global organisations and overseas educational organisations with a focus on practical learning	0	14	14
Totals	**39**	**39**	**78**

issues papers, conference proceedings, newsletters, case studies or fact sheets (Adams et al., 2016).

We were specifically interested in grey literature from organisations renowned for producing high-quality education research studies in this broad field of practical learning. Given our end focus on engineering we took a report published by the Royal Academy of Engineering, *The UK STEM education landscape*, (Morgan and Kirby, 2016) as a starting point. The report notes that there are over 600 organisations involved in supporting engineering education.

Out of these 600, Morgan and Kirby name more than 100 organisations from which we selected a sub-set of 39. This was augmented with a further 39 organisations with which we were familiar through our own networks and previous research, making a total of 78. This number included international organisations, which had not been included in the Academy's list.

The categories of organisations, following that expressed in the Academy's list (ibid, p.6), are displayed in **Table 1** and the full list of names is in Appendix 3.

A further 16 reviews or research reports located through this part of the search were included in our scoping review, making 36 papers in total. The studies included in our review are shown as starred items in the references list.

Beyond grey literature there is another even less defined category increasingly referred to as grey information (Adams et al., 2016). Such information, produced by schools and other organisations, informed our selection of promising case study schools (see **Table 3** in Section 5), and once verified, it could also have the potential to act as confirmation from or challenge to themes found in the literature.

2.2.2 Building theory

This research builds on theory-based approaches to understanding how learning about engineering in schools works well, now increasingly validated in the field (Lucas et al., 2014; Lucas et al., 2017). The data generated through our systematic searching (2.2.1) enabled us to identify themes, summarise these, look for connections and points of divergence, explore definitions and approaches, and generally synthesise a range of qualitative and quantitative data.

The two main approaches we adopted for this aspect of the research are often used in health research,

Figure 3:
Our TOC as seven steps

a. If we better understand the ubiquity and complexity of practical learning
And
b. If we can suggest a range of benefits that it can confer on learners in schools and in life
And
c. If we can show that, when done effectively, practical learning can enable students to achieve as well in standardised tests as with more traditional methods
And
d. If we can better distil the essence of excellent practical learning and identify promising secondary schools doing it well
Then
e. School leaders, teachers and policymakers will see the wider benefits of practical learning, and more high-quality practical learning will take place within the formal curriculum of secondary schools
And
f. More young people will want to explore engineering when they leave school
And
g. Society in general will begin to see that practical learning is a valuable part of almost all learning that is worthwhile at school and in life.

less so in education, thematic analysis and meta-study. Thematic analysis, 'a method for identifying, analysing and reporting patterns (themes) within data' (Braun and Clarke, 2006, p.79) was used initially to report themes we considered important to understanding the outcomes of practical learning for learners and features of high-quality practical teaching.

Along with thematic analysis we adopted key aspects from an approach known as meta-study (Paterson et al., 2001). Meta-study involves analysing the theories that led researchers to identify relevant research topics and frame the ways these were interpreted, careful examination of the way in which the methodological approaches are used to gather and interpret data and shape findings, and an attempt to reinterpret findings from studies in light of data and findings from other studies.

Our TOC for this study can be described as seven steps (a-g) (**Figure 3**).

2.2.3 Engaging with practice

While some aspects of practical learning have been relatively well-researched as we have discussed earlier, such studies almost always ask a different question from the ones on which we focused. The number of schools choosing to focus on practical learning *and* achieving good test results[1] is small, estimated to be fewer than a few hundred. An increasingly helpful method in seeking to understand the practices of early adopters is positive deviance. Positive deviance assumes that in any context, certain individuals facing similar challenges, constraints and resource deprivations to their peers will employ uncommon but successful strategies that enable them to find better solutions. By studying these individuals and their institutions, innovative solutions can be identified (Bradley et al., 2009).

A few well-regarded organisations have been actively promoting and supporting the development of high-quality practical learning in various forms and these gave us an initial starting point to identify schools. These organisations are listed in Appendix 3. Other sources included case studies in research reports and grey literature and information on websites of organisations providing educational material for teachers. Lists of Free Schools such as Studio Schools

1 We used the Ofsted category 'Good' as the minimum quality threshold for schools to be included even though we are aware that there are excellent practices in practical learning in schools which are consequently excluded.

Figure 4:
An overview of secondary schools with promising practices in practical learning in England

and UTCs, established specifically to offer a practical as well as an academic education, were useful starting points. We also drew on our own knowledge of the field and teachers' networks to identify likely candidate schools.

The small-scale nature of this research meant that we had to rely mainly on secondary sources for this element of our review where the information about the schools was in the public domain.

While direct engagement with schools would have been desirable it was beyond the scope of this study and made less feasible due to challenges during the COVID-19 pandemic in 2020. Ways in which our selected schools have addressed practical learning are discussed in Section 5 and the schools are shown on the map above (**Figure 4**).

We have been assisted in all aspects of this research by an expert Advisory Panel, see Appendix 2. Members of the group were selected based on their experience of engineering education in secondary schools and their shared vision for the value of practical learning. Their role was to support the research team by acting as 'trusted and knowledgeable colleagues' and provide a sounding board at points through the research process (Custer et al., 2010).

2.3 In summary

While there are several high-quality studies into the impact of practical learning on students, which we analyse in the following sections of the report, these almost always focus on learner outcomes as gauged through one element only: attainment in standardised tests. We note some further limitations affecting our study in Appendix 2.

Both research and policy discourse discussions about practical learning almost always end up being polarised – academic versus practical, high status versus learning of lower value. Our research questions seek to identify potentially wider benefits of three kinds of practical learning used in schools: PBL, IBL and PrBL, especially the opportunities they afford for would-be engineers. Our overall approach to the research is theory-based, combining rigorous analysis of a range of data with a deliberate re-examination of many of the assumptions and preconceptions that have led to conclusions being drawn and offering a potential narrative of a different future.

3. Practical learning in schools: the state of play

An important philosophical distinction has been made many times between 'knowing that' and 'knowing how' – between propositional knowledge and practical know-how. Propositional knowledge is the knowledge of the physical and social world that can be put down in statements, verified by reference to experience, give rise to explanatory theories and that can be transmitted as such. Practical knowledge, on the other hand, 'knowing how', often escapes articulation in 'knowledge that', even if attempts are made to write about such practical knowledge.

Pring, R. in Kehoe, D (ed.) (2007) *Practice Makes Perfect: The Importance of Practical Learning*. London: Social Market Foundation (p.83)

This section begins with a brief overview of the key features of the three approaches to practical learning we have selected for this review – PBL, IBL and PrBL.

This is followed by a thematic analysis of the positive outcomes for learners of these approaches. The analysis is divided into two main sections: the first explores outcomes for knowledge acquisition and the second explores the impact of practical learning on developing a wider set of habits of mind likely to be useful for success throughout an individual's lifetime.

3.1 Three common approaches

The three most widely used and evaluated ways of emphasising the practical aspects of learning are PBL, IBL and PrBL. Each of these three approaches has its origins in attempts to find a method of education that fostered the acquisition of knowledge at a deep, rather than surface, level and that also afforded the learner opportunities to apply this knowledge in an authentic context where it was valued. Underlying each approach is an attempt to motivate learners to apply themselves to what they are learning through some form of relevant, practical activity that stimulates their curiosity.

3.1.1 Project-based learning

PBL is learning that is structured around an extended project or investigation, potentially involving several disciplines rather than a single subject. PBL may often be the core way of organising a school timetable.

Before being adopted in schools in the 20th century, PBL had been used centuries earlier in the education of architects and engineers as a method of combining theory and practice (Craig and Marshall, 2019). Subsequently, the 'project method' was proposed as a means of involving children in purposeful educational activity that would set them on the path to becoming adults who can take responsibility for their own actions and participate in civic democracy (Kilpatrick, 1918).

During the 1960s PBL, with its emphasis on active learner engagement, was embraced by the so-called 'progressive education' movement, which popularised 'child-centred' methods (Condliffe et al., 2017) based on a constructivist approach to learning (Holm, 2011).

While there are many different approaches to PBL, most authors agree on the five core characteristics proposed by Thomas (2000), one of the most referenced authors in the literature since 2000. These features apply to the nature of the project:

- Projects are central, not peripheral to the curriculum, the project **is** the curriculum.
- Projects are focused on questions or problems that 'drive' students to encounter (and struggle with) the central concepts and principles of a discipline.
- Projects involve students in a constructive investigation.

- Projects are student-driven to some significant degree.
- Projects are realistic, not school-like.

These 'original' features of the project have been explored and expanded by subsequent authors. Some emphasise PBL as involving a creative act that takes place over time, which gives students hands-on opportunities to work with concepts from course materials, discuss their approach in peer groups and present their work (Chen and Yang, 2019). The extended period allowed for projects and the importance of having an end result, whether a product, presentation or performance is noted (Holm, 2011; Hood-Cattaneo, 2017). While the specific output can be the result of individual or collaborative student activity, the PBL process should involve the exploration of real-world problems and the challenges, which are 'not school-like', support 'deeper learning' (Condliffe et al., 2017, p.2).

Collaborative social interactions also occur between the students and the teacher (Hasni et al., 2016) and the active role played by the teacher is a critical component of PBL. Critics of student-centred pedagogies such as PBL suggest that student investigations place too much cognitive load on students' memory and can result in lack of learning, when compared with more traditional teaching that provides content instruction (Kirschner et al., 2006) but the teacher is not standing back and releasing control over the classroom, as often presumed in these critiques; the teacher plays an active role in PBL by using appropriate scaffolding and guidance when necessary (Thys et al., 2016).

There are examples of PBL use in a wide range of subjects including the sciences, social sciences and humanities (Condliffe et al., Craig and Marshall, 2019; 2017; Hasni, et al., 2016; Kingston, 2018; Kokotsaki et al., 2016) and it has always had a central place in technology and engineering education (Fleer, 2015; Hasni et al., 2016).

PBL is now advocated as an essential strategy for developing the kind of competences young people need for success in the modern world and for lifelong learning (Pellegrino and Hilton, 2012; World Economic Forum, 2020). Current models of PBL, such as PBLWorks (Buck Institute for Education, n.d.) and REAL Projects (Innovation Unit, 2020), epitomise the pedagogic manifestation of PBL and are used in schools around the world.

3.1.2 Inquiry-based learning

IBL is learning that focuses on harnessing and developing learners' curiosity and critical thinking by structuring the curriculum around a series of questions to develop knowledge and understanding. It seeks to promote engagement and ownership and can be used in any subject and in a range of formal

and informal settings. It can be used with individuals or in groups and the question guiding the inquiry can be differentiated to ensure that it is pitched at the right level of difficulty for students.

Like PBL, IBL owes its origins to the experiential learning philosophy of John Dewey and was adopted by the discovery learning movement in the 1960s as a way of learning science content. In the 1960s and 1970s the science curricula in England, supported by the Nuffield Foundation, placed strong emphasis on practical scientific discovery (Holman, 2017, p.34) and several Nuffield 11 to 14 cross-curricular STEM projects are available on the STEM Learning website (STEM Learning, n.d.).

Indeed, IBL has long been associated with science education as a method for cultivating science process skills and for encouraging learners to 'think like a scientist' (Khalaf and Zin, 2018). It also encompasses the practical skills of using and manipulating scientific equipment and conducting experiments to make observations in order to actively inquire into a phenomenon or problem (Hood-Cattaneo, 2017; Lazonder and Harmsen, 2016; Minner et al., 2010).

3.1.3 Problem-based learning

PrBL is learning in which complex real-world problems are used as the mechanism to help learners understand concepts and acquire knowledge and understanding in context as opposed to through direct instruction. PrBL is a pedagogy that was originally developed at McMaster University in Canada in the search for a more effective approach to medical education (Hood-Cattaneo, 2017; Jerzembek and Murphy, 2013; Demirel and Dagyar, 2016; Wilder, 2015). The aim was to develop doctors' non-routine problem-solving skills while at the same time developing their knowledge base (Savery, 2019).

PrBL is found more frequently in higher education than in schools, particularly in medical and engineering education. Aalborg University in Denmark is a leading example of its application at a whole-institution level (Aalborg University, 2015) and hosts the UNESCO-supported Centre for Problem Based Learning to promote PrBL in engineering education.

3.1.4 Three pedagogies compared

Despite these different origins, the three approaches share several overlapping characteristics derived from their common constructivist underpinning. They are inquiry-based, the starting point for each being a question, puzzle or problem that engages the students' interest; the inquiries focus on real-world issues; they promote student agency in knowledge acquisition or creation and the use of cognitive tools such as problem-solving and metacognition; they can be either individual or group activities, but they involve social interaction; and there is a concrete outcome (Hood-Cattaneo, 2017; Rogers et al., 2019; Savery, 2019). Some of the ways in which these characteristics are perceived differently between each approach, and within in some cases, are shown in **Table 2**.

Whereas many secondary school teachers in the UK may not be familiar with PBL, IBL or PrBL in their full form as pedagogy, they will recognise constituent elements of each that they use in their classroom teaching methods. Hood-Cattaneo (2017) recognised this distinction between the terms when used as pedagogy, meaning a complete learning environment, and method, meaning a tool or technique, which may explain why we see some lack of consensus in the following review of their impact.

3.2 Practical learning for knowledge acquisition

Studies comparing the practical learning approaches with traditional teaching methods have, in general, found the outcomes to be at best equal to but no better than traditional methods for teaching academic content. While some studies report positive gains, others report the opposite, or no significant difference but studies inevitably vary according to the approach investigated, the subject and other moderators such as student characteristics.

3.2.1 Practical learning outcomes for knowledge acquisition in specific subjects

While it is claimed that students in project-based classrooms have exhibited greater gains in content knowledge than their peers taught through traditional instruction (Chen and Yang, 2019; Craig and Marshall, 2019; Holm, 2011), there are differences according to subjects. Positive impacts of PBL on content learning have been noted in science, technology and social studies classes (Condliffe et al., 2017; Craig and Marshall, 2019; Hasni, et al., 2016; Kingston, 2018; Kokotsaki et al., 2016), and also in cross-curricular learning (Rogers et al., 2019). One recent study suggests that learning gains from PBL are higher for social sciences than for STEM subjects (Chen and Yang, 2019).

With IBL, the process of engaging in scientific inquiry and undertaking scientific practical work are both associated with positive knowledge outcomes. Investigative activities that emphasise students' active

Table 2:
Characteristics of practical learning – a summary in quotes

What is said about …	In PBL	In IBL	In PrBL
The starting point	'… a driving question to motivate learning' (Leggett and Harrington, 2019, p.3)	'… inquiry-based classrooms are driven by questions that focus and frame inquiries' (Hood-Cattaneo, 2017, p.147)	'… the learning process always starts with a problem. The problem describes an event or phenomenon in daily life in need of explaining.' (Wijnia et al., 2017, p.12)
Real-world issues	'… focus on problems in their real-life setting' (Merritt et al., 2017, p.4/14)	Learners 'manipulate a combination of hands-on and computer-based science equipment and materials … to gain an understanding of the natural world' (Akuma and Callaghan, 2019, p.621)	'The activities carried out in PBL must be those valued in the real world' (Savery, 2019, p.86)
Student agency and relationship to knowledge	'A systematic teaching and learning method … enabling them [students] to acquire knowledge' (Chen and Yang, 2019, p.71) '… students must be active in the construction of knowledge … (Leggett and Harrington, 2019, p.3)	'… students find things out for themselves by pursuing an idea about which they are curious' (Bennett et al., 2018, p.1756)	'… promotes problems as a process of learning and … reinforcement of existing knowledge integrated with new content acquisition and new information towards problem resolution' (Mustaffa et al., 2013) '… students' prior knowledge is insufficient to understand the problem completely, students formulate learning issues (i.e., questions) for further self-study' (Wijnia et al., 2017, p.12) 'places the learner at the centre of the educational activity where a problem stimulates information retrieval and the application of reasoning mechanisms' (Jerzembek and Murphy, 2013, p.206)
Social interaction between students and teachers; other interactions (for example, related to embodied cognition)	'Collaboration … aims to allow students to communicate their ideas and promote discourse around the phenomena under exploration' (Hasni et al., 2016, p.205)	'… pupils engaging in science learning will be simultaneously talking and thinking, as well as using their bodies to sense and manipulate their environment' (Hetherington et al., 2019, p.143)	'Students work collaboratively to define and solve the posed problem' (Wilder, 2015, p.415)
Outputs	'product or presentation to an audience' (Chen and Yang, 2019, p.71) Final product or artefact 'meaningful on a personal level' to the student (Hasni et al. 2016, p.205)	'Learners formulate explanations from evidence to address scientifically oriented questions … evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding … communicate and justify their proposed explanations' (Minner et al., 2010, p.3)	'students … find … practical solutions over (sic) a defined problem' (Demirel and Dagyar, 2016, p.2117) 'A closing analysis of what has been learned from work with the problem and a discussion of what concepts and principles have been learned is essential' (Savery, 2019, p.86)

thinking and taking responsibility for their learning are associated with improved content learning, especially of scientific concepts (Furtak et al., 2012; Lazonder and Harmsen, 2016; Minner et al., 2010).

However, in contrast with these findings reporting gains in students' science knowledge through IBL, other studies have noted that a greater exposure to IBL is associated with lower science scores, and that teacher-directed science instruction correlates more positively with students' higher PISA test scores in science (OECD, 2016; Denoël et al., 2017).

This negative association between inquiry-based science teaching and science understanding is greatly reduced when lessons are delivered in 'disciplined' science classes (Mostafa et al., 2018) or when the right balance between teacher-directed and inquiry methods is found. Denoël et al.'s (2017) analysis of the PISA 2015 data, which looked specifically at the results for the EU and England found that a combination of teacher-directed and inquiry-based teaching yielded the best PISA scores, because, they surmised, that students need a strong base of content knowledge before they are able to benefit from practical inquiry. Some inquiry-led practices are less effective than others. Some of the least structured inquiry activities are the least effective, including 'having students design their own experiments, asking them to do investigations to test ideas, having a class debate about investigations, and requiring students to argue about science questions' (Denoël et al., 2017, p.43).

This finding was repeated after further analysis of the PISA 2015 data (Jerrim et al., 2019) who found 'little evidence that the frequency of inquiry-based instruction is positively associated with teenagers' performance in science examinations' even when classroom discipline (their proxy for quality) was taken into account.

And yet, in technology, the subject through which engineering is commonly introduced in schools, and where science and mathematics can be drawn on for solving problems, the project reflects the inseparability of doing and knowing for learning, where bodily experiences are essential for learning (Fleer, 2015; Mioduser, 2015; Pirhonen, 2018).

3.2.2 Impact of practical learning on mathematics and literacy

Evidence for the effectiveness of PBL in the core subjects of mathematics and literacy is limited (Kingston, 2018). Specifically, in England, Menzies et al. (2019) found that adopting PBL had no clear impact on literacy as measured by the Progress in English assessment.

One UK study did find that PBL led to an increase in content knowledge in mathematics because students developed different types of knowledge and conceptual understanding through PBL rather than just information recall (Boaler, 1998, cited in Kokotsaki et al., 2016 and in Rogers et al., 2019).

Elsewhere however, it has been found that PBL only matched performance in mathematics (Craig and Marshall, 2019) and it has been suggested that mathematics teachers find it difficult to integrate PBL into their instruction (Condliffe et al., 2017).

3.2.3 Impact of individual projects for academic knowledge gain

Evidence from England suggests a positive impact on students undertaking individual projects for a post-16 qualification, the Extended Project Qualification (EPQ). Taking the EPQ concurrently with A levels has shown to enhance performance in English, business, sciences, and art and humanities A levels. By preparing students more effectively for university teaching, the EPQ may also enhance their prospects of gaining a first-class or upper second-class degree, in addition to increasing their likelihood of surviving their first year at university (Stephenson and Isaacs, 2019).

A review of independent inquiry-based projects in science found evidence to suggest that they were associated with gains in students' learning of science ideas (Bennett et al., 2018). However, an evaluation of a specific instance of student participation in an independent science project (the CREST Silver Award), found that students achieved no additional attainment in science compared to the control group (Husain, 2019), unless they were completing the project outside of class time. The assumption was that those attempting to complete the project in class had less time because of preparation for GCSEs (Husain, 2019).

3.2.4 Longer-term versus short-term gains in knowledge with practical learning

In higher education, where most of the research into PrBL is located, the approach has been found to be more effective than traditional lecture-based programmes for long-term retention of knowledge, in particular in medical education where a doctor must retain knowledge for practice beyond the

final examination of the course. Furthermore, PrBL students are more effective at integrating and explaining concepts than those who are taught traditionally. However traditional methods appear to be more effective for short-term content acquisition (Hoidn and Kärkkäinen, 2014; Wilder, 2015) and are more likely to produce better outcomes for the assessment of basic science knowledge (Strobel and van Barneveld, 2009).

At primary and secondary levels, where short-term knowledge acquisition is more likely to be assessed than longer-term gains, the evidence is also more inconclusive. In one review the evidence for content acquisition and learning gain through PrBL was found to be limited (Jerzembek and Murphy, 2013).

However, another review found that PrBL did have a positive impact on school pupils' academic achievement, knowledge retention, conceptual development, and attitudes, and that PrBL was at least as effective as traditional instruction in relationship to student academic achievement and knowledge retention (Merritt et al., 2017).

3.2.5 Specific moderators of practical learning that can lead to positive outcomes

Luckin et al.'s (2017) analyses of teaching through collaboration and through problem-solving revealed that both strategies have positive effects on pupils' achievement and the Education Endowment Foundation (EEF) has found that that the impact of collaborative learning is consistently positive (EEF, 2018).

However, it has been observed that that teachers struggled to incorporate PrBL into mathematics (Merritt et al., 2017) and the OECD TALIS survey for 2013 also found that mathematics teachers are least likely of all subject teachers to use collaborative work, which is normally a feature of PrBL (OECD, 2013).

The importance of teacher guidance for positive practical science outcomes noted in the PISA studies above reflects other findings that a significant influence on impact for learning in IBL is the degree of guidance provided by the teacher. Learning gains from teacher-guided inquiry contexts were higher than those from traditional lessons or student-led activities (Furtak et al., 2012) and learners who are given guidance act more skillfully during the inquiry task. Learners receiving guidance are also more successful in obtaining topical information from their investigational practices and score higher on tests of learning outcomes administered after the inquiry (Lazonder and Harmsen, 2016). The importance of teacher guidance for IBL and our other forms of practical learning is explored further in Section 4.

3.2.6 Impact of practical learning on specific sub-sets of the student population

Studies that investigated the impact of PBL on specific sub-sets of the school population have found positive academic outcomes with underrepresented groups in science (Hasni et al., 2016), with girls (Sivia, 2019) and with students with learning difficulties (Holm, 2011). However, outcomes for students from low socioeconomic groups are mixed, sometimes reported as performing below their peers (Leggett et al., 2019) and sometimes with enhanced outcomes

(Kingston, 2018). A similar inconclusive finding is noted for students of lower or higher levels of achievement (Condliffe et al., 2017).

IBL appears to be effective for students with social-emotional and behavioural difficulties, where the reduced demands on language and literacy skills serve to simplify the task for them (Zweers et al. 2019).

However, overall, the ambiguity of findings provides support for the argument that that the education of disadvantaged students should not be further put at risk by implementing practical learning in mainstream classrooms when it is unlikely to offer benefits when compared with direct teacher-led instruction.

3.3 Practical learning for developing habits of mind for success in life

As explained in Section 2, the focus to date on research into the impact of practical learning has not yet shifted towards the wider potential benefits of the kinds of pedagogies we have been discussing. Consequently, there are very few high-quality meta-reviews of the kind we have analysed in 3.2. This does not mean that there is no evidence of wider benefits, just that this has not yet been conclusively demonstrated.

Nevertheless, there are some helpful indicators, which we summarise below.

3.3.1 Impact of practical learning on problem solving and creativity

When students work in groups on ill-structured problems, their problem-solving abilities are enhanced (Mustaffa and Ismail, 2013) and superior quality problem-solving occurs when students are working collaboratively rather than in competition with each other (Luckin et al., 2017). Students experiencing PrBL are also better able to apply their learning to real-world situations (Hoidn and Kärkkäinen, 2014) and tackle problems in new situations (Thomas, 2000).

The learning processes of PBL can support the development of students' creativity to overcome technical problems through increased discussion between students and teachers, (Hasni et al., 2016). Furthermore, Bennett et al. (2018) found that IBL can increase creativity and skills, but as most teachers appear to be using science practicals to increase motivation rather than for learning science or developing scientific skills, despite the potential for them to do both, there is limited evidence to suggest that it does improve practical skills, because of the way in which the research has been reported (Holman, 2017). Furthermore, some UK science

teachers do not believe that scientific inquiry can develop creative thinking (Hetherington et al., 2019).

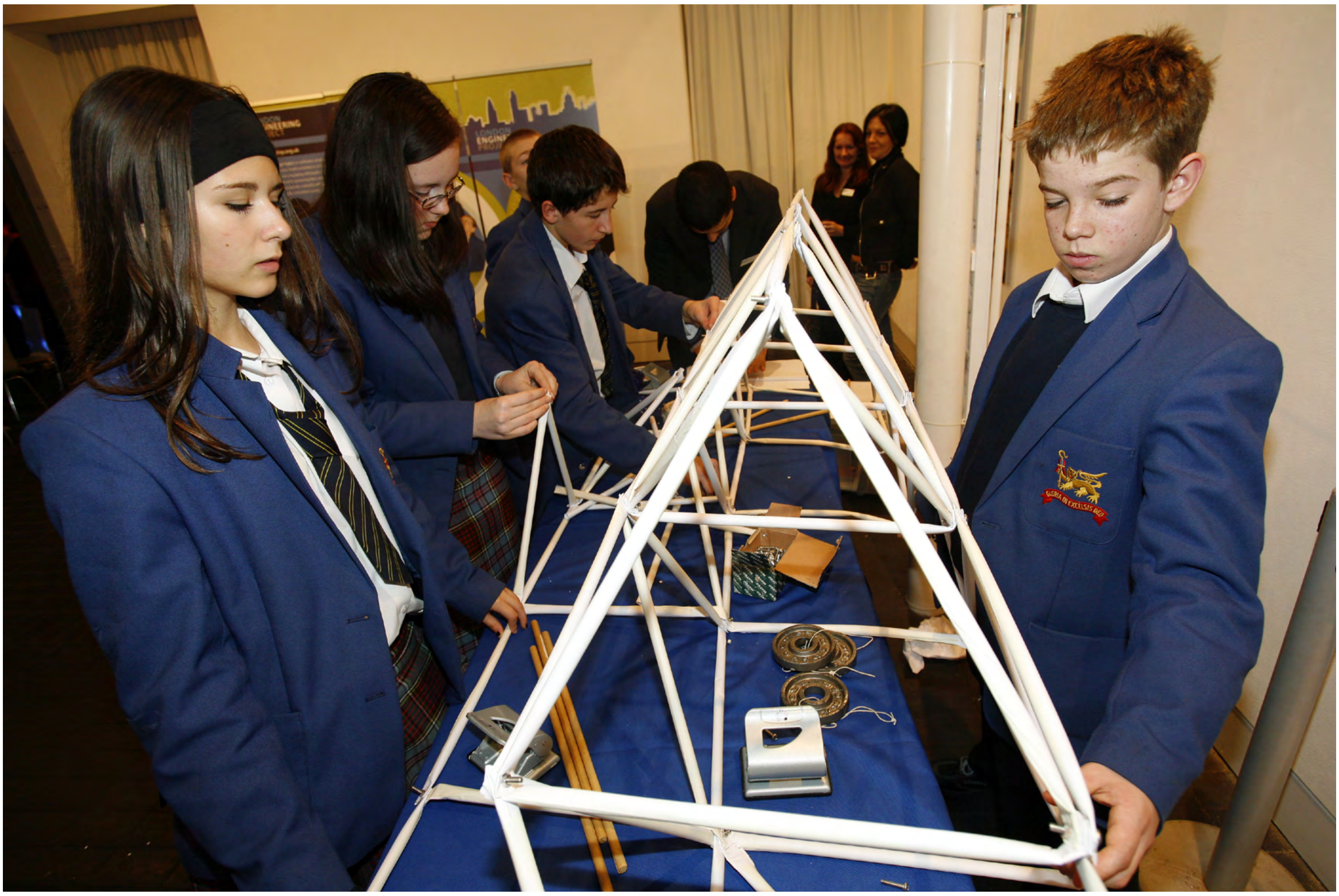
3.3.2 Impact of practical learning on communication and collaboration

Menzies et al. (2016) found, from observations and feedback from schools, that PBL 'may enhance' pupils' skills in oracy, communication, teamwork, and self-directed learning skills' (p.4). However, findings on the impact of practical work on teamwork can be ambiguous; some studies report a positive impact (for example Mustaffa and Ismail, 2013) and others report a negative impact, particularly where evidence relied on student feedback (Ralph, 2016). It can be imagined that students working in high-performing teams might be more satisfied with the experience than those whose team members did not get along.

Although past research was less focused on evaluating the impact of practical learning on wider skills such as communication and working collaboratively, as we noted in Section 2.1, interest in developing students' 'employability' skills within the education system is growing. Researchers are beginning specifically to address the relationship between practical learning and capability, particularly in nations where such skills, often referred to by them as 21st century skills, are a focus of national interest. Small-scale research studies from countries including Canada (Sivia et al., 2019), Emirates (Bani-Hamad & Abdullah, 2019) and Indonesia (Triana et al., 2019) have all reported positive gains in students' communication and collaboration through PBL. The researchers in each case acknowledge that their studies lacked the scale to generalise robustly from their results, but they point to interesting conclusions. For example, Sivia et al. (2019) found that science students might become more engaged civically with their community through PBL, which suggests an interesting possibility for raising interest in engineering if it is understood by students as a matter of civic engagement.

3.3.3 Enhancing student interest in and attitude towards a subject

In science, students find projects and practicals interesting and can more readily see links between science and the real world as a result, which inspires them to engage in the learning and introduces them to real scientific work (Hasni et al., 2016; Holman, 2017; Sivia, 2019). However, caution should be observed when discussing science, as students' preference for practical work may not be the same for all three sciences. As Sharpe and Abrahams (2020) noted, students enjoyed practical work in physics and chemistry more than in biology, since



they found the first two subjects harder than the third and saw practical work as an enjoyable change of activity.

Authentic learning activities based on real-world problems engaged students in STEM learning (Julià and Antolí, 2019) and also in technology, when student interest increases as they can see the relationship between the practical activity and its theoretical underpinning (McGeown, 2019).

Independent inquiry projects can also lead to an improvement in attitudes to science, particularly among students with lower socioeconomic status and ethnic groups (Bennett et al., 2018), girls (Mostafa et al., 2018) and students with social-emotional and behavioural difficulties (Zweers et al., 2019).

Several authors reported that PBL has a positive impact on student engagement, interest in the task, motivation, self-efficacy, and other interpersonal competencies (Condliffe et al., 2017; Reis et al., 2017; Sivia, 2019; Wijnia et al. 2017).

3.3.4 Enhancing self-efficacy and self-confidence

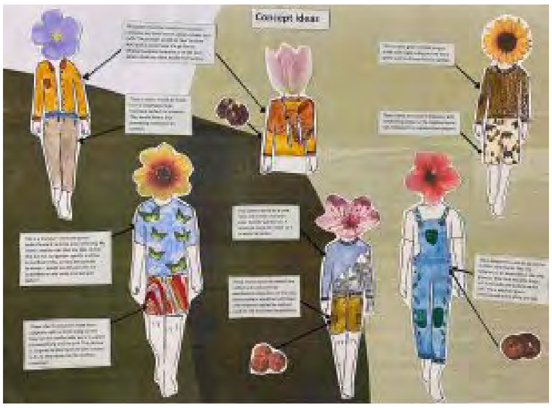
PBL can enhance students' self-efficacy in physics (Samsudin, 2020). PrBL develops student's self-regulation and self-efficacy (Jerzembek and Murphy, 2013). Collaborative learning activities lead to higher motivation to engage in a task than traditional approaches to instruction, which is important to note since motivation to engage in a task is fundamental to learning and is likely to be the driving force behind cognitive learning (Luckin et al., 2017).

With higher education students, PrBL boosts their self-confidence and benefits their communication and interpersonal skills, having a positive impact on students' motivation, satisfaction, and attitudes toward learning (Hoidn and Kärkkäinen, 2014)

3.3.5 Getting the timing right for practical learning

As with the need to have sufficient underpinning knowledge to successfully engage in practical learning, students also need a certain level of confidence and skill to successfully engage with the demands of studying through the approaches we examined. For example, students reported challenges in engaging with PBL processes, in particular using research skills and engaging in discussion with teachers and peers (Hasni et al., 2016).

Husain (2019) found no evidence to suggest that undertaking CREST Silver Award projects enhanced aspiration towards STEM careers or improved



self-efficacy in science, but the students were undertaking these projects in their GCSE year, when the requirements for knowledge for the exam would possibly have outweighed the interest generated by the project.

Correlating with this experience of students undertaking CREST projects in their GCSE year, Sharpe and Abrahams (2020) also found that although the affective value of practical work existed to varying degrees in all three sciences, this value decreased as students approached their GCSE examinations at age 16. This research suggested that teachers should begin practical work early in Key Stage 3 and reduce the amount of practical work in Key Stage 4 when students' preference for non-practical, exam orientated, teaching increases.

3.3.6 Issues with measuring capability gains in practical learning

Very few studies until recently have sought to use the research to show the impact that PBL had on the relationship between the approach and capabilities. Those that did try to show a relationship, did not use research tools developed for the field (Hasni et al., 2016, p.223).

Many teachers suppose that practical work increases students' interest in a subject, which should lead to stronger motivation to study and a greater sense of agency as students can exercise greater control over their learning. There has been some evidence to support this view from the earliest period of our study (Thomas, 2000) to the current day.

In the evaluation of the EEF study on PBL, students talked enthusiastically about their projects, and teachers observing their students' behaviours reported benefits in terms of 'attainment, confidence, learning skills, and engagement in class' (Menzies et al. 2016 p.53). However, the results from the formal test used in the evaluation showed no impact on student engagement (Menzies et al., 2016).

This aligns with caveats expressed by other researchers who suggest that positive results relating to dispositional gains should be regarded with some caution because judgements often rested on students using self-report measures, which are not regarded as strong proof (Condliffe et al., 2017; Reis et al., 2017; Sivia, 2019; Wijnia et al., 2017). However, it might equally suggest that there is value in undertaking in-depth qualitative research to gather evidence about value of practical learning to students and teachers. It also affords the opportunity of gathering the views of other stakeholders such as employers and parents/carers (McCrone et al., 2019).

3.4 In summary

We examined the research into three common expressions of practical learning, PBL, PrBL and IBL, to review the extent to which learning outcomes

associated with knowledge and with wider habits of mind for learning existed and how strong the evidence was for each aspect.

The three approaches have a significant number of attributes in common:

- All revolve around an activity that has several defined features that make it what it is: a task, a question or a problem, each with an end in view, starting, managing and finishing a project, solving a problem or completing an inquiry.
- The activity works best when it has relevance to students, either through its resemblance to real-world or professional challenges, or be based on students' individual interests. It can be an individual or a group endeavour.
- The level of student involvement in the choice of topic for the focus of the activity can vary from being the student's own choice to a topic set by the teacher or another, for example an employer.
- Purposive collaborative social interaction takes place throughout the activity between students and other students, their teachers, or members of the community such as employers.
- The role played by the teacher in ensuring that students have sufficient underpinning conceptual knowledge, in scaffolding and guiding the inquiry, and in providing feedback, is complex and requires professional development and support.
- A thorough understanding of the subject(s) being studied through these approaches is important; to suggest otherwise risks the approach being devalued and a poorly executed intervention.

When we examined the learning outcomes claimed for each approach, much of the research covering secondary education is concerned with justifying the use of the method in the classroom by comparing it with 'traditional instruction' and seeking to demonstrate that it leads to higher gains in academic learning.

However, given the wide range of variables possible in the implementation of practical learning, despite the common attributes listed above, and also of traditional learning, it is very difficult to say with conviction that practical learning does or does not lead to enhanced learning of academic content in specific subjects, but what we can say is as follows.

In science, there is evidence to suggest that PBL, independent IBL and PrBL can lead to gains in content knowledge and enhanced longer-term retention of knowledge. But, there is also evidence from large-scale international surveys that IBL leads to a lowering of science understanding and attainment. However, school science is normally composed of three subjects, each of which may have different results.

For mathematics, the evidence for content learning is both positive and negative, but the principal positive outcome was derived from research that is now over 20 years old. More recent research suggests that mathematics teachers make less use of any of these practical learning approaches than teachers in other subjects.

For literacy there is no evidence of positive impact in knowledge gain.

A surprising outcome of our research was that only one review (Hasni et al., 2016) specifically addressed the impact of practical learning on outcomes for the subject of technology, which is often the primary vehicle for introducing engineering into the secondary school curriculum. Although the review linked technology with science, the findings reported knowledge gain in technology as well as science.

Furthermore, some highly relevant research suggests that embodied cognition offers an important avenue for exploring learning in technology education (Mioduser, 2015; Niiranen, 2019; Pirhonen, 2018) and in practical science (Hetherington et al., 2018; Roth, 2018). The subject of computing, a recent addition to the curriculum in England that replaces ICT, might also be worth exploring through this lens.

Despite the fact that little research has, so far, specifically explored the impact of practical learning for developing dispositions and capabilities, there is a reasonable amount of evidence to suggest that our three forms of practical learning can support outcomes for both these areas, albeit with caveats around the security of some of the findings because of the limited use of appropriate measuring instruments. However, as more education systems embed learning for wider capabilities (21st century skills) within their curricula, research interest is growing in establishing the relationship between practical learning and developing attitude and capability.

So far, studies have shown that our three forms of practical learning enhance engagement, motivation, self-regulation, communication, creativity, and problem-solving abilities, including tackling problems in new situations enhanced.

Students enjoy practical learning, but despite the motivational interest engendered through the novelty aspect, this feeling wears off once more pressing examinations loom on the timetable, when the activity leads to classroom disruption, or when links between the activity and theoretical concepts are not fully drawn. Collaborative learning in the context of practical learning can also enhance motivation and teamwork, again, providing the activity is well managed.

Research into the value of practical learning for specific sub-groups of students is inconclusive and while this line of research provides important data to aid understanding about equality of educational opportunity, it may risk perpetuating the existing biases underpinning the current academic-practical divide in education by suggesting that some learners are 'better suited' than others to a different style of teaching. A more fruitful approach would appear to lie in researching the factors contributing to raising the quality of implementation of practical learning (Jerrim et al., 2019) and investigating factors such as guidance, authenticity and collaboration and other moderators – in other words, concentrating on the reason why and under which conditions educational interventions are effective instead of just measuring their effectiveness (Polyzois et al., 2010). Some of this research is examined in the next section.

So while recognising the legitimacy of the research that currently underpins a knowledge-rich and content-focused curriculum for young people, we suggest that practical learning strategies can, under the right circumstances, develop content learning in subjects that matter to engineering. They can also support the broader aims of education by developing motivation to engage, creativity and problem-solving. We are not arguing for a complete adoption of practical learning, but education must include a balance of teaching strategies, as Denoël et al. (2017) note: 'our research found that student outcomes are highest with a combination of teacher-directed instruction in most to all classes and inquiry-based teaching in some classes' (p.9).

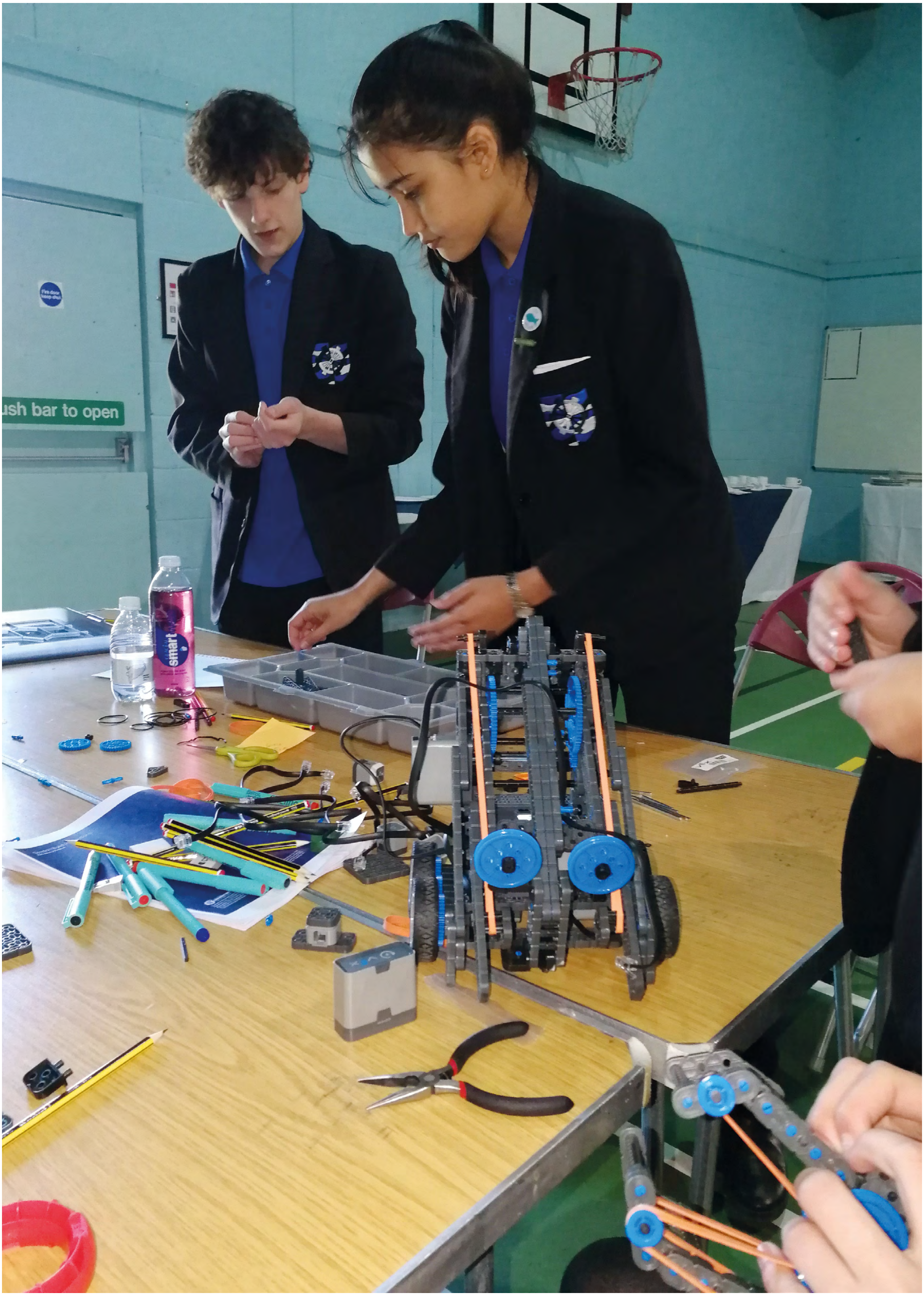
As research into embodied cognition and education expands to support an increased understanding of practical learning strategies, it is possible that in a parallel line of investigation more sophisticated understandings about the fallibility and changeability of disciplinary knowledge might emerge to change perceptions about how content knowledge should be perceived in education as it moves towards 2030 (OECD, 2017).

4. High-quality practical teaching in secondary schools

> **Bodily movement and brain activity are functionally interdependent, and their synergy is so powerfully formulated that no single science or discipline can independently explain human skill or behaviour…**
>
> Wilson, F. (1998) *The Hand: How its use shapes the brain, language, and human culture*. New York: Pantheon Books (p.10)

We have explored some of the defining characteristics of the three expressions of practical learning in the previous section, but there is no singular approach to any of them. There is also a considerable degree of overlap between the three; each might encompass several characteristics that could be present in other types of flexible learning approaches (Jerzembek and Murphy, 2013; Luckin et al., 2017).

Indeed, the complexity of practical learning practices across the range of STEM subjects makes identifying the features of best practice an ambitious goal. Although according to Cukurova et al. (2017) it might be possible to conceptualise best practice at three levels: macro (environment and learning spaces); mezzo (groups and learning activities); and micro (learning analytics or tracking data about individual student's performance) (p.5). For our analysis in this section, as with Section 3, we present a thematic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summary across all three approaches in order to synthesize factors important to the high-quality implementation of practical learning in schools. We begin by addressing contextual issues such as the school culture and leadership that influence implementation at a macro level, followed by the curriculum, the nature of the learning task, the role of the student, the role of the teacher, and the assessment strategy.

4.1 School culture and leadership

Implementing practical learning methods in a school involves complex processes. Not only does it need teachers and students to be familiar with the approach (Demirel and Dagyar, 2016) but it also requires school administrators and other staff to be sympathetic to it (Wilder, 2015). Practical learning requires the allocation of substantial resources, including physical and timetable space, since Cukurova et al. (2017) noticed that the organisation of learning spaces made a difference to the engagement of students in practical work. They identified that student movement is key to quality interaction between groups working together on tasks. They explored the layout and height of tables while students were engaged in practical work and found that hexagonal or round tables at standing height and seating that enabled students to perch beside tables encouraged far more movement between groups and hence exchange of ideas between group members, than rectangular tables and chairs of traditional height.

Factors such as such the cost of pursuing a project-based approach in terms of time, resources, and balance with other school and system demands, in particular teacher workload and the wider assessment model, remain unclear (Holm, 2011) and may require a significant change in practice for the whole school (Menzies et al., 2016). So support from senior leadership is crucial (Kokotsaki et al., 2016).

Teachers can be sceptical about the value of collaborative learning in projects, lacking trust in their students' capacity to work together and therefore regarding it as potentially disruptive to good classroom management (Luckin et al., 2017). There is some support for this view from the student perspective also, as students who reported that they worked in disciplined practical inquiry classrooms achieved higher scores in science than those who reported that their classrooms were disorganised (Mostafa et al., 2018). Students can also regard group working with suspicion (Luckin et al., 2017) despite reporting enjoyment when engaged on project work (Menzies et al., 2016).

Teachers are well aware of these and other challenges in implementing innovative pedagogies and need to access regular support through networking and professional development opportunities (Kokotsaki et al., 2016).

School leaders must therefore engage with a wide range of factors associated with a pedagogic leadership model, similar to those we identified for successfully leading engineering in schools including setting direction, developing people, managing teaching and learning, and redesigning the organisation (Lucas and Hanson, 2018).

4.2 Practical learning embedded within the curriculum

Finding time for practical learning within a full timetable and a crowded curriculum is not easy for teachers faced with busy workloads and a high-stakes accountability environment that makes failure seem high-risk (Luckin et al., 2017). The discipline-based departmental structure common in secondary schools makes any attempt to engage in cross-curricular projects challenging, even for subjects such a D&T that would benefit from links to mathematics and science (Buntting and Jones, 2015).

Therefore, much practical learning, particularly for subjects aligned to STEM, takes place outside school time through extra-curricular activities and enrichment. However, despite much of this activity providing excellent experiential learning, it is often not well aligned with the curriculum nor evaluated sufficiently rigorously to demonstrate that it makes a difference to practical learning. Despite an encouraging increase in interest in engineering through outreach activities, only a small proportion of students had experienced them and interest from girls remains low (Engineering UK, 2019).

The Ofsted Education Inspection Framework (Ofsted, 2019) supports a broad and balanced curriculum in England, and possibly offers some hope for a role for practical learning but this may be negated by accountability demands that emphasise good performances at GCSE. Ofsted itself has noted that some schools do not believe it is possible to maintain both (Ofsted, 2020). As we noted above, when discipline-based GCSEs and the framework of the EBacc dominate the timetable, there is a tendency for practical learning approaches to be eschewed in favour of more didactic ones. In the discussion on assessment further on we note the impact of an examination-driven assessment regime on practical learning.

4.3 An authentic learning task

For each of our practical learning expressions, the starting point of the learning activity is a question or a problem. Practical learning tasks offer an

opportunity to engage students in learning through authentic problems or questions. Problems and questions relating to the real world have the power to contextualise the learning and make it appear more relevant to students. To make the most of this feature, it is important to be clear about the meaning of 'context' since, as Hasni et al. (2016) argue, contextualisation can occur through multiple ways, including:

- engaging students in a learning context approximating real-life working conditions, as in a laboratory or factory
- using an environment familiar to students, as in around the school or the surrounding play area
- showing the students how the content can be useful to them, as in using knowledge about the body's energy needs to draft a menu for sports enthusiasts
- linking the task to socio-scientific issues that young people express interest in, such as climate change or recycling.

Technology projects, for example, afford particular opportunities to connect students with their community, either externally through the involvement of industry in projects (McCrone et al., 2019; McGeown, 2019) or internally with their community of classmates (Ferreira and Trudel, 2012). However, extensive planning is required when working with industry to ensure that employers and teachers understand each other's needs and assumptions about the purpose of the liaison (McGeown, 2019), particularly when student tasks are embedded within workplace visits (Smit et al., 2019).

The purpose or aim of the task should also influence the degree of structure imposed on the problem or question. Sometimes the teacher will set structured questions that require students to follow a well-defined series of steps to arrive at an answer, for example in a science practical (Akuma and Callaghan, 2019). At other times, the teacher will propose 'ill structured' problems that require students to work actively and collaboratively in small groups to investigate, pose questions, gather information, and carry out the work necessary to resolve the problem (Merritt et al., 2017). Criticism of practical learning approaches is often focused on the belief that students need sufficient content knowledge in order to be able to be able to learn from activities that are not specifically directed by the teacher (Kirschner et al., 2006). However, as we see later on, the role of the teacher in guiding practical learning is critical to success.

4.4 Fostering student agency

Practical learning requires students to have good self and time management skills, including making safe and productive use of technological resources. When students are involved in high-quality group work, they tend to share equal levels of agency and participation (Cukurova et al., 2017; Kokotsaki et al., 2016).

An element of student choice and autonomy throughout the PBL process can help students develop a sense of ownership and control over their learning (Kokotsaki et al., 2016). PBL should enable learners to decide on the knowledge and skills required to resolve a problem rather than work to a pre-determined set of questions. For example, given the problem of how to improve the healthy eating nature of a school's meal service, the students should work through a series of processes. They must collaboratively consider the problem posed, clarify all unfamiliar concepts, and then define the problem and formulate learning objectives. They must decide what facts they need to consider, incorporating their prior knowledge and hypothesise the solutions. Having identified their knowledge gaps, they can exercise self-directed learning to seek information from a range of different sources inside and outside the school. They share their findings with their group and if necessary, repeat the previous steps until their solution is finalised. They then share the solution with their teacher and other groups (Jerzembek and Murphy, 2013; Wilder, 2015). In doing so they are applying skills of communication, mathematics and negotiation (Jerzembek and Murphy, 2013). They should also have an opportunity to discuss how the content they have learnt may be useful in new situations and reflect on the processes they have used in solving the problem (Merritt et al., 2017).

When undertaking independent practical work, either in the form of the EPQ or an independent science research project, students enjoyed taking responsibility for their learning and took more pride in their work since they were studying something personally meaningful for them (Bennett et al., 2018; Stephenson and Isaacs, 2019). As they drafted and redrafted their product and reflected on their performance, they were demonstrating attributes associated with a growth mindset (Stephenson and Isaacs, 2019).

4.5 Teachers' roles in practical learning

As noted in **Figure 1**, one of the 10 decisions that teachers make when involved in vocational pedagogy is the extent to which they adopt a didactive or facilitative role. High-quality practical learning requires skills across this continuum. We have suggested that explicit instruction is a valuable approach under certain circumstances (Hodgen et al., 2020) and although overload on students' working memory in practical learning approaches has been of concern (Kirshner et al., 2006), the growth in understanding about cognitive load in collaborative learning situations might mitigate some of these concerns and offer guidelines for teachers to help them design more effective collaborative learning experiences (Kirschner et al., 2018), which could be used in conjunction with our findings below.

So, far from being a 'one-size fits all' requirement for teachers to adopt a specific approach, practical learning approaches require teachers to be skilled at employing a repertoire of different teaching strategies at each stage of the project or inquiry process. Although the precise nature of these strategies depends on the teacher's purpose in using practical work, for example whether they are using it for conceptual or procedural learning (Abrahams and Millar, 2008). Unfortunately, some research found that teachers were not able to make these distinctions clearly (Abrahams and Millar, 2008; McGeown, 2019). Overall, students need to be effectively guided and supported, and this requires teachers to balance didactic instruction with independent inquiry to ensure that students develop a certain level of knowledge and skills before being comfortably engaged in independent work (Kokotsaki et al., 2016).

Teachers should present open-ended questions at the beginning of the process and demonstrate considerable confidence in their ability to manage open-ended class discussion. During the implementation stage they should guide students by situating new learning in the context of old, persuade learners to engage in the inquiry, keep them on task and provide support. They need to have a clear understanding of the stages of the problem-solving or inquiry process and ensure that students experience each stage, including reflection on their experience and findings at the end (Akuma and Callaghan, 2019; Hasni et al., 2016). There is clearly a detailed and active role for teachers in successful practical learning but unfortunately although some teachers may claim to believe they are guiding student practical learning, they are doing little more than observing the activity (Han et al., 2015).

Successful guidance depends on teachers understanding children's developmental differences in scientific reasoning (formulating hypotheses, designing experiments and evaluating the evidence). When this is taken into account, it was found that more specific types of guidance for younger learners might be more beneficial and that in this case, findings might be counter-intuitive, since younger learners can cope with more general and less specific forms of guidance, while older learners do benefit from specific scaffolding and explanations. However, the number of studies from which data could be synthesised for this study was small (Lazonder and Harmsen 2016).

An earlier study also found that hands-on science practical inquiries on their own are not sufficient to secure academic learning, learners need time after the inquiry to process their observations (Minner, et al., 2010, p.20).

It is not surprising that some teachers hold negative views about the value of practical learning, finding it time-consuming to run and difficult to manage the time needed by students to explore avenues within the constraints of the curriculum (Akuma and Callaghan, 2019; Bennett et al., 2018; Hasni et al., 2016). Unfortunately, these negative views held by teachers, which, in the case of IBL, may be borne out of lack of confidence in their scientific knowledge or in their ability to ask open-ended questions, are likely to affect all stages of the inquiry process (Akuma and Callaghan, 2019).

The need to relinquish control over some aspects of classroom management is challenging for many teachers. However, teachers involved in supporting EPQ students reported that once released from the accountability of an exam performance, they found the EPQ was an opportunity to relinquish control for studying to the student (Stephenson and Isaacs, 2019).

4.6 Assessment

In high-quality practical learning, assessment should include opportunities for reflection and self and peer evaluation, as evidence of progress needs to be regularly monitored and recorded (Kokotsaki et al., 2016). However, teachers may struggle during the process of formative assessment to pose suitable questions and make constructive comments (Akuma and Callaghan, 2019).

Furthermore, the exam-driven form of summative assessment prevailing in education systems discourages teachers from seeking ways to assess the outcomes of practical learning beyond content knowledge (Luckin et al., 2017; Wilder, 2015). So character and capability outcomes that underpin successful cognitive learning, such as curiosity, creativity and collaboration, communication, decision-making, critical thinking, and problem-solving, are assumed to be developed but regarded as too difficult to assess, or not worth assessing (Craig and Marshall, 2019).

However, there is plenty of evidence to suggest how these dispositions and skills might be assessed. Numerous ideas for teachers and students to track and record progress in developing creativity using real-world and online options are available (Lucas and Spencer, 2017). The observable behaviours that students demonstrate when collaborating with others, including explaining their thinking to others, adjusting their ideas in response to their understanding of others' viewpoints, and responding to challenges by offering counter evidence, could be used to develop criteria for assessing collaborative learning (Luckin et al., 2017). High-quality collaborative practical learning also involves equal contributions from students and synchronous physical movements when they are interacting with each other (Cukurova et al., 2017).

Moreover, a disconnect between how research studies have used assessment to gauge the impact of practical learning and how national assessments are used is cited as one of the reasons underpinning the lack of consensus on the impact of practical learning approaches (Wilder, 2015). Studies that use practical skills tests, such as clinical skills tests with medical students, are more likely to show positive results for PrBL than studies using multiple-choice tests of knowledge. Standardised tests used pre and post the intervention are less likely to capture the full extent of learning gains (Wilder, 2015), particularly learning gains in creativity and critical thinking that have been achieved because students have engaged with real-world content through a project (Craig and Marshall, 2019).

Changes to traditional methods of assessment in secondary schools are required if the wider outcomes of PrBL are to be fully recognised, according to Wilder (2015), who notes that:

'Unfortunately, due to a potential disconnect between the intentions behind PBL and the assessments used to measure its outcomes, the argument for wider implementation of PBL across various disciplines in secondary grades may appear feeble at this time.' p.432.

Current assessment demands are also damaging and restricting practical science, according to a review of its status in schools (SCORE, 2008) and students become less interested in undertaking projects and practical work as they approach the time for taking external examinations (Husain, 2019; Sharpe and Abrahams, 2020).

4.7 In summary

As we suggested in our summaries of previous sections, practical learning is often misunderstood and undervalued, possibly because it is more complex than generally thought. This position has led to research that often presents the choice between academic and practical learning as a binary decision, whereas from our analysis in this section we have suggested that there are a wide range of features that contribute to high-quality practical learning. The main learning points that might guide future implementation are listed below. They are not ranked in order of importance, which might help teachers apply the most important points first, as suggested by Hasni et al. (2016), but they are a starting point for further consideration.

School culture, leadership and the curriculum:

- Implementing practical learning requires a receptive school culture.
- Practical learning should be aligned with other curriculum demands, such as GCSEs.
- Flexible spaces and flexible seating are required for high-quality practical activity.
- If practical learning is taking place outside time-tabled sessions it is helpful to consider how it could be aligned with the concurrent curriculum delivery.
- Teacher networking and professional development opportunities are desirable.
- Support for cross-disciplinary working within the school is desirable.

Learning task:

- The context needs to be carefully clarified to show why it is relevant to addressing the task and how it connects with the students' perspective.
- The aim of the task needs to be matched with the degree of structure imposed on the problem or question.
- Careful estimation of the amount of time required is important with time built in for reflection and improvement on the first response.
- The roles of external participants/organisations/employers should be clearly articulated and carefully agreed.

Students need to:

- have a degree of agency in planning their learning
- exercise self-management and time-management skills
- be involved in decision-making about the task
- be able to communicate and share their ideas
- exercise a systematic approach to problem-solving
- know how to seek information from a range of different sources
- collaborate with others
- be given opportunities to take pride in their work.

Teachers need to:

- balance didactic instruction with independent inquiry to ensure that students develop a certain level of knowledge and skills before being comfortably engaged in independent or collaborative work
- prompt and manage open-ended class discussion
- situate new learning in the context of previous learning
- ensure students progress through and experience all stages of the inquiry or problem-solving process
- base guidance for students based on the teacher's knowledge of students' developmental understanding of concepts, for example in science
- place students in groups, as appropriate for the task
- expose the links between the practical activity and the conceptual theory, including links between disciplines
- allow time for students to process their thinking following the activity.

Assessment:

- Student self- and peer evaluation of progress needs to be regularly monitored and recorded.
- Assessment instruments should track progression in terms of content (knowledge acquisition) and habits of mind (character and dispositions for learning).

Many of these points are covered in the well-evidenced guides to PBL, published by the Paul Hamlyn Foundation (2012) or the Edge Foundation's Project-based Learning Toolkit (Edge Future Learning, n.d.). For teachers of STEM subjects, David Barlex and Frank Banks (Banks and Barlex, 2021) offer detailed guidance on using PBL in STEM subjects. These authors discuss the challenge of managing open-ended projects with large classes and introduce techniques such as systematic inventive thinking to open up problem-solving systematically, rather than having students waste time on coming up with random ideas unrelated to the subject in hand. They stress the importance of teaching knowledge when needed, address issues of student ownership, and how to recognise and reward the thinking process involved as well as the product. Finally, they explore how to create learning environments in which students can work independently and learn from each other.

5. Practical learning in secondary schools: promising practices

There are beacons of hope even within this highly restrictive system – enlightened head teachers, principals and governors whose schools and colleges are striving to create well rounded individuals with the skills that employers are really looking for.

Kenneth Baker in Edge Foundation (2018) *Towards a Twenty-First Century Education System: Edge Future Learning*. London: Edge Foundation (p.3)

Our exploration of practical learning in the previous two sections was based on a review of the academic literature published since 2000 that addressed three examples of practical learning. In this section we engage with practice and identify specific cases of practical learning in action in secondary schools in England.

5.1 Search process

Schools with promising practices were identified through our grey literature and grey information searches. Case studies of practices in named schools are typically produced by well-regarded organisations that seek to support innovation in practical learning in collaboration with those schools that have been implementing the practice. It was through such organisations that the majority of our schools were found.

There are clearly many more routes we could have used to gather examples, including primary research methods, but the scope of the present study precluded those for now.

In addition to being cited in a published source, two further criteria for inclusion in our list were preferably that schools had implemented practical learning mainly within the curriculum rather than as an extra-curricular activity, *and* that they met a minimum threshold of 'Good' in their most recent Ofsted report. The former was identified through the case study reports and the latter through checking the status of the school's latest Ofsted report on the school website. All the information about the schools was therefore readily available in the public domain at the time of publication of this report.

In addition to published sources, we drew upon the knowledge of members of our Advisory Panel who were invited to identify schools with which they collaborated. We also included schools already known to the research team through their engagement with our research and consultancy activities.

A total of 37 secondary schools were identified as examples of promising practitioners of practical learning. The schools and sources in which the cases were reported are listed in **Table 3** (schools found in several sources are only recorded once) and in Appendix 4. An analysis of the key themes emerging from the case studies, is discussed with reference to the features of high-quality practical teaching and learning identified in Section 4. A map showing the location of the schools is provided in **Figure 4**.

5.2 School culture and leadership

'We believe that school should be a true balance of head (academics) heart (character and well-being) and hand (generating ideas, problem solving and making)... 'real-world learning with hands-on projects where students have the chance to create beautiful work and exhibit it to the public' (School 21)

Most schools (21) have academy status, while eight are managed by local authorities, five are UTCs, two are voluntary aided and one is an independent school. The theme of partnership and engagement outside the school is a defining feature of the school culture. At the macro level, many schools exhibited a strong commitment to practical learning through their engagement with one or more of the leading

Table 3:
Schools showing promising practice in practical learning and their source

Organisation and website	Relevant activity	Source	Schools
Association for Science Education (ASE) www.ase.org.uk	Following the publication of the Gatsby Foundation Benchmarks for good practical science, the ASE developed resources in support of the implementation of the benchmarks. One activity involved working with schools in developing a written policy for science practicals, in line with Gatsby Benchmark 1.	Needham, R. (2019) *Good practical science – making it happen. Writing a policy: Case studies.* Hatfield: ASE.	Elthorne Park High School www.ephs.ealing.sch.uk Helston Community College www.helston.cornwall.sch.uk/web Scalby School www.scalbyschool.org.uk/our-school Sir James Smith's Community School www.sirjamessmiths.cornwall.sch.uk/index.asp Saint George Catholic College www.stgcc.co.uk
Comino Foundation https://cominofoundation.org.uk	The Comino Foundation works with teachers and young people to support innovative practice, champion work in schools, and help to bring the real world of science, careers and curriculum innovation into the classroom. Comino works in collaboration with the Ideas Foundation in Greater Manchester to foster closer connections between schools and the creative industries sector in this region.	1. North West Comino Creative Consortium (NWCCC) *Yearbook 2019*.	Abraham Moss Community School www.abrahammoss.manchester.sch.uk/app/os#!/home Falinge Park High School www.falingepark.com Fred Longworth High School https://flhs.org.uk/wordpress/ The Derby High School http://thederbyhighschool.co.uk
		2. Comino Foundation (2020) *Cultural digital designers in residence in schools 2020*. Manchester: Comino Foundation.	Ladybridge High School www.ladybridgehigh.co.uk/about
Edge Foundation www.edge.co.uk	The Edge Foundation encourages schools to engage in real-world learning by fostering links between the school and the local community. Edge offers guidance, models and resources to schools on project-based learning and engaging with local communities.	1. Edge Foundation (2018) *Towards a twenty-first century education system: Edge future learning.* London: Edge Foundation.	TAG The Academy Grimsby https://academy.grimsby.ac.uk/who-are-we UTC Reading www.utcreading.co.uk Westminster Academy www.westminsteracademy.org.uk XP School https://xpschool.org/ and https://xpschool.org/our-expeditions

Organisation and website	Relevant activity	Source	Schools
		2. Edge Foundation (2019b) *School 21 and XP: real world learning*. London: Edge Foundation.	School 21 www.school21.org.uk/rwlp and www.school21.org.uk/design-principles
		3. McCrone, T. et al. (2019) *Evaluation of University Technical Colleges*. Slough: NFER (on behalf of Edge Foundation).	Liverpool Life Sciences UTC https://lifesciencesutc.co.uk
Gatsby Charitable Foundation www.gatsby.org.uk and **University of York Science Education Group** www.york.ac.uk/education/research/uyseg	The Gatsby Charitable Foundation provided a grant for research to be undertaken by the University of York Science Education Group to investigate why and how teachers use open-ended investigative work with students in post-16 science. The purpose was to identify the enablers and barriers to these investigations faced by teachers in schools in England.	Dunlop, L., Knox, K., Turkenburg--van Diepen, M. & Bennett, J. (2019) *Open-ended and extended investigative projects in science. Report to The Gatsby Charitable Foundation*. London: The Gatsby Charitable Foundation.	Dame Alice Owen's School https://damealiceowens.herts.sch.uk/ Greenhead College www.greenhead.ac.uk The Judd School www.judd.online Tonbridge Grammar School www.tgs.kent.sch.uk Westminster City School www.wcsch.com
Innovation Unit and REAL Projects www.innovationunit.org	Innovation Unit has encouraged schools to use PBL to foster engagement with the outside community, develop skills, and enhance student motivation through observing professionals in action. REAL Projects are modelled on PBL used in expeditionary learning derived from USA.	Paul Hamlyn Foundation and Innovation Unit (2012) *Work that matters: the teacher's guide to project-based learning*. London: Paul Hamlyn Foundation. And other sources including school websites and REAL Projects Case Studies. Available: https://drive.google.com/file/d/0B00-zpItGS5eM2I6dGtYb1kxdm8/view	Copleston High School www.copleston.suffolk.sch.uk Cramlington Learning Village www.cramlingtonlv.co.uk Kingsmeadow Community School www.kingsmeadow.org.uk and www.kingsmeadow.org.uk/real-project-based-learning Knutsford Academy www.knutsfordacademy.org.uk Matthew Moss High School www.mmhs.co.uk Wapping High School https://wappinghigh.org

Organisation and website	Relevant activity	Source	Schools
James Dyson Foundation www.jamesdysonfoundation.com	Between 2012 and 2018 the James Dyson Foundation ran a research project with schools in Bath. The aim was 'to inspire young people to become designers and engineers by bringing real-life design engineering into the classroom, through problem-focused, open-ended projects supported by access to high-tech equipment' (p.16).	James Dyson Foundation (2019) *Addressing the skills shortage: a new approach to engineering in schools*. Dyson Ltd.	Chew Valley School www.chewvalleyschool.co.uk Hayesfield Girls' School www.hayesfield.com Ralph Allen School www.ralphallenschool.com Wellsway School www.wellswayschool.com
Project research team and Expert Advisory Panel	The Royal Academy of Engineering supports the research into EHoM and signature pedagogies undertaken by the Centre for Real-World Learning at the University of Winchester.	1. Lucas, B. et al. (2017) *Learning to be an engineer: implications for the education system*. London: Royal Academy of Engineering.	Bohunt School www.bohunt.hants.sch.uk The JCB Academy (UTC) http://jcbacademy.com
		2. Lucas, B. and Hanson, J. (2018) *Learning to be an engineer: implications for school leadership*. London: Royal Academy of Engineering	UTC Sheffield City Centre http://city.utcsheffield.org.uk
		3. Lucas, B. and Spencer, E. (2020) *Zest for Learning: Developing curious learners who relish real-world challenges*. Carmarthen: Crown House Publishing	Bedales www.bedales.org.uk/bedales and www.bedales.org.uk/our-school/academic-success/bedales-assessed-courses-bac Shireland Collegiate Academy www.collegiateacademy.org.uk
		4. Other recommendation	UTC Portsmouth http://www.utcportsmouth.org

foundations or subject associations whose reports we analysed. At the whole-school level, two schools adopted the US model of expeditionary learning to guide their PBL activity (Edge Foundation, 2019b). In other schools, strong departmental leadership was exhibited, as when science subject leaders led in the development of a practical science policy (ASE, 2019) or art and technology inspired cross-curricular learning happened (Comino Foundation, 2020). Frequently the school's involvement included committing a significant budget to the activity; schools working with the James Dyson Foundation contributed £25,000 to upgrading their equipment and teaching spaces (James Dyson Foundation, 2019).

Cultivating the school's place in the local community through practical learning was of major importance to many schools. As we shall see below, this was represented through partnerships with employers, with cultural bodies such as museums and art galleries and with educational bodies such as local colleges and universities, as well as local primary schools.

Strong links with employers are to be expected in UTCs, which were established to provide technical education to meet the needs of their local economies. The NFER's second report into UTCs highlights the different approaches to PBL with employers adopted by three of them: UTC Reading has an extensive and well-structured programme of engagement with employers embedded within the curriculum, including co-teaching of units and PBL; Aston University Engineering Academy uses PBL in dedicated weekly time for the student professional development element in the curriculum; and Liverpool Life Sciences UTC uses PBL not to deliver the curriculum but to cover the science that local employers need that does not align neatly with a qualification (McCrone et al., 2019).

School 21 collaborates with local employers to run an extensive programme of real-world learning placements for students. The school finds that the employers are eager to work with the school when they see the positive outcomes for students and themselves of these placements (Edge Foundation, 2019b). An important feature of School 21's approach to practical learning is its development of communication skills, including oracy, in primary pupils to prepare them for participation in real-world learning at secondary level (Edge Foundation, 2019b), a process made easier because the school takes pupils from 4 to 18.

School links with local cultural bodies such as museums and arts organisations provide another

important practical route for pupils to develop skills, to learn about the heritage of their local area and to reflect on their own place within that heritage. Year 7 students at Wapping High School went into the community to find local historical heroes and captured their stories through interviews, then analysed primary and secondary sources to verify their accounts (Paul Hamlyn Foundation, 2012). Students from Abraham Moss Community School worked with a local photographer and Manchester Art Gallery to explore the theme of human rights and links to slavery. Students from Fred Longworth High School worked with a local 3D digital designer and the Museum of Science and Industry in Manchester to create an interactive 3D game to be located in the museum (North West Comino Creative Consortium (NWCCC), 2019).

Other schools engage with educational bodies such as local colleges and universities. The Academy Grimsby (TAG) collaborates with a local college to offer greater choice to students, particularly in studying technical and professional subjects such as engineering and health and social care (Edge Foundation, 2018). Teachers at The Judd School and Westminster City School who were devising open-ended investigative science projects for their sixth-form students found universities willing to work with them to provide expert input when needed (Dunlop et al., 2019).

Another common feature supporting the quality of the practical learning noted in many schools was extensive professional development for teachers and support staff. More time than average was given to CPD to enable teachers to adjust the curriculum to include PBL and to gain a deeper understanding of the skills it was intended to develop in pupils (Edge Foundation, 2018; 2019b). Many schools provided ongoing support for teachers as they implemented new practice; Saint George Catholic College made practical science the focus of teaching observations and learning walks and Elthorne Park High School linked observations of practical science lessons to setting appraisal targets (Needham, 2019).

5.3 Practical learning embedded within the curriculum

> **'The Academy offers an integrated, competency assessed (without levels structure), thematic curriculum at KS3 and a weekly extended period of time (focus days) to students in KS4 and KS5. This has provided increased enriched activities to students as well as a platform for excellent controlled assessment delivery'**
> (Shireland Collegiate Academy)

One of the most useful factors for teachers reading these case studies in the reports will undoubtedly be the way in which practical learning has been embedded into the mainstream curriculum. Apart from the UTCs, where practical learning is embedded in all years, much of the practical activity in academies and maintained schools takes place in Years 7 and 8, the lower secondary stage of Key Stage 3, where there is less risk to disruption of students' preparation for public examination. An exception to this is the practical learning activity reported by Dunlop et al. (2019), which takes place during the sixth form.

Furthermore, many schools adopting PBL made significant changes to the normal timetabling pattern of 50-minute lessons to enable projects to take place over an extended period of the term; students at XP School take two expeditions a year, each lasting half a term (Edge Foundation, 2018), and students at Knutsford Academy spent eight weeks on a project (Paul Hamlyn Foundation, 2012).

Schools also used PBL to foster cross-curricular learning, demonstrating that the challenge of enabling teachers to work across disciplinary and departmental boundaries in secondary schools can be overcome. In Falinge Park High School, subject leaders in personal, social, health and economic education, citizenship and computer science collaborated with the careers leader on a project to teach students about digital resilience and curatorship (NWCCC, 2019). At Ralph Allen School, Year 7 students have, in addition to the individual subject lessons, a STEM lesson once a week in which they work on a number of projects, including the Dyson Challenge, that draw on their subject knowledge from the individual subjects (James Dyson Foundation, 2019). Helston Community College ensures that its practical science activities are explicitly linked to other subjects, particularly maths (Needham, 2019). Shireland Collegiate Academy has gone further than most schools in integrating all subjects at Key Stage 3 into a series of themed topics, each lasting about six weeks, which together cover all areas of the National Curriculum and involve the students in a wide range of practical activities (Lucas and Spencer, 2020).

It is clear therefore that schools are using practical learning to develop students' capabilities, attitudes and academic learning linked to the curriculum. Many schools ensure that the learning outcomes from PBL are rigorously mapped on to the National Curriculum and GCSE programmes of study. Sir James Smith's Community School took the opportunity afforded by developing their practical science policy to identify how practical activities in KS3 could lay the foundation for activities in later years and GCSE (Needham, 2019). XP School maps its expeditions carefully to the National Curriculum and GCSE syllabus so that 'while students experience the curriculum holistically, teachers are absolutely clear exactly which elements of individual subjects are being taught at any time' (Edge Foundation, 2018, p.23). The school stresses the robustness of its offering on its website:

'The curriculum at XP is standards-based and teacher-led. We use the National Curriculum at Key Stage 3 and 4 to guide us as to which standards we cover deeply. Our approach is to teach this knowledge and skills-based content through cross-subject learning expeditions. Each expedition is rigorously mapped against the National Curriculum standards to ensure coverage and depth' (XP School)

Many schools appear to be using practical learning because, as noted by School 21, it can promote holistic learning, moving pupils 'beyond the knowledge needed to pass exams' (Edge, 2019b, p.6). This school focuses particularly on developing pupils' oracy skills through discussion and debate while other schools develop independent learning skills through projects, either technical projects (UTC Reading) or through an individual extended essay for the IBCP as at Westminster Academy (Edge Foundation, 2018). Pupils learning D&T through projects in collaboration with James Dyson were encouraged to exercise autonomy similar to that of professional engineers in the design process (James Dyson Foundation, 2019).

The Derby High School uses experiential learning not only to ensure its pupils gain experience of the world around them but also to:

'create learning experiences for all our students which allow them to develop incredibly important transferable life and work skills' (Assistant Principal, NWCCC, 2019, p.49)

Practical learning developed students' communication and teamwork skills at UTC Reading (Edge 2018) and their leadership skills at Wapping High School (Paul Hamlyn Foundation, 2012).

The exercise of developing a practical science policy prompted schools to think specifically about how they were developing both skills and knowledge within practical lessons. Elthorne Park High School developed an example of a lesson plan statement that epitomized the 'split-screen' approach to teaching knowledge and skills as exemplified by Guy Claxton (Lucas et al., 2014). The example showed how developing practical competencies in using an ammeter and voltmeter would be done through the whole class practical, while developing knowledge and understanding of scientific concepts (the motor effect and Fleming's Left-Hand rule) would be done through a teacher demonstration (Needham, 2019, p.9)

The promotion of students' curiosity and their ability to ask questions that challenged both themselves and others was a key outcome of many of the Comino projects, particularly in Abraham Moss Community School's project on the theme of human rights, or that of Ladybridge High School investigating the impact on slavery on the local community (NWCCC, 2020). The creativity demonstrated by students is also evident in many of the case studies from several sources.

5.4 An authentic learning task

'The project has undoubtedly benefited our students, especially in terms of aspiration and engagement with real industries outside of the school bubble. For me, the most powerful thing has been watching students' game plans literally come to life as Tom arrived with their designed pieces in the flesh – an incredibly powerful thing' (Teacher, NWCCC, 2019, p.43)

All the features of high-quality practical learning tasks are evident in the cases examined here. Projects start with an essential question or problem that leads students to explore real-world issues such as the veracity of online communication (Falinge Park High School), human rights (Ladybridge High School; Abraham Moss Community School), science in the media (Helston Community College), or the impact of economic change on the local community such as closure of the coal mining pits (XP School). The contextualisation of the task to the students' experience and environment is clear as students explore topics relevant to their own backgrounds or issues that directly affect them, such as their own digital safety (NWCCC, 2019).

Experts from the community work alongside students as they undertake investigations in the community, collecting evidence through interviews and photographs that they verify in secondary sources. Multiple iterations of work are encouraged and students critique each other's work at Knutsford Academy (Paul Hamlyn Foundation, 2012). Visiting design engineers pose design challenges for students at Hayesfield Girls' School, who learn to solve problems through an iterative approach to investigating, evaluating and developing (Hayesfield Girls' School). Drafting prior to producing final pieces of work also plays an important part in the project process at Bedales (Lucas and Spencer, 2020).

Most of the projects finish with a presentation, a display or a product, which is often curated to be made available to future students and the public. Wapping High School students created a book of local historical heroes that went on sale through the local bookshop (Paul Hamlyn Foundation, 2012). Fred Longworth High School students created an interactive 3D game later held in a museum (NWCCC, 2019). Copleston High School students staged a Remembrance Day service at their local church (Paul Hamlyn Foundation 2012).

With many of the cases here, further information on aspects such as how the time needed for the task was decided, what structure was provided, or who initiated the guiding question or problem would have aided our understanding of the implementation of the practical activity. This more detailed approach was adopted by the research team at the University of York when investigating teachers' perceptions of open-ended science projects, and the level of information provided for each case study makes them more relatable to teachers (Dunlop et al., 2019).

5.5 Fostering student agency

'We have freedom of speech and we can have our own ideas, for example I started a medical society. I am in charge of it. It is independent and I have responsibility for it' (Student, Edge Foundation, 2019b, p.14.)

The imperative for schools of the future to develop learner agency so that students possess the skills and mindset to take responsibility for their own learning and exercise effective citizenship has been noted (World Economic Forum, 2020). The practical learning tasks in the cases we have examined in this section demonstrate how this agency might be achieved. Schools pay particular attention to developing the skills pupils will need to exercise agency, such as oracy, as at School 21, while UTC Reading encourages a growth mindset as students take risks during projects and learn from their mistakes (Edge Foundation, 2018; 2019b). Knutsford Academy and Cramlington Learning Village encourage respect for other people's ideas as students critique each other's work (Paul Hamlyn Foundation, 2012).

Students engage constructively but critically with their local communities and experience personal growth through the projects as they reflect on the impact on themselves of the issues they were researching. Students at Abraham Moss Community School reflected on their own human rights and the extent to which they themselves had encountered racism and sexism but realised that the project was giving them a framework to highlight the importance and power of their own voice (Comino Foundation, 2020).

By experiencing what it is like to work for local employers or to meet professional experts, students develop their confidence and, having observed professional standards in a realistic environment, can aspire to raise the quality of their own work (Edge Foundation, 2019b; Paul Hamlyn Foundation, 2012), as one student recognised:

'We [the students] have got organisational and presentation skills – social skills come naturally as we are continually using them here. This school does quite a good job at [developing our] public speaking' (Young person, Edge Foundation, 2019b, p.15)

5.6 Teachers' roles in practical learning

'... projects act as a conduit to a wider world of real-world learning from a frequently insular life within traditional education. The classroom walls dissolve and the teacher is repositioned as facilitator in a more complex dialogue between arts professionals, cultural institutions and student'
(Director, NWCCC, 2019, p.29)

The varied roles of the teacher in supporting practical work were visible in these cases, from initiating and managing the overall activity to supervising student work while it was ongoing.

Several schools have a member of staff dedicated to liaising with the local community and identifying project opportunities, for example at XP School (Edge Foundation, 2019b). The significant effort involved in ensuring that employer engagement in practical work works smoothly, and to the benefit of both school and employer, is also clearly evident in accounts of UTC operations, where recruiting staff with the right background for both liaising with industry and engaging students in PBL is key to success (McCrone et al., 2019).

Health and safety is an issue to be taken into account, especially with open-ended science projects, where teachers value the support of technicians (Dunlop et al., 2019). However, it is often necessary for teachers themselves to invest time and effort in planning the field trips and undertaking risk assessments before the projects begin in the community (NWCCC, 2019).

In their role as facilitators, teachers have a crucial role in inspiring students to participate in practical work that is a challenging mode of learning and may not always appear relevant to students, but some teachers realise they have a responsibility to open a gateway to opportunity through practical work:

'... not all of our schoolchildren are going to be scientists, but for that percentage that are I think it's important that we give them an opportunity to develop their handling skills, to develop their skills, but also to understand what they're doing, and why.' (Teacher, Dunlop et al., 2019)

In doing so, both teachers and students come to realise that teachers are not the sole providers of information (Paul Hamlyn Foundation, 2012).

The subtle balancing act for teachers between allowing students to follow their own interests and ensuring that they have enough underpinning theory and practical skill is very evident in all the case studies on open-ended investigative projects (Dunlop et al., 2019). At Scalby School, students are coached in the use of equipment before the science practical work begins (ASE, 2019).

Teachers collaborate with each other to plan activities and support each other, including, at Saint George Catholic College, identifying that newly qualified teachers have different support needs to prepare for more effective science practicals than the more experienced teachers who were developing the policy (Needham, 2019).

5.7 Assessment

'All too often, a large number of excessively prescriptive GCSE syllabuses squeezed out opportunity for appropriate, imaginative and challenging work with particular groups and individuals, and they placed too much emphasis on terminal written exams. Coursework, potentially such a rich tool for developing independent learning skills, was tied to laborious mark schemes' (Bedales)

This quote from the Bedales website illustrates the frustration that many schools experience with the current educational assessment regime and its lack of opportunities to assess practical work. However, while an independent school has the resources to challenge the system, many schools in our selection provided little information about the methods used to assess practical learning.

While the case studies included in this section demonstrate use of practical work aimed at developing academic learning, dispositions and capabilities, there was often little or no information provided about the methods used to assess learning and progression in these cases. Providing further information on this aspect of practical learning would be invaluable for teachers looking for justification to introduce it within the curriculum, particularly when it is not a requirement of the assessment regime.

However, assessment information was a feature of the case studies reported by the University of York research team, in which teachers described how they found ways of making open-ended investigative project work 'count' in post-16 science teaching despite not being included within examination specifications, since as the authors note:

'assessment is an important driver for classroom practice, and a way to ensure that this happens is to change policy to require open-ended investigative work in post-16 examination specifications' (Dunlop et al., 2019, p.6)

So whereas a school such as Tonbridge Grammar School, which offers the International Baccalaureate Diploma Programme, can enable almost all sixth-form students to complete an independent science investigation, other schools such as Westminster City School incorporate CREST awards into timetabled sessions or use open-ended project work to count towards the practical endorsement for A level (Dunlop et al., 2019).

5.8 In summary

Overall, this section has demonstrated that there are several secondary schools acting as beacons of good practice undertaking practical learning and that much can be gained from reading reports of their activities. Several of the reports studied for this section include guidance on delivering various aspects of practical learning. The Innovation Unit (Paul Hamlyn Foundation, 2012) and Edge Foundation (2018) offer extensive guidance on all the stages of PBL. McCrone et al. (2019) offer helpful advice in securing effective employer engagement for practical learning, which is aimed at UTCs but applicable to most schools. However, as the balance of evidence in the different sections shows, there are still some gaps in our knowledge that would be worth investigating further.

It would be helpful to have more detail about the pedagogy underpinning the successful projects. For example, while there is helpful guidance on establishing successful partnerships with local industry, several other aspects would all benefit from further illumination. These include strategies for aligning the practical work with theory, for embedding students' underpinning knowledge and guiding its recall and utilisation at appropriate moments; the coaching of students in the skills they will need before the project starts; the formative feedback that keeps them on track when their interests might lead them down a blind alley; and the summative assessment that demonstrates the value of the outcomes, both to the examining bodies and the young people themselves.

It is important to understand what works in specific circumstances since many schools in which the most innovative practices are taking place are small, between 350 and 500 pupils, so it is vitally important to gain further knowledge of how such innovation might be scaled up.

It is also challenging to sustain innovative practical learning in the current educational environment. We found two examples of schools reported as cases studies demonstrating innovative examples of practical learning, that had closed since the publication of the report in which they were featured. Both had received an inadequate grade from Ofsted, which had been followed by a re-brokering and inclusion with a multi-academy trust. They have subsequently re-opened under new names but have not been included in our selection.

Another critical aspect going forward is gaining a clearer perspective on how the requirements in schools to adjust to measures required after the COVID-19 pandemic may impact on practical and creative learning. The government consultation on proposed changes to the assessment of GCSE, AS and A levels for 2021 revealed a number of teachers' concerns, particularly about having enough time to cover content and issues of inequality of learning experiences that might result from changes to practical work (Ofqual, 2020a).

The guidelines published after the consultation include some options for schools on reducing content coverage. They also include many instances of where the requirement for practical work has been replaced by teacher demonstration, for example in science and D&T, and where group assessments, for example in music and dance, have been reduced (Ofqual, 2020b). The Design and Technology Association notes that such changes as apply to D&T are understandable given the circumstances, but it is important to recognise that they do not afford the same quality of learning as actually using tools and machinery and should not be seen as an alternative in the longer term (Ryan, 2020).

Although the use of online learning during the COVID-19 lockdown has highlighted concerns about inequalities in students' access to technology (Ofqual, 2020a), it would be interesting to discover to what extent schools are able to continue in their efforts to provide a blend of online and face-to-face learning to take advantage of digital technologies. Using technology effectively in education is challenging at the best of times (EEF, 2019) but there might be opportunities to review how it can be used to support practical learning.

6. Reframing practical learning to engage tomorrow's engineers at school

> **In the spirit of learning the whole game, we can call this broad view learning by wholes …**
>
> Perkins, D. (2009) *Making Learning Whole: How seven principles of teaching can transform education*. San Fransisco: CA: Jossey-Bass (p.8)

In this section we revisit our TOC in the light of this research and map the evidence we have found for practical learning against our hypotheses. We offer a revised definition of practical learning that is about the whole game of learning rather being seen as an alternative to 'academic' learning or as any one of the three specific methods we review.

We then return to our model of EHoM and suggest ways in which practical learning as conceived in all its complexity might encourage the development of would-be engineers in secondary schools.

6.1 Mapping evidence against theory

Our TOC posited the following series of steps in a hypothesis about the benefits of practical learning:

6.1.1 Emerging evidence

Here we explore, line by line, what we have learned against each of our conjectures, (a) to (d). Then, in 6.1.2 we review any evidence we have found that casts light on how these might turn out in practice, (e) to (g).

For each of the first four steps we suggest the current degree to which the evidence we have found supports our hypothesis through a red/amber/green summary and a one-word description:

Red – Not at all supported

Amber – Partly supported

Green – Considerably supported/considerably supported but in need of further research/considerably supported but in need of further exemplification/wholly supported.

a. *If we better understand the ubiquity and complexity of practical learning….*

Considerably supported

A careful examination of the National Curriculum in England reveals that practical learning is ubiquitous. It can be found in almost every subject, and potentially in every classroom, not just in laboratories, workshops or in the field, see **Table 4**.

Words, too, act as clues to practical components, some more obvious than others: painting, drawing, artefact, presentation, problem, poem, draft, fieldwork, conversation, model, improvisation, composition, game, performance, practice, and, from science a word that is often seen as a bellwether for the presence or absence of practical learning, the 'practical'.

But evidence suggests that that practical learning is a complex construct to understand. In part, this is the legacy of the Cartesian duality and the separation of mind and body learning that has encouraged a hierarchy of subjects, depending on the degree to which they embrace mathematics. Even when practical learning is acknowledged in disciplines, it is often found under different terms. This breadth, together with the lack of a common terminology with which to discuss and synthesise research about it, adds to the difficulty of fully understanding it.

We selected three examples to research, but even with these there is uncertainty about terminology and how one form, for example PBL, is different or similar to PrBL and IBL (Luckin et al., 2017). There are numerous other terms we could have selected, each with their own research base, for example expeditionary learning, flipped learning, active learning. However, our research has enabled some of our following hypotheses to be addressed.

Figure 3 (repeated):
Our TOC as seven steps

a. If we better understand the ubiquity and complexity of practical learning
And
b. If we can suggest a range of benefits that it can confer on learners in schools and in life
And
c. If we can show that, when done effectively, practical learning can enable students to achieve as well in standardised tests as with more traditional methods
And
d. If we can better distil the essence of excellent practical learning and identify promising secondary schools doing it well
Then
e. School leaders, teachers and policymakers will see the wider benefits of practical learning, and more high-quality practical learning will take place within the formal curriculum of secondary schools
And
f. More young people will want to explore engineering when they leave school
And
g. Society in general will begin to see that practical learning is a valuable part of almost all learning that is worthwhile at school and in life.

b. *If we can suggest a range of benefits that it can confer on learners in schools and in life*

Partly supported

Evidence is beginning to suggest that practical learning can confer a range of benefits on learners. But, perhaps because this has not been a focus of much rigorous research to date, the evidence base is not yet strong enough.

Nevertheless, we have found indications that practical learning can increase students' motivation (Wijnia et al., 2017) engagement, interest in the task and their self-belief (Condliffe et al., 2017; Jerzembek and Murphy, 2013; Wijnia et al., 2017) and generate enthusiasm for learning (Menzies et al., 2016).

Students can see links between the subject and the real world when engaged in science projects (Hasni et al., 2016) and more readily understand underpinning technology theory through projects (McGeown, 2019).

It also seems likely that positive character attributes such as resilience, flexibility and learning from feedback can be developed through practical learning but the tools used in research studies to evaluate these attributes have not always been sufficiently robust to confirm this at present (Leggett and Harrington, 2019; Menzies et al., 2016; Rogers et al.,2019).

Regarding specific student groups, independent science inquiry projects can benefit disadvantaged students (Bennett et al., 2018) and practical work can enhance girls' interest in science and technology (Kokotsaki et al., 2016; Mostafa et al., 2018). Students with socio-emotional and behavioural difficulties also benefit because practical tasks make fewer language and literacy demands on them (Zweers et al., 2019).

Participating in practical learning can benefit students when they progress beyond school. Undertaking independent research projects develops the self-regulation that enables them to cope more successfully with university teaching (Stephenson and Isaacs, 2019) and experience of group projects enhances their collaboration skills (Rogers et al., 2019) and teamwork (Menzies et al., 2016) as desired by engineering courses (Hitt, 2020).

Future work will require individuals with people and personal skills (Edge Foundation, 2018) and critical

Table 4:
Words used to describe practical learning in subjects at Key Stages 3 and 4
(Adapted from Department for Education (2014) *Key Stages 3 and 4 Framework document*. DfE)

Subject	Words describing practical learning at KS3 and KS4
Art and design	Produce creative work, evaluate, analyse, record observations, handle different materials …
Computing	Design, use and evaluate computational abstractions, solve a problem, create, re-use, revise and re-purpose digital artefacts …
Citizenship	Research and interrogate evidence, debate and evaluate viewpoints, present reasoned arguments, take informed action, use a range of research strategies, carry out simple operations, undertake creative projects …
Design and technology	Identify and solve own design problems, develop specifications, generate creative ideas, select from and use specialist tools, techniques, processes, equipment, select from and use a wider, more complex range of material, investigate, test, cook dishes, select and prepare ingredients, use utensils and electrical equipment …
English	Read independently, write accurately, fluently and effectively, plan, draft, edit and proof-read, speak confidently and effectively, give short speeches and presentations, participate in formal debates and structured discussions, improvise, rehearse and perform, make notes, draft and write, work effectively in groups, listen to and build on the contributions of others, listen and respond …
Geography	Interpret Ordnance Survey maps, use Geographical Information Systems, use fieldwork in contrasting locations to collect, analyse and draw conclusions from geographical data …
History	Pursue historically valid enquiries including some they have framed themselves, create relevant, structured and evidentially supported accounts …
Languages	Identify and use tenses, use and manipulate, develop and use, listen, transcribe, initiate and develop conversations, speak coherently and confidently, read and show comprehension, write prose, write creatively, translate …
Mathematics	Select and use appropriate calculation strategies, move freely between different numerical, algebraic, graphical and diagrammatic representations, make and test conjectures about patterns and relationships, reason deductively, express their arguments formally, solve problems, model situations mathematically, select appropriate concepts, methods and techniques to apply to unfamiliar and nonroutine problems, use a calculator and other technologies, recognise, sketch and produce/interpret graphs, find approximate solutions to contextual problems, draw and measure, describe, sketch and draw, identify and construct, record, describe and analyse, solve quadratic and simultaneous equations, compare lengths, areas and volumes, interpret and construct tables and line graphs …
Music	Play and perform, improvise and compose, listen …
Physical education	Use a range of tactics and strategies to overcome opponents in team and individual games, develop technique and improve performance, perform dances, take part in outdoor and adventurous activities, work in a team, solve problems, take part in …
Science	Apply mathematical knowledge, collect, present and analyse data, ask questions and develop a line of enquiry, make predictions, use appropriate techniques, apparatus, and materials during fieldwork and laboratory work, make and record observations and measurements, apply sampling techniques, present, evaluate, apply, question, plan experiments, make and record observations …

thinking (Economist Intelligence Unit, 2019). As noted above, practical learning can enhance collaboration skills, and evidence also suggests that it can enhance creativity (Bennett et al., 2018), critical thinking and problem-solving (Hasni et al., 2016; Wilder, 2015).

c. If we can show that, when done effectively, practical learning can enable students to achieve as well in standardised tests as with more traditional methods

Considerably supported but in need of further research and exemplification

When done well, practical learning can enhance academic content learning but often no better than or equal to traditional methods of teaching (Condliffe et al., 2017; Jerzembek and Murphy, 2013; Merritt et al., 2017).

PBL can have a positive, but marginal, effect on students' academic learning (Chen and Yang, 2019). In some cases, depending on the subject, it can match conventional teaching (in mathematics) or exceed it (in science) (Craig and Marshall, 2019). Knowledge retention over a longer period is also enhanced with PrBL (Merritt et al., 2017).

Section 3 summarises recent high-quality research relating to this hypothesis in some detail.

d. If we can better distil the essence of excellent practical learning and identify promising secondary schools doing it well

Considerably supported but in need of further exemplification

At its most successful, practical learning flourishes in a school environment where it is embedded in the culture of the school in a strategic manner (Luckin et al., 2017). The support of senior leaders is crucial to ensure that timetables, flexible teaching spaces and other resources are available (Kokotsaki et al., 2016). The ability of teachers to work effectively across departmental boundaries with cross-curricular projects is important (Menzies et al., 2016).

The design of the practical learning task requires careful consideration (Luckin et al., 2017), with an appropriate balance of structure and openness, depending on the teacher's understanding of the knowledge and skill levels of their learners ((Akuma and Callaghan, 2019). It is likely to be linked to real-world or authentic contexts (Condliffe et al., 2017; Hasni et al., 2016).

Students need to feel that they are exercising some control over their learning through choice of topic or over the information they seek (Jerzembek and Murphy, 2013; McCrone et al., 2019), developing an equal sense of ownership (Kokotsaki et al., 2016). Students need time to go through all the steps of an enquiry or problem-solving process, and repeat them if necessary, to improve on their work (Wilder, 2015). They should have an opportunity to present their work to others.

Practical learning works best when teachers are clear about their purpose in using practical work (Abrahams and Millar, 2008), are skilled in scaffolding and guiding learning (Lazonder and Harmsen, 2016) and in asking questions (Akuma and Callaghan, 2019). They also have to be confident enough to relinquish some control to students and not take it back as soon as students show signs of struggling (Luckin et al., 2017).

Assessment needs to enable the full range of learning outcomes of head, heart and hand to be demonstrated (Wilder, 2015). As more research from the field of embodied cognition enters education, we can begin to interpret practical learning in different ways, as some researchers are beginning to do with science practicals (Hetherington et al., 2018; Roth, 2018).

In addition to innovative specialist schools such as UTCs and studio schools, we have been able to identify some mainstream academies and other schools that appear to offer practical learning experiences *and* satisfy quality criteria. Section 5 offers a brief analysis of these exemplars, which exhibit many of the factors we identified in (e). However, we used mainly secondary sources for this, and in some cases, the promising practice appeared no longer to exist. Nevertheless, our collation of case studies from organisations that have a significant role in promoting practical learning provides a useful starting point for further research.

School leadership is key to the successful introduction of practical learning, not just in securing resource, but most importantly, in creating an ethos where risk taking is encouraged (Edge Foundation, 2019b; Luckin et al., 2017).

Regular teacher support and development is required (Edge Foundation, 2019b). Change needs to be introduced gradually and over a sustained period, with teachers encouraged to take small, incremental steps of change (Luckin et al., 2017). Subject leaders should work with teachers to review their practice, agree a set of guiding principles or policy and monitor progress (Needham, 2019).

It is important to engage the community outside the school, particularly to target the 'right' employers - those with a real interest in working with students in this way – to be involved in projects (McCrone et al., 2019). Partnering with an organisation that has supported other schools in adopting this approach and joining a network that fosters a community of practice can be beneficial (Edge Foundation, 2019b; Paul Hamlyn Foundation, 2012).

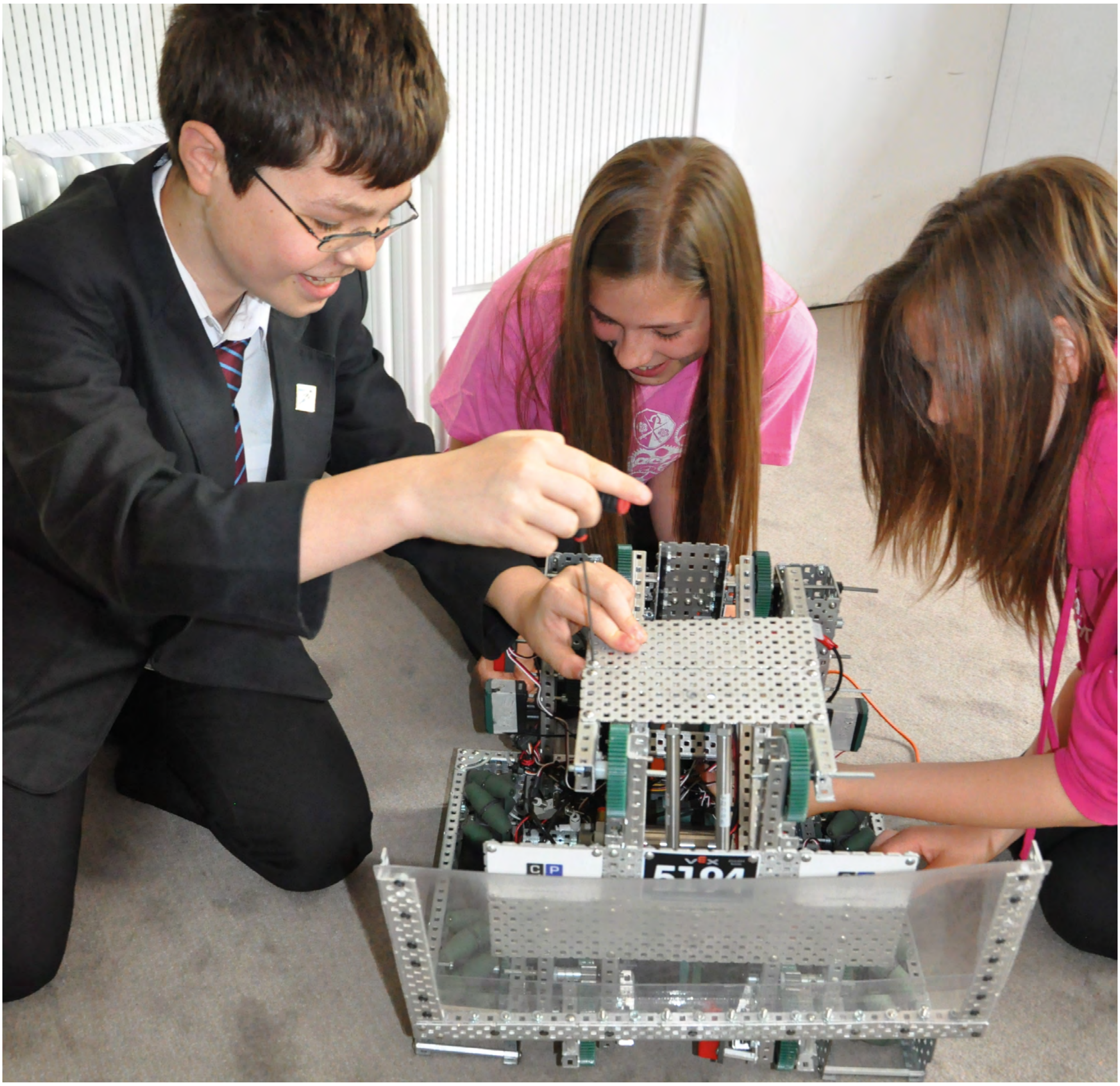
Practice makes perfect, as they say. This sentiment is particularly important here as schools need to provide an appropriate length of time for the impact of practical learning to be fully evaluated and not expect a quick fix or that an isolated snapshop of activity will show the full range of outcomes on learners (Wilder, 2015). Tools and methods of assessment appropriate to measuring the full range of outcomes of practical learning need to be used (Leggett and Harrington, 2019; Menzies et al., 2016; Rogers et al., 2019).

6.1.2 Changing hearts and minds

With the remaining four lines of speculation we reflect on the likelihood of change and the methods by which this might be achieved. We are necessarily more circumspect at this stage and draw from what we know from the introduction of other curriculum innovations in secondary schools.

e. ***School leaders, teachers and policymakers will see the wider benefits of practical learning and more high-quality practical learning will take place within the formal curriculum of secondary schools …***

We have made some modest progress in validating some of the aspects of our broad conjecture about



better understanding of practical learning and the benefits it brings, making it more accessible and attractive to schools and teachers. At the same time, we have tamped down some of the myths associated with its more popular versions – PrBL, IBL and PBL.

By demonstrating that practical learning, when well done, can achieve results that are on a par with more traditional methods we can begin to assuage this legitimate concern. By suggesting the other benefits practical learning can bring to students we appeal to the kind of more holistic, expansive education that many school leaders want.

If the evidence of the full range of positive outcomes for students of practical learning can be shared widely, and the benefits shown, concerns about reactions from bodies such as Ofsted in England can be reduced. School leaders can recognise that good learning can sound and look different to what they are used to but be confident in advocating their practical learning approach to Ofsted (Luckin et al., 2017). The current Ofsted framework (2019) requires schools to be explicit about their 'intent', 'leaders take on or construct a curriculum that is ambitious and designed to give all learners, particularly the most disadvantaged and those with special educational needs and/or disabilities (SEND) or high needs, the knowledge and cultural capital they need to succeed in life' (p.9). It invites schools to 'support learners to develop their character – including their resilience, confidence and independence – and help them know how to keep physically and mentally healthy' (p.11). Practical learning of the kinds we have described has a well-evidenced role in contributing to these kinds of outcomes.

While there are currently relatively few school leaders taking the approaches we are advocating, there is, we believe, cause for realistic expectation that various forces are beginning to align. Evidence of efficacy is growing; there are some compelling proofs of concept; there is demand from employers; and England's accountability body, Ofsted, is clearly giving schools 'permission' to reimagine practical learning and be clearer about their intentions regarding their curriculum offer. This increasing consensus may encourage policymakers to revisit the theoretical–practical divide in the English curriculum.

Our promising practice schools were selected specifically because they exhibit high-quality practical learning within the formal curriculum (**Table 3**) and further opportunities to learn from them could enhance perceptions about the validity of practical learning across the curriculum, rather than in one or two obvious subjects like technology, art or music.

In the short-term post-COVID-19, it is likely that schools will be under pressure to focus on the basic subject knowledge that students will have missed and it will be important to stress the contributions of practical learning to, for example, wellbeing, resilience and creative problem-solving.

f. More young people will want to explore engineering when they leave school …

Engineering is both a concept or field *and* a description of a broad range of career options. In our earlier research (see **Figure 2**) we articulated a set of EHoM, which are the 'threads' that link engineering to its many applications in the real world. Like the concept of creativity or a career in medicine, engineering is multi- and trans-disciplinary and necessarily requires individuals to combine theory with practice, the academic and the practical.

While it is a conjecture only at this stage, we suggest that it is at least plausible that if we can reimagine the educational experiences of young people at secondary school, specifically ensuring that there is a better blend of practical learning with its associated teaching and learning methods, young people will have experiences bringing them much closer to thinking and acting like an engineer (or doctor or nurse or designer, for example).

The evidence about the extent to which students enjoy practical work suggests that, while welcoming it as a diversion from the norm, they are strategic about when and why it is beneficial for them. They value it for enabling them to develop technical skills in using equipment, which leads to an enhancement of academic learning. They enjoy the freedom from traditional academic study afforded by PBL. They see PBL giving them employability skills, particularly the ability to work with others (McCrone et al., 2019).

Students also reported that science projects taught them about what it was like to be involved in real scientific research and were happy to spend more time on projects and less time in the traditional classroom, according to some studies (Hasni et al., 2016). In fact, students see practical work as the essential part of learning science (Holman, 2017).

So, given this enthusiasm for practical work, it would seem possible that efforts to increase the connections between practical work and engineering while at school might increase the possibility of them exploring it when they leave school.

This possibility has been recognised by engineers themselves, as David Blockley, a professor of civil engineering, bemoans the fact that 'practical people are often made to feel inferior compared to those with more theoretical knowledge' (p.3). He suggests that 'we are all engineers' (p.vii) since we all solve problems, and he provides a compelling rationale for the need to re-establish the connection between theoretical and practical in people's minds (Blockley, 2020).

g. Society in general will begin to see that practical learning is a valuable part of almost all learning that is worthwhile at school and in life …

In a throwaway society, the rest of the world is waking up to the importance of making, as demonstrated through the growth of the maker movement (Martin, 2015). At the same time, the popularity of television programmes such as *The Repair Shop*, *The Great British Bake Off* and *The Great British Sewing Bee*, all of which celebrate the passion, creativity, problem-solving and expert knowledge of the participants, indicates a growing interest in these aspects of practical activity.

It has been noteworthy that, during the COVID-19 crisis, we have seen engineers come into their own, demonstrating the value not only of their disciplinary expertise but also their ability to work collaboratively with others from many different fields to solve urgent problems.

Beyond school, employers, universities and colleges want students with both disciplinary knowledge and the kinds of habits of mind or dispositions for learning we have explored in Section 3. For a decade, the CBI (2019) has championed the arguments we are making for a broad set of habits of mind: 'wider character, behaviours and attributes are considered to be the most important consideration when recruiting school and college leavers' (p.8). It also urges schools to keep the role of disciplinary knowledge in perspective: 'close to three-quarters (74%) of employers are satisfied with the academic knowledge of young people who have applied for jobs during the past 12 months' (p.8).

6.2 Arguing for a more complex approach to practical learning

The research into practical learning that we have reviewed suggests that it should be more valued in secondary education than appears to be the case now. We have restated the pernicious fault line that continues to exist between practical and academic learning, one which so often leaves the former being under-valued. We have suggested that this simplistic, binary understanding of the place of the practical in education is not working.

We have found that practical learning can foster academic learning under the right circumstances and that it can develop character and dispositions for learning needed for life after school.

However, the complexity of practical learning and the conditions under which it flourishes lack wider understanding. The 10 dimensions of decision-making for vocational pedagogy (**Figure 1**) were an earlier manifestation of the decisions that teachers make when deciding which methods to use. The research discussed in Section 4 highlights further challenges in teaching for achieving a dynamic blend of theory and practice that represents a reimagined view of practical learning as contributing to a whole education.

Terms like PBL, IBL and PrBL may themselves be part of the problem in understanding practical learning. Each has become, in a sense, an educational brand that comes freighted with associations. Some see them as a distraction from teacher-led, knowledge-based instruction. Others regard them as the only way of preparing young people for a world that is not organised into neat, discrete subjects. The net result is educational 'noise', which blocks out the quieter voice of reason and diverts school leaders away from the small changes that teachers can make in the classroom to make learning more practical, more holistic. The lists of verbs used to describe what students should be able to do through the subjects of the National Curriculum (**Table 4**) illustrate the scope for practical learning in the classroom that enables students to experience the whole game of learning using their heads, hearts and hands.

Of all the typologies we have encountered in this research, the one created by David Perkins (2009) seems most relevant in helping us to reimagine practical learning. Here is an adapted version of his seven principles. In each case we have kept the wording of each principle and then added our own interpretation to the topic of practical learning:

1. Play the whole game. Use extended projects and authentic contexts. Combine theory and practice, matching the level and specificity of tasks to students' prior knowledge and experience.
2. Make the game worth playing. Work hard at engaging learners giving them choices wherever possible. Find the right level of challenge and support to motivate all learners. Pick your moment to introduce theoretical explanations.
3. Work on the hard parts. Discover the most effective ways of practising. Explicitly teach how to give and receive feedback. Create opportunities for display and performance. Encourage students to talk out loud while they are undertaking a practical task.
4. Play out of town. Build familiarity of tasks by extensive practice in one context. Ask students to explain their choice of methods wherever

possible. Invite them to think where else they might use any technique they learn in the classroom or workshop. Help them to see patterns and learn rules.

5. Uncover the hidden game. Make the processes of learning as visible as possible. When learning complex processes. Take opportunities to get beneath the skin of whatever you are learning to see its organisational and design structures.
6. Learn from the team. Develop robust ways of working in groups, being sure to practise many different team roles. Seek out and connect with expert communities of practice beyond school, especially those doing the work for a living.
7. Learn from the game of learning. Where possible make sure learners are in the driving seat, developing their own tried and tested tactics and strategies as they develop habits of mind that will help them at school and in life.

The Perkins principles offer an antidote to education systems that have lost their heart and relevance, with curricula so full of 'stuff' to be remembered and used on demand in public tests, their central purpose lost, a mindless experience for too many students. Whole learning, as advocated by Perkins, is not like that. It is a complex, engaging, real, challenging mix of theory and practice, the ideal preparation for a lifetime of learning.

In a similar way in this report, we are trying to offer an antidote to an education system in England that, we believe, has focused too much on the head and not enough on the hand and the heart. In a sense, to borrow the title of Perkins' book, we are making practical learning whole again.

In seeking to understand practical learning we chose to focus on the three approaches most widely used in schools – PBL, IBL and PrBL.

We started our study with a working definition of practical learning that reflected this choice:

"Practical learning involves head, heart and hand working in harmony. In schools this means using approaches such as project-based, inquiry-based and problem-based learning which encourage students to explore real-world challenges and offer learners opportunities to work with resources of many kinds to make things that work or make things work better."

But in the light of our research, we decided that a more nuanced definition of practical learning was required, one that did not privilege our three selected approaches:

"Practical learning is defined as learning that is whole, involving head, heart and hand working in harmony. In schools this requires teachers to use carefully chosen strategies that encourage students to experience and navigate real-world challenges and acquire and apply their knowledge in a range of settings as they explicitly seek to develop a set of wider dispositions for learning for life."

6.3 Practical learning as an encouragement to would-be engineers in secondary schools

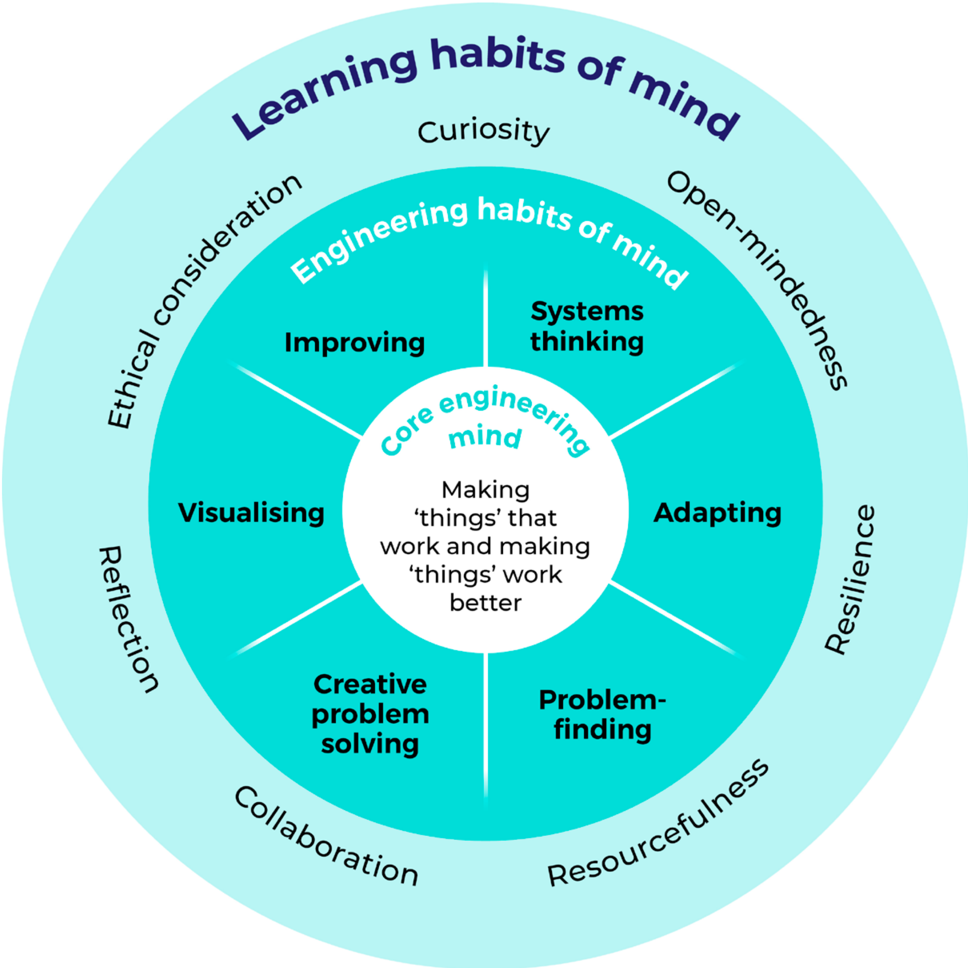
Many of the reviews analysed for this report found that that students value learning through projects, investigations and problem-solving when it is done well, at the right time and with appropriate purpose. In our previous research into education for engineering, we identified six EHoM (**Figure 2**) that are particularly associated with the ways in which engineers think and act: systems thinking, adapting, creative problem-solving, problem-finding, improving, and visualising (Lucas et al., 2014). We further documented how several practical learning and teaching strategies such as modelling, reflecting, engineering design, tinkering, and projects with employers could be used by teachers to cultivate EHoM and develop greater awareness of engineering among pupils (Lucas et al., 2017). Some of the resources developed by teachers in support of these approaches are available on the Royal Academy of Engineering website (www.raeng.org.uk).

These approaches were used primarily in D&T, science and engineering classes. However, the expressions of practical learning across all subjects in **Table 4** suggest that many more subjects could become vehicles for encouraging would-be engineers if they used projects, inquiries or problems as the driver for learning, and even more so if they were cross-curricular.

Our earlier work, when combined with findings from this current research into the ways in which practical learning can develop dispositions and capabilities, albeit slender at present, confirms that such approaches would be worth pursuing to engage would-be engineers by raising awareness of EHoM. We have seen that:

- PBL can encourage creative problem solving (Hasni et al., 2016), the ability to transfer learning to the solving of new problems (Thomas, 2000) and it also fosters cross-curricular learning (Rogers et al. 2019) and collaboration skills (Bani-Hamad and Abdullah, 2019), all of which are important for problem solving in multi-disciplinary engineering teams

Figure 2 (repeated):
Engineering habits of mind (EHoM) (Lucas, Hanson and Claxton, 2014)



- appropriately guided investigative activity can stimulate students' curiosity and increase their ability to take responsibility for their own learning (Bennett et al., 2018; Stephenson and Isaacs, 2019), dispositions that are core to problem finding and improving
- learning through problems supports students' ability to integrate and explain concepts and apply their learning to real-world situations (Hoidn and Kärkkäinen, 2014), which are core to systems thinking and adapting, while groups working on problems benefits students' interpersonal and social skills (Jerzembek and Murphy, 2013)

There are also wider perspectives on practical learning that may have a bearing on attracting would-be engineers, for example practical learning's role in increasing equity of access to STEM subjects (APPG on Diversity and Inclusion in STEM, 2020) and its role in changing perspectives on engineering careers (The Nursery, 2016; Institute of Engineering and Technology (IET), 2019).

Practical learning can help students find a meaningful connection with STEM, since the practical context of science can attract students with low science capital to engage with the subject, whereas a reduction of practical work can detract from studying science (APPG, 2020). We have noted caveats around treating practical learning as being 'just for fun' and this finding reinforces our recommendation that it should not be dismissed lightly. Indeed, the APPG recommends that the government should consider 'The role that students' practical work plays in equity and how they perceive science, including the content of practical work, how it is assessed and how it is resourced in all schools' (ibid, 2020, p.8).

Inquiries into the perceptions of children, parents and teachers about engineering as a career frequently find that the breadth of engineering is not well understood, but that when a wider range of career options associated with design, art and music, as well as science and technology, and stories about improving people's lives are explored, engineering appears more inspirational and accessible (The Nursery, 2016; IET, 2019). This suggests that offering opportunities for cross-curricular projects, especially those involving employers, might afford opportunities for raising interest in engineering.

6.4 In summary

If school leaders, teachers and policymakers are to understand the complexity and see the many benefits of practical learning in schools then, we suggest, a number of conditions will need to have been met.

Perhaps most importantly schools will need to be able to go beyond the rhetoric of claim and counter claim about approaches such as PBL, IBL and PrBL. They will need to understand the conditions in which such methods are as likely to produce academic results as more conventional methods.

School leaders will need to be able to articulate a fuller set of desired outcomes for their learners, the development of character and of those habits of mind, which will prepare students well for the world beyond school. There is the beginnings of an evidence base for such benefits of practical learning, but more is needed. Similarly, there are some promising practices in schools, but more rigorous exemplification and evaluation of these is needed.

Practical learning is an integral part of good teaching and learning, much closer to what David Perkins calls 'whole' learning. For practical learning to be well-regarded and well-taught, it will be helpful if all those who have a stake in the education of young people can go beyond the tired clichés of academic versus practical and see the two as seamlessly integrated, with the latter calling for a repertoire of pedagogies from teachers just as 'academic' learning does.

It is a conjecture at this stage as to whether schools who reimagine practical learning in the ways we have identified in this report will encourage more engineers. But it is a proposition that seems reasonable to explore given what we already know about the kinds of habits of mind engineers display and the ways in which high-quality practical learning can cultivate these.

7. Conclusions and recommendations

> **Our bodies do not just intrude on the way we understand and produce language. They influence our attempts to interact intelligently with the world around us. The interconnection of the abstract and the concrete reveals itself in how we behave, as well as in what is going on in our minds.**
>
> Claxton, G. (2015) *Intelligence in the Flesh: Why your body needs your mind much more than it thinks*. New Haven, CT: Yale University Press (p.156–157)

In this research we drew on high-quality research, especially research since 2000, to explore the claims and counter claims associated with the three main methods of practical learning in schools – PBL, IBL and PrBL.

We have explicitly looked beyond the typical research question asked about these three methods, trying to establish whether traditional teaching is better or less good than more traditional ones. Unfortunately, by 'better' such research tends to mean 'better at teaching students to acquire knowledge' rather than, say, better 'in terms of becoming more powerful learners' or 'in terms of character development' or 'in becoming more employable'.

7.1 Conclusions

We conclude that, when done well, PBL, IBL and PrBL are as good as (but no better) than more traditional approaches in ensuring students acquire knowledge. We offer several caveats as to when and how these methods work well and less well.

Importantly we also describe the many other benefits that the three approaches to practical learning we examined confer on students including problem-solving, creativity, communication, collaboration, and a sense of agency. These areas are much less well-evidenced as they have only recently come to the attention of researchers.

Drawing on current research we identify the key features of high-quality practical learning in terms of school context and leadership, the kinds of tasks that work best, the most effective roles for students and teachers, and the ways in which student progress is tracked. As exemplars of these approaches, we have identified 36 schools that seem to be deliberately teaching practical learning using one or more of the three methods we have examined and that have also attracted the attention of third-party organisations with specialist knowledge of practical learning.

7.2 From theory to practical action

We started this research with a TOC, which in essence asked four questions that we needed to be able to answer if we were going to be able persuade others that practical learning really matters in schools.

We asked whether it is possible to better understand the ubiquity and complexity of practical learning. It is. Practical learning, albeit not described as such, appears in every subject of the National Curriculum. Practical learning continues to be under-valued by dint of its history in English education. There is an increasingly robust evidence base describing best practices.

We asked whether the range of benefits practical learning can confer on learners can be described. There definitely are important benefits and we have made a good start in articulating them. But we recognise that there is more to do. Certainly, school leaders and teachers can talk with increased confidence to external bodies such as Ofsted and local employers and parents about some of the reasons why they might choose to focus on practical learning with their students.

We asked whether it can be shown that, when done effectively, practical learning can enable students to achieve as well in standardised tests as with more traditional methods. The evidence suggests that they can, with certain important moderating factors that we have described.

Finally, we asked whether it is possible to distil the essence of excellent practical learning and identify promising secondary schools. It is possible to describe some of the ingredients of high-quality practical teaching and learning, and we have identified some 36 promising schools (although we have not been able to verify their practices as part of the scope of this study).

We have met our four objectives wholly or in part and believe we can realistically call on this evidence to support schools to change their practices.

Along the way we have tried to reimagine practical learning so that it is seen as an integral part of any worthwhile learning we might want secondary aged students to undertake. We have taken the phrase 'making learning whole' (Perkins, 2009) as an instruction to all those in the education system to put the practical back into learning, to be explicit about this and to become skilled at choosing a blend of pedagogies to achieve this.

In summary we conclude that:

- practical learning is complex, valuable and an integral part of almost all learning
- without paying explicit attention to creating opportunities for practical learning, it is likely to be overlooked, ignored or undervalued in secondary schools, which are largely measured by success at GCSE and A levels
- the three methods we have explored in particular – PBL, IBL and PrBL – generate unhelpful responses in some school leaders and teachers, at least in part because they are only known by their media hype and not examined with a more critical lens
- there are some practical steps we now need to take to take our reimagining of practical learning in secondary schools to the next stage.

7.3 Recommendations

In the light of this research we suggest that:

- further qualitative research is undertaken to describe excellent practical learning in schools to produce detailed secondary school case studies so that the field can be better understood on the ground and practices that might make engineering more visible to young people can be better evaluated
- the Academy uses examples of schools that have embedded high-quality practical learning to understand more about the potential of such approaches for attracting young people to learn about engineering and consider engineering as a career
- the Academy considers further investigation into the role of embodied cognition in continuing to build a better understanding the field of practical learning
- the Academy, through initiatives such as This is Engineering, and with partner bodies such as the Crafts Council, the Royal Society and Comino Foundation acts as a catalyst for wider inquiry into the role of practical learning in schools to continue to reimagine practical learning so that it is valued and offered explicitly in all secondary schools.

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Appendix 1: Overview of recent reports

All Our Futures: Creativity, Culture and Education. **(NACCCE, 1999)**

Ken Robinson's report emphasised the importance of creativity. Abilities in this area, it argued, are developed through practical application, and young people need experience of practical processes to understand them and be able to control them for the different disciplines and for work (p.34).

Prosperity for All in the Global Economy: World class skills **(Leitch, 2006) Leitch Review of Skills**

This review found technical and practical skills to be lacking in over 2/5 of employees reported by employers as having a gap in their skills (p.41).

***Open to Ideas*, (Parliamentary Skills Group, 2011)**

This review found an 'institutional prejudice' against vocational and practical learning in educational practical and policy (p.15). Contributor John Dunford (of organisation Whole Education) argued for a broad and balanced curriculum, combining theoretical and practical learning, with success stories from overseas.

Review of vocational education: The Wolf report **(Wolf, 2011) Department for Education**

This review begins with the problem that the UK has failed to provide a proper technical and practical education. It argues that early specialism is not the way forward (p.40; p.107) (and so a broad and balanced curriculum to 16 is to be desired).

First Steps: a new approach for schools **(CBI, 2012) Confederation of British Industry**

Against a background of global competition, this report sets out businesses' views on school reform. Its focus is on improving education standards/ educational attainment to match other countries for the economy as well as impacts upon crime, health, and parenting. The report emphasises the importance of working out what the goal of education, and the purpose of schools, should be. It assumes this might be 'core and enabling subjects young people are expected to master, but also the behaviours and attitudes' (p.7). For primary schools, the desirability of 'an experimental-based approach that engages young people' (p.9) is mentioned. 'Practically based' subjects are called 'enabling', which the CBI argues should be rigorous, stretching and taken by all children (p.31).

***Manifesto for the Creative Economy*, (Bakhshi et al., 2013) NESTA**

This review begins with the problem of economic change, reduction in profitability, and the need to refresh policy, particularly around growth of the digital economy. In terms of its recommendations for schools, it sets out that teenagers 'should have the opportunity to learn creative digital skills, such as designing apps and games, as part of a fusion in the curriculum covering technology and art, as well as mathematics, science and the humanities. (p.7).

The Future of Work: Jobs and skills in 2030 **(Störmer et al., 2014) UK Commission for Employment and Skills**

This report anticipates the potentially disruptive impacts of new technologies on work. It aims to help inform changes in the UK that might help create an 'agile, demand-led skills engine that can respond rapidly to this transformational agenda' (p.i). The report does not deal specifically with schools. In terms of recommendations to education and training providers, the report recommends close collaboration with employers, and the need to adapt programmes 'to reflect the critical importance of an interdisciplinary approach to innovation in the workplace and the all-pervasive influence of technology' (p.109).

***Our Future Is In the Making*, (Crafts Council, 2014)**

This manifesto for education recognises the importance of the craft sector for employment and the UK economy. It proposes a plan of action that involves putting craft and making at the heart of education to stimulate uptake in art, craft, design and technology GCSEs by revitalising learning with hands-on experience.

How Well Do Schools Prepare Children For Their Future? (All-Party Parliamentary Group for Education, 2017)

As part of this report, the increasing demand for STEM workers is noted, 'particularly in the digital technology workforce' (p.8). Literacy, mathematics and ICT count as basic skills in this area. The report notes that the perceived difficulty of STEM careers – or, conversely, the low status and manual nature in some cases – puts young people off. The high demands for literacy in early science teaching are thought to put learners off, 'despite the fact that other skillsets such as spatial awareness are more conducive to success later on' (p.9). It may be that more practical forms of learning in schools could help, although this is not proposed in the report. The exclusion of D&T from the EBacc was noted, and 'sends a clear message that technical education is not considered as important as more academic subjects' (p.19).

Report of the Independent Panel on Technical Education (Independent Panel on Technical Education, 2016) Department for Education

Established by the Minister for Skills, this panel was tasked with advising minsters on actions to improve the quality of technical education in England and simplify the system to ensure the right skills were delivered. An economic and a social imperative are drivers of the review. The delivery of technical education focuses on 16–18-year-olds. Technical options can be pursued through college and apprenticeships, and the panel stated that the options need to be clearly different because they have different purposes (p.9). The need for English and mathematics are 'vital' for technical routes (p.12). There is no suggestion that technical education should be introduced before 16, but that careers education and guidance are important in schools (p.20).

The Future of Education: An Essay Collection (Huynh, 2019) Institute for Public Policy Research

A collection of essays in which Martin Robinson's piece *Technology and Creativity: Are you the maker or the tool*? reminds us of the need to go back to basics as children learn practically. Robinson makes the important point that schools should not come to rely on technology that learns and adapts, but 'should teach children how to make aesthetic choices with tools that are in their total control, developing their own taste and discrimination, before they dabble extensively in the immanent world of modern 'cybernetic' technology' (p.21).

Peter Hyman's piece on *Success in the 21st Century* argues that we need an education for 'head, heart and hand' (p. 47). An academic education (head) will teach an in-depth knowledge of key concepts and knowledge. A character education (heart) will provide experiences for young people to develop ethical and performance character traits. A 'can-do' education (hand) provides opportunity for young people 'to respond to client briefs, to understand design thinking, to apply knowledge and … and produce work through craftsmanship …'

Durham Commission on Creativity in Education (2019) Arts Council England

The commission has developed a vision for promoting creativity in education through the promotion of teaching *for* creativity across all areas of the school curriculum and for all pupils. In terms of practical learning, it recommends provision of opportunities for learners to 'problem solve, experiment, take risks, make mistakes, try again' (p.18). Teaching for creativity allows 'genuine scholarship, craftsmanship, a fascination with ideas and absorption in a discipline' (p.20). These are not inherently practical but could be enhanced by practical learning. The report recommends that the arts should be integral to the curriculum for all children, and not just an add-on (p.23).

Appendix 2: Our approach to the research discussed in more detail

Appendix 2 provides further details on the methods we used to search for and collate existing evidence about outcomes of practical learning from research and grey literature. It also discusses the challenge of engaging with school practice and identifies members of our expert Advisory Panel. Finally, it identifies some of the limitations to our study.

Collating existing evidence – literature search

The first stage of the research process was to undertake a review of systematic reviews and meta-analyses published in academic journals. This literature base was then extended using a thorough review of grey literature, which yielded additional reviews. Using the search terms project-based learning, i/enquiry-based learning and problem-based learning in conjunction with search terms related to reviews, we undertook a systematic search of databases through Ebscohost, which includes Academic Search Complete, British Education Index (BEI) and Education Resources Information Centre (ERIC), and through Scopus and Web of Science.

We sought meta-reviews, meta-analyses, systematic reviews and syntheses of research or literature reviews published in peer-reviewed journals since 2000 in the English language. In total, 34 reviews were located, published between 2000 and 2019. After scanning their titles and abstracts to extract key data about their educational level, the subject focus of the review, the methodology, and the nature of the items they reviewed, 16 were included in our list for analysis. The search terms were used again for the second database search to locate any recent reviews or relevant research published between completing the first review and 2020. A further four reviews were found, all of which were included for analysis, totaling 20.

The primary criteria for inclusion in our analysis were that papers referred to research in secondary schools (there were a few exceptions to this) and that they mainly examined research published in peer-reviewed literature rather than in unpublished theses or conference papers.

Our approach to searching for grey literature

Grey literature is defined as literature 'not controlled by commercial publishing organisations' (Adams et al., 2016). Non-commercial organisations that might publish grey literature range from large bodies with a wide social or cultural remit, such as charitable foundations that offer significant grants for education research, to governments and their agencies, policy think-tanks or small organisations with a specific social or cultural agenda. In applied fields of study such as education, bodies like these frequently support evaluations of research interventions providing valuable evidence of impact of educational innovation in practitioner contexts illustrating, for example, how and why the interventions are effective, or not, and what other developments need to take place (Adams et al., 2016).

Grey literature can also help to reduce the impact of publication bias, since studies with null findings are less likely to be published in peer-reviewed journals (Adams et al., 2016). While grey literature is often regarded as more ephemeral or of lesser quality than research published in peer-reviewed academic journals, it is a key source of data for research into an emerging field.

After identifying organisations that might potentially produce high-quality education research in our broad field of practical learning (Appendix 3), the search was conducted by accessing each organisation's website and searching for documents referring to any form of practical learning that had been published between 2010 and 2020. Documents were found on the websites using the search terms practical, project or inquiry in keyword searches and by searching pages listing their publications and research. Just over half of the organisations searched (42) offered up something of relevance to our research.

The documents found can be categorised broadly into four groups, of which items from the first three contributed to our study:

- Research reports such as evaluations of educational interventions and literature reviews.
- Opinion pieces and policy documents, some of which are from international organisations, that reflect the values of the organisation and are often written in response to perceived educational challenges.
- Case studies of schools engaging in best practice in a practical learning approach supported by the organisation.
- Resources and guidance for teachers, such as teaching schemes.

A further 16 reviews or research reports identified from the grey literature were of sufficient significance to our research to be included in our scoping review, making a total of 36 papers for the review. The studies included in our review are shown as starred items in the references list.

The research reports from UK organisations included in our review offered important insights into the state of practical learning in England and provided a counterweight to balance the large number of reviews in the research literature that originated from North America and elsewhere. The reports from the Education Endowment Foundation and the Gatsby Foundation are of note in this category, as too are the reports from the OECD that present analysis from the PISA tests, much of which is given weight in education policy making in the UK.

For each included paper we summarised the authors' findings on the key characteristics of the practical learning approach; its impact on student outcomes relating to knowledge gain, dispositions and habits of mind; features associated with high-quality use of the pedagogy; and any specific theme addressed by the authors, for example use of the pedagogy with disadvantaged students. This analysis is presented in Sections 3 and 4 of our report.

Some of the research reports and several of the opinion pieces and policy documents found in the grey literature provided evidence for the wider argument in support of practical learning in schools. While they were not included in the review itself, they provided useful contextual information on the state of practical learning in education in the UK and evidence of the wider international demand for education systems to recognise the importance of practical learning.

Grey information

Adams et al. (2016) note that 'much knowledge and evidence in public health, and other fields, accumulates from innovation in practice. This knowledge may not even be of sufficient formality to meet the definition of grey literature' (p.1). Increasingly referred to as grey information, it may be even harder to search for and retrieve than grey literature. However, since it is typically produced by schools and other organisations, we aimed to carefully review it to inform our selection of schools exhibiting promising practice.

Engaging with practice

From the websites and reports providing case studies of schools, details of the school and the nature of the intervention were noted and added to our map of promising practice (**Figure 4**). However, the lack of standardised terminology for practical learning made it challenging to locate specific examples of practical learning on school websites and many schools did not give sufficient detail about their approach. It is possible that viewing practical learning solely through the wide lens of approaches such as PBL can sometimes lead to loss of visibility of the small everyday teaching and learning activities that could be harnessed in support of practical learning. These details could be the focus of further research.

Advisory Panel meetings and membership

The panel met on two occasions. In the first meeting held face to face, an initial scoping review of the research into practical learning was presented and members engaged in structured discussion to refine the agenda and research questions for the project. In the second meeting held virtually, they reflected on and discussed the outcomes of the review, helping to refine the thinking of the research team and formulate recommendations. They also engaged in the identification of good practice by recommending names of schools and responding to our questions along the way.

Membership:

David Barlex, Independent Consultant

Tom Beresford, Associate, Innovation Unit

José Chambers, Development Fellow, Comino Foundation

Daniel Charny, Director, Forth Together CIC, and Professor of Design, Kingston University

Nicky Dewar, Learning and Skills Director, Crafts Council

Peter Finegold, Head of Policy, Education and Skills, The Royal Society

Thomas Gunter, Education Policy Advisor: Education and Skills, Royal Academy of Engineering

Professor Tim Ibell FREng, Department of Architecture and Civil Engineering, University of Bath, and Royal Academy of Engineering Lead Fellow for the research project

Tami McCrone, Senior Research Manager, National Foundation for Educational Research

David Montagu, Policy Advisor (Education), The Royal Society

Rhys Morgan, Director, Engineering and Education, Royal Academy of Engineering

Jonathan Nicholls, Principal, UTC Reading

David Perry, Chair of Trustees, Comino Foundation

Alex Reynolds, Principal, UTC Sheffield City Centre

Tony Ryan, Chief Executive, Design and Technology Association

Limitations

Practical learning is a very broad term and lacks a well-defined theoretical body of knowledge to interrogate, particularly as applied to secondary education. The terminology is imprecise and all the variants of practical pedagogies, such as PBL, IBL and PrBL, overlap to some extent. Other more colloquial terms such as hands-on or making also lack precision. This could have affected the literature search process and means that we might have missed relevant reviews.

We also focused on material in the English language, which, given the apparent interest in approaches like PBL in the Middle East and Asia, could have meant that we missed interesting findings. It also meant that much of the research we analysed was carried out in North America and may not be generalisable to England.

We excluded conference papers from our grey literature search since they are used primarily to report work in progress and we were seeking authoritative summaries of the state of knowledge about practical learning. We also excluded theses and some reviews that relied heavily on data from theses.

The reviews we analysed used several different methodologies, including statistical meta-analyses, systematic reviews and literature reviews. In reporting our summary of outcomes, we are describing what the researchers themselves have claimed to be their results, we have not done any further analysis of the data to verify its validity. It is worth noting that many of the authors of the meta-reviews we included do themselves note the lack of consistent impact measures or lack of detail about assessment methods used in the research they reviewed.

Finally, there is the possibility that our positive bias towards practical learning may have influenced our selection and interpretation of material.

Appendix 3: Organisations searched for grey literature

UK Organisations	Website (url correct at date of publication)
Association for Science Education	www.ase.org.uk/resources
British Science Association	www.britishscienceassociation.org/
Centre for the Advancement of Science and Engineering (CASE)	www.sciencecampaign.org.uk/
Centre for Education and Youth (formerly LKMco)	https://cfey.org/2019/09/lkmco-is-now-the-cfey-centre-for-education-and-youth/
Centre for Educational Neuroscience	www.educationalneuroscience.org.uk
City and Guilds	www.cityandguildsgroup.com/
Comino Foundation	https://cominofoundation.org.uk/our-work/developing-personal-capabilities/
Computing at School	www.computingatschool.org.uk/
Confederation of British Industry (CBI)	www.cbi.org.uk/
Crafts Council	www.craftscouncil.org.uk/what-we-do/education-manifesto/
CCE (Creativity, Culture and Education)	www.creativitycultureeducation.org/
Demos	demos.co.uk/project/learning-by-doing/
Design and Technology Association	www.data.org.uk/for-education/research/
Edge Foundation	www.edge.co.uk/
EDSK (Education and Skills)	www.edsk.org/
Education Endowment Foundation	educationendowmentfoundation.org.uk/
Education Policy Institute	https://epi.org.uk/
Engaged Learning	http://engagedlearning.co.uk/about-us/
Engineering Development Trust (EDT)	www.etrust.org.uk/
EngineeringUK	www.engineeringuk.com/
Engineers Trust (Charitable Trust Fund of the Worshipful Company of Engineers)	http://engineerscompany.org.uk/engineers-trust/
ERA Foundation	www.erafoundation.org/outreach/stem-accord/
Fixperts at FixEd	http://fixing.education/fixperts

UK Organisations	Website (url correct at date of publication)
Gatsby Foundation	www.gatsby.org.uk/education
Ideas Foundation	www.ideasfoundation.org.uk/
Impetus	https://impetus.org.uk/why-we-exist
Innovation Unit/REAL Projects	www.innovationunit.org/ www.real-projects.org/
Institution of Engineering and Technology (IET)	www.theiet.org/impact-society/sectors/education-and-skills/
Institute for Effective Education	the-iee.org.uk/
Institute for Public Policy Research	www.ippr.org/about
Institute of Physics	www.iop.org/#gref
Institution of Mechanical Engineers	www.imeche.org/
James Dyson Foundation	www.jamesdysonfoundation.co.uk/
Joint Mathematical Council	www.jmc.org.uk/
Lloyd's Register Foundation	www.lrfoundation.org.uk/en/
NESTA (National Endowment for Science, Technology and the Arts)	www.nesta.org.uk/about-us/
NFER	www.nfer.ac.uk/
Nuffield Foundation	https://resources.nuffieldfoundation.org/practical-work-learning/about-project
OfQual	www.gov.uk/government/organisations/ofqual
Ofsted	www.gov.uk/government/organisations/ofsted
Ogden Trust	www.ogdentrust.com/
Paul Hamlyn Foundation	www.phf.org.uk/programmes/learning-futures/
Pearson	www.pearson.com/en-gb.html
Policy Exchange	https://policyexchange.org.uk/about-us/
Raspberry Pi Foundation	www.raspberrypi.org/research-and-insights/
REECE Foundation	www.reece-foundation.org/
Royal Academy of Engineering	www.raeng.org.uk/education
Royal Commission for the Exhibition of 1851	www.royalcommission1851.org/
Royal Institution	www.rigb.org/about
Royal Society	https://royalsociety.org/
Royal Society of Arts	www.thersa.org/
Salters' Institute	www.saltersinstitute.co.uk/
Smallpeice Trust	www.smallpeicetrust.org.uk/about-us
Social Market Foundation	www.smf.co.uk/

UK Organisations	Website (url correct at date of publication)
STEM Learning	www.stem.org.uk/
STEAM Co.	www.steamco.org.uk/#creativity
Sutton Trust	www.suttontrust.com/our-research/
The Skills Builder Partnership	www.skillsbuilder.org/
UK Forum for Computing Education (UKforCE)	www.ewc.wales/learningexchange/index.php/en/resources/search-resources/item/1146-uk-forum-for-computing-education-ukforce
Wellcome Trust	https://wellcome.ac.uk/reports/review-ofsted-school-inspection-reports-2017-to-2018
Whole Education	www.wholeeducation.org/about-us/
WISE	www.wisecampaign.org.uk/
International organisations	**Website (url correct at date of publication)**
Brookings Institution	www.brookings.edu/about-us/
Buck Institute/ PBL Works	https://studentsatthecenterhub.org/resource/buck-institute-for-education-bie/
EduChange	https://educhange.com/intsciwhat/
EdVisions	http://edvisions.org/
EU/EC/Joint Research Centre	https://cordis.europa.eu/project/id/244380
GettingSmart	www.gettingsmart.com/its-a-project-based-world/
Institute for Personalized Learning	https://institute4pl.org/
JFF	www.jff.org/what-we-do/impact-stories/supporting-states-districts-to-implement-student-centered-deeper-learning-practices/
LEGO Foundation	www.legofoundation.com/en/what-we-do/research-centre/
McKinsey & Company	www.mckinsey.com/
Mitchell Institute, Victoria, Aus.	www.vu.edu.au/mitchell-institute
OECD	www.oecd.org/education/2030-project/teaching-and-learning/learning/skills/
PBL training institutes and 21stC learning conferences	www.bobpearlman.org/Learning21/pbl_institutes.htm
UNESCO	https://en.unesco.org/themes/education and https://en.unesco.org/futuresofeducation/#s2

Appendix 4: List of schools demonstrating promising practices

School name	Location	Website
Abraham Moss Community School	Manchester	www.abrahammoss.manchester.sch.uk/app/os#!/home
Bedales	Petersfield	www.bedales.org.uk/bedales
Bohunt School	Liphook	www.bohunt.hants.sch.uk/
Chew Valley School	Bristol	www.chewvalleyschool.co.uk/
Copleston High School	Ipswich	www.copleston.suffolk.sch.uk
Cramlington Learning Village	Northumberland	www.cramlingtonlv.co.uk/
Dame Alice Owen's School	London	damealiceowens.herts.sch.uk/
Elthorne Park High School	London	www.ephs.ealing.sch.uk/
Falinge Park High School	Rochdale	www.falingepark.com/
Fred Longworth High School	Manchester	https://flhs.org.uk/wordpress/
Greenhead College	Huddersfield	www.greenhead.ac.uk/
Hayesfield Girls' School	Bath	www.hayesfield.com/
Helston Community College	Helston	www.helston.cornwall.sch.uk/web
Kingsmeadow Community School	Gateshead	www.kingsmeadow.org.uk/
Knutsford Academy	Knutsford	www.knutsfordacademy.org.uk
Ladybridge High School	Bolton	www.ladybridgehigh.co.uk/about
Liverpool Life Sciences UTC	Liverpool	https://lifesciencesutc.co.uk
Matthew Moss High School	Rochdale	www.mmhs.co.uk/
Ralph Allen School	Bath	hwww.ralphallenschool.com/

School name	Location	Website
Saint George Catholic College	Southampton	www.stgcc.co.uk/
Scalby School	Scarborough	www.scalbyschool.org.uk/our-school/
School 21	London	www.school21.org.uk/rwlp
Shireland Collegiate Academy	Smethwick	www.collegiateacademy.org.uk
Sir James Smith's Community School	Camelford	www.sirjamessmiths.cornwall.sch.uk/index.asp
The Academy Grimsby (TAG)	Grimsby	https://academy.grimsby.ac.uk/who-are-we/
The Derby High School	Bury	http://thederbyhighschool.co.uk/
The JCB Academy	Rocester	http://jcbacademy.com
The Judd School	Tonbridge	www.judd.online/
Tonbridge Grammar School	Tonbridge	www.tgs.kent.sch.uk/
UTC Portsmouth	Portsmouth	http://www.utcportsmouth.org
UTC Reading	Reading	www.utcreading.co.uk
UTC Sheffield City Centre	Sheffield	http://city.utcsheffield.org.uk
Wapping High School	London	https://wappinghigh.org/
Wellsway School	Bristol	www.wellswayschool.com/
Westminster Academy	London	www.westminsteracademy.org.uk/
Westminster City School	London	www.wcsch.com/
XP School	Doncaster	https://xpschool.org/

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The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

In collaboration with our Fellows and partners, we're growing talent and developing skills for the future, driving innovation and building global partnerships, and influencing policy and engaging the public.

Together we're working to tackle the greatest challenges of our age.

What we do

Talent & diversity

We're growing talent by training, supporting, mentoring and funding the most talented and creative researchers, innovators and leaders from across the engineering profession.

We're developing skills for the future by identifying the challenges of an ever-changing world and developing the skills and approaches we need to build a resilient and diverse engineering profession.

Innovation

We're driving innovation by investing in some of the country's most creative and exciting engineering ideas and businesses.

We're building global partnerships that bring the world's best engineers from industry, entrepreneurship and academia together to collaborate on creative innovations that address the greatest global challenges of our age.

Policy & engagement

We're influencing policy through the National Engineering Policy Centre – providing independent expert support to policymakers on issues of importance.

We're engaging the public by opening their eyes to the wonders of engineering and inspiring young people to become the next generation of engineers.

Note: All the information included in this document was accurate at the time of publication.

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel: +44 (0)20 7766 0600
www.raeng.org.uk
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