The Journal of Emergent Science

Issue 20 January 2021

The Association for Science Education
Promoting Excellence in Science Teaching and Learning

why & how?
PRIMARY SCIENCE TEACHING TRUST

Contents

Issue 20 January 2021

Contributions

Research Review

Original Research

Research Guidance

Regulars

Editor:
Sarah Earle
s.earle@bathspa.ac.uk

Executive Editor:
Jane Hanrott
janehanrott@ase.org.uk

Cover Photo :
Wellcome: from 'Curious Crown' – a Zoom In Zoom Out activity of a poppy (https://explorify.wellcome.ac.uk/en/activities/zoom-in-zoom-out/curious-crown)

Publisher:
Association for Science Education (ASE) College Lane, Hatfield, Herts, AL10 9AA, UK

ISSN: 2046-4754

The Journal of Emergent Science (JES) is published by ASE in partnership with the Primary Science Teaching Trust (PSTT).

It is free to access for all.

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Editorial

● Sarah Earle

As the new Editor, I am delighted to welcome you to the 20th issue of the Association for Science Education's ***Journal of Emergent Science (JES)****. To briefly introduce myself, I was a primary school teacher in the South West of England for 13 years before becoming a teacher educator at Bath Spa University in 2012. From the outset I have been keen to use and develop research, as a teacher-researcher in the classroom, then as research leader for projects such as Teacher Assessment in Primary Science (TAPS). I am keen to enable maximum dissemination and application of research, so am pleased to take the lead on* ***JES****, an open access biannual e-journal thanks to the support of the Primary Science Teaching Trust (PSTT).*

The aim of *JES* is to bridge the gap between research and practice, so we invite contributions and readership from all early years practitioners, primary school teachers, teacher educators and researchers. My aim as Editor is to draw together research from across the sector, providing support for all those involved in science education for children from birth to 11 years of age. In order to make the writing for, and the reading of, *JES* more accessible, the following new categories of articles have been created:

- ***Original research:*** articles describing both small-scale practitioner research and larger projects are welcome for this section. These articles will include descriptions of how the research was carried out, as well as discussions of findings and literature.
- ***Research review:*** a summary of a larger project or perspective piece reviewing current research in the field. These articles will provide a review of current literature in the field or an accessible summary of research that has been reported in more depth elsewhere.
- ***Research guidance:*** utilising relevant examples to provide support for practitioner research. These articles will consider research processes and methodology, supporting researchers at all levels to reflect on their practice.

For further details about contributing to *JES*, please see the details on page 38. The deadline for the next issue is the end of April 2021 and prospective authors are encouraged to get in touch if they would like to discuss submissions to this or future issues.

This issue begins with two ***Research reviews***. First, **Louise Stubberfield** provides a summary of findings from Wellcome's primary science campaign using data from their 2016-20 reports. She describes a slow increase in the amount of time spent on science in primary schools in England, but also ongoing concerns for teacher confidence in teaching and assessing science. Next, **Gina Rippon** draws upon a wide range of evidence from cognitive neuroscience to consider the origins and impact of gender stereotyping.

She persuasively argues that gendered expectations and behaviours are developed at an early age and, if educators are aware of this, they can counteract the development of negative beliefs about who can and can't do science.

There are two ***Original research*** articles in this issue. **Derek Bell** and **Denis Mareshal** draw together educational neuroscience research on inhibitory control, along with longstanding research on misconceptions and 'wait time', to explore a randomised control trial of a computer-based intervention from the UnLocke Project to support pupils to 'stop and think'.

Next, **Jeannette Morgan** and **Dudley Shallcross** explore the use of sound sensors as a proxy for air pollution in an urban school environment. They argue that, with careful placing of sensors, there is a strong enough correlation between carbon monoxide levels and sound levels to enable the use of sound sensors to provoke primary school discussions and investigations.

Finally, in this issue's ***Research guidance*** article, **Lynne Bianchi** discusses the process of constructing a research frame with her team, to help reflect on their philosophical standpoint and underlying assumptions for research method choices.

The last issue of *JES* (issue 19) began by considering the response to the COVID-19 pandemic and what is now clear is that its impact will be far-reaching and long-lasting. With such a global experience, it may be that now more than ever is the time to share research and practice. It is hoped that this publication can support such collaboration as we all work to support young children's science education.

Dr. Sarah Earle is Editor of the *Journal of Emergent Science* and Reader in Education at Bath Spa University.
E-mail: s.earle@bathspa.ac.uk
Twitter: @PriSciEarle

Slowly does it – using research to improve primary science

● Louise Stubberfield

Abstract

This is a review of primary science in England since 2016 using data from Wellcome's primary science campaign. This article provides a summary, with the full research reports referenced for readers to access further detail. Data suggest that subject leadership for science is slowly being better supported and that schools are increasing the amount of time spent teaching science. Questions are raised still about teachers' confidence in specific areas of subject knowledge and pedagogical content knowledge, as well as assessment of progress in science and the impact that this has on learners. These data are discussed in the current context in which schools, educators and learners find themselves: one where science has increased importance to mitigate the impact of a pandemic.

Keywords: Primary science, subject leadership, subject knowledge

Background

Primary science education has long been characterised by concerns that it is hard to teach, hard to resource and not quite as important as other core subjects (Wellcome, 2014). Since the introduction of the National Curriculum in 1988 for all schools in England, Wales and Northern Ireland, regular reviews have produced very similar recommendations that primary science needs to be improved (for example, Ofsted, 2013). Interventions and reforms that promise exciting new ideas to solve the problem of the moment and raise standards are launched, but, without buy-in from everyone, such interventions have an impact only for a short time and rarely lead to sustained change (Ryder, 2015). While the appetite and will of enthusiasts to champion good primary science has always been strong, it is an ongoing battle to change the overall narrative for primary science. But, why? What needs to be done differently?

Wellcome, an independent international charitable foundation, decided to explore what it might take to improve primary science and launched a campaign to run from 2016 to 2021. However, rather than start with designing interventions to address the widely accepted recommendations, Wellcome first commissioned independent market research to understand exactly what was happening in primary science in England, reaching out to teachers and school leaders, including those who did not identify with science. Using questionnaires, interviews and focus groups, the picture that emerged was complex and concerning.

Although teachers and school leaders recognised that science is important societally and has many benefits for learners, several factors led to science being low on the priority list:

- pressure on school leaders to raise standards exclusively in English and mathematics;
- lack of recognition and support for science subject leaders compared to that for subject leaders in English and mathematics; and
- low accountability for attainment and progress in science.

School leaders often wanted to improve science in their schools, but felt that they had to focus on other areas more urgently. With science having such a low priority, teachers may not have thought that they needed to worry much about investing in it. Consequently, science was often taught through worksheets and was rarely given enough time in the weekly timetable to support good progression. Looking further into teachers' attitudes towards science, it became clear that other factors contributed to their views:

- perceptions that practical science lessons are harder to manage;
- no support in school;
- inadequate or poorly managed resources;
- low confidence in their own science knowledge or how to teach science; and
- perceptions that science is hard and for 'sciencey' people.

The market research also showed that, when primary science was given priority and taught successfully, it was the science subject leader, backed by school leaders, who was pivotal in that success. Wellcome identified that science subject leaders (or their equivalent in all UK nations) were the key audience to secure change (Wellcome 2017a, 2017b).

Wellcome realised that it needed to reach out to teachers to engage them over time and, by working closely with other sectoral organisations, to present a clear pathway of support and development to achieve more and better primary science teaching. Explorify, a free digital tool (www.explorify.wellcome.ac.uk) was created in 2017 to reach teachers who might not usually seek support for science.

Annual monitoring surveys have been used to understand changes and impacts on primary science education during the campaign. This paper reviews the state of primary science education in England from 2016 using data collated from the annual evaluation and monitoring.

As we review the data, we must consider the current context in which schools are operating. From late March 2020 until the start of the 2020-2021 academic year, learners were not in school due to the Coronavirus pandemic and their access to quality teaching was limited. Although schools worked hard to support home learning and many organisations across the science education sector adapted quickly to provide free support, the experience for many pupils will have impacted negatively on their learning and progress (Education Endowment Foundation (EEF), 2020), particularly in science (Canovan & Fallon, 2020). Learning will continue to be disrupted until the pandemic is controlled, and school development priorities will need to be adjusted accordingly.

Methodology

Wellcome commissioned CFE Research to undertake independent evaluation providing information on the state of primary science throughout the UK over the period of the campaign (2016-2021). Methods included the use of computer-assisted telephone interviews, online surveys, depth interviews, study visits and pupil surveys.

Baseline research

Baseline research carried out in 2016-2017 (for detailed methodology, refer to Wellcome, 2017b) with schools throughout the UK comprised:

- computer-assisted telephone interviews with 902 science leaders (or equivalent);
- online teaching survey completed by 1010 teachers;
- 50 depth interviews; and
- pupil surveys.

Key questions addressed the amount of time spent teaching science and how the curriculum is delivered, leadership of science, views and perceptions of primary science, including teachers' confidence.

Interim evaluation

Evaluations carried out in 2018/19 (Wellcome, 2019) and 2019/2020 (Wellcome, 2020a) used the same type of data collections and analyses as the baseline, but sought to understand key questions about teaching of science in England only (see Table 1 on the next page).

Table 1. Data collection.

	2018/2019 evaluation England only	2019/2020 evaluation England only
Computer-assisted telephone interviews	683 science leaders	831 science leaders
Online teacher survey	713 teachers from 274 schools	421 teachers from 204 schools
Semi-structured interviews	36	32
Case study visits	4 schools	Deferred to 2021

In 2020, data collection was impacted slightly by the COVID19 pandemic. At the time of school closures, the online teaching survey was incomplete and case study visits could not be completed. Teachers who completed the online survey after school closures were asked to refer to their practice prior to the lockdown. The data are statistically robust, even though fewer online surveys were completed compared with the previous years.

Results

Data below (Table 2) have been collated from the baseline report (Wellcome, 2017b) and interim evaluations (Wellcome, 2019, 2020a) to show trends for schools in England. These data relate to how schools lead and deliver science in school through proxy indicators including time allocated for teaching, support for science leaders and their access to professional development (PD) and support for teachers.

Table 2. Key indicators for science delivery and leadership in school (Wellcome 2017b, 2019, 2020a).

	2016/2017	2018/2019	2019/2020
Proportion of schools including science in school development plan	60%	56%	62%
Proportion of schools with science subject leader	95%	93%	98%
Average science teaching time, statutory primary-age pupils, per week	1.7 hours (1 hr 42 min)	1.8 hours (1 hr 48 min)	1.85 hours (1 hr 51 min)
Proportion of schools providing at least two hours science per week	43%	49%	53%
Percentage of science leaders having dedicated management time	52%	49%	61%
Percentage of science leaders accessing professional development for science leadership or school development	52%	54%	57%
Percentage of teachers not receiving any support in school for science	31%	15%	9%

Figure 1. Percentage of respondents reporting high levels of confidence.

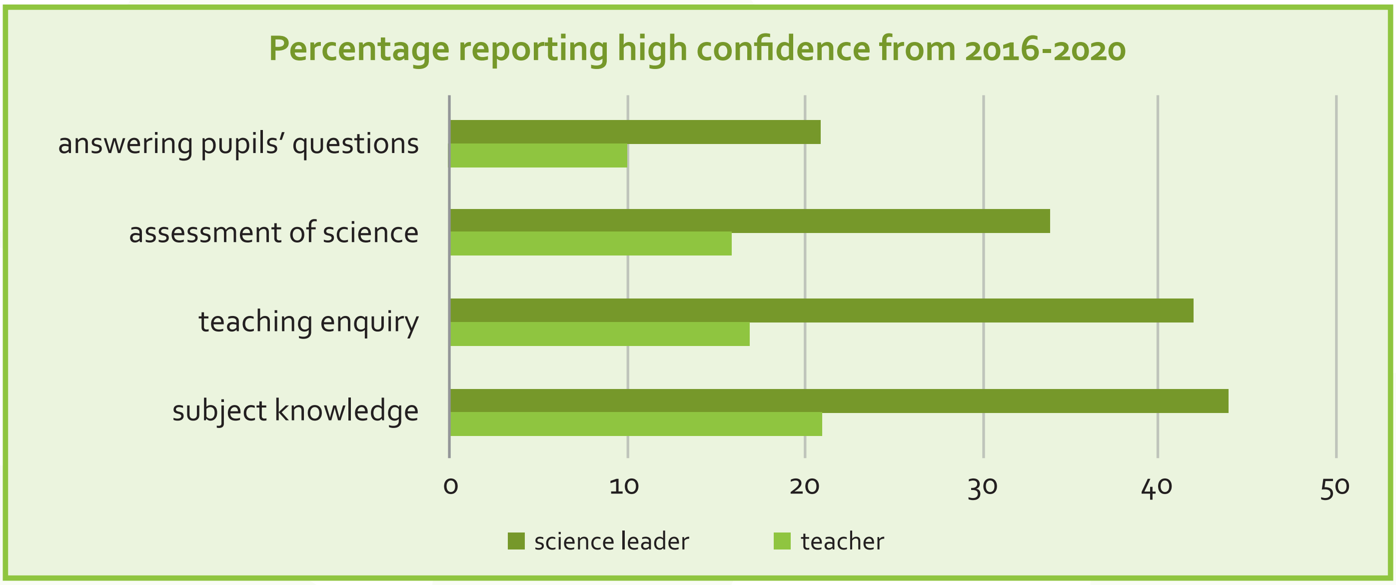
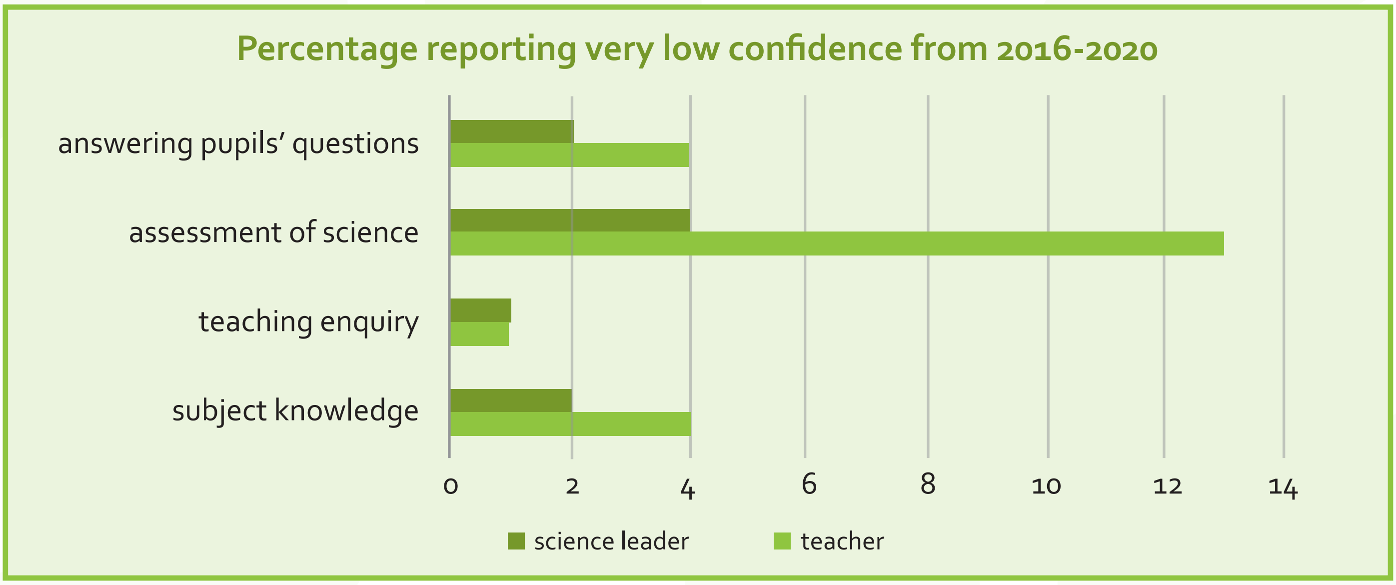


Figure 2. Percentage of respondents reporting very low levels of confidence.



Neither subject leaders' nor teachers' levels of confidence in aspects of teaching science varied significantly over the three surveys. Subject leaders were more confident than teachers in all areas: science subject knowledge, teaching scientific enquiry, undertaking science assessment and answering pupils' questions. More than a fifth of science leaders have high levels of confidence in these areas (Figure 1).

Table 3. Proportion of teachers reporting low levels of confidence in teaching some science topics.

Science topic	2016/17	2018/19	2019/20
Electricity	12%	11%	15%
Light	12%	9%	12%
Forces	16%	14%	12%
Evolution	23%	21%	21%

Although teachers had indicated in market research that they lacked confidence in teaching science, this was not strongly apparent except in relation to assessment (Figure 2 on page 8).

Exploring levels of confidence around teaching specific science topics showed some anxieties around teaching evolution, electricity, forces and light (Table 3 on page 8). Further exploration showed that teachers were unsure of their subject knowledge and pedagogical content knowledge (for further discussion, see Welcome 2020a).

Conclusions

Although school leaders agree that it is important for pupils to study science and that scientific skills are transferable (Wellcome, 2017b), the priority given to science in schools is varied. Less than two thirds of schools included science in their school development plan, even though the importance of a balanced and relevant curriculum (including science) has become more prominent since Ofsted revised its inspection framework (Ofsted, 2019). Despite this, there are indications that some aspects of provision for primary science are improving.

It could be argued that the average amount of time given to teaching science in 2016 was unlikely to be enough to secure good progress. By 2020, the number of schools providing at least two hours' science teaching per week has increased by 10% to more than half, and the average time allocated to teaching has increased by nine minutes. However, the timetable allocation is not as important as making sure that science teaching time is used effectively (for further discussion, see full report, Wellcome, 2020a). For example, around two fifths of schools using Explorify reported that they had increased the amount of science teaching because they had included Explorify activities at other times in the teaching week, but others advised that Explorify has helped them make better use of their teaching time as they've improved their understanding of children's prior knowledge:

'The difference is that two hours will be more useful and more meaningful because you're not going over things the children already know' (Wellcome, 2020a).

In England, most schools have a science subject leader and there is strong evidence that science leaders are being given more opportunities for professional development and more meaningful management time for their roles. Many are confident in their role and able to support their colleagues. More than half the teachers reported that science leaders in their schools provide training or coaching and mentoring to help them to teach science better. Since 2016, the proportion of schools that offered teachers no form of support at all for science dropped from 31% to 9%.

Teachers self-report that they are mostly confident about teaching science. However, some have anxieties about teaching certain topics of science, especially forces, light, electricity and evolution. There has been little change in the proportion of teachers who report low confidence in teaching these topics (up to 20%) since 2016. Over one-eighth of teachers report low confidence in assessment of science too, which is also concerning.

Discussion

Primary science provision is improving slowly. Teaching English and maths has always taken priority in schools, but science must have a secure place within a balanced curriculum that prepares pupils for their futures.

The Coronavirus pandemic has put science in the spotlight, but we know that many young people do not see that science is relevant to them (Wellcome, 2020b) and 44% of primary pupils think you have to be clever to be able to do science (Wellcome, 2017a). The pre-campaign market research undertaken by Wellcome indicated too that many teachers simply do not identify with science, so it may be harder for them to build engagement in science with their pupils. Those of us working in the science education sector need to be mindful that our provision is accessible, especially to those teachers who do not see themselves as 'sciencey', so that they can enjoy teaching science. Wellcome's research shows that enjoying teaching science is key to building teaching confidence (Wellcome, 2020a).

More than ever it is vital that children in primary school understand how we use science in all aspects of our lives and that it is relevant for everyone. Making enough time for science rather than leaving it to a weekly slot in the timetable, embedding it fully in the curriculum and linking it to everyday life are essential.

Persistent low levels of confidence in teaching key science topics are concerning. These topics may not be highlighted in the national curriculum for every year group (DfE, 2013), but it is essential that all teachers understand where the science they teach fits in with children's progression in all aspects of science.

Low confidence in assessment (formative and summative) was also flagged by science leaders and teachers. Assessment is integral to good teaching and should be part of the planning process, not a process added on afterwards. The data on low confidence suggest that a sizeable proportion of teachers lack understanding of how children progress in science and that processes in schools are not supporting continuity of learning in science. Schools should audit professional learning needs and make them part of the school development plan.

The positives for primary science come from effective science subject leadership. As Wellcome identified at the outset, subject leaders are the drivers of improvement in primary science. Those new in role have found the support from the sector invaluable. These are teachers and leaders actively seeking to access provision and support that they expect will make a difference in their schools, rather than having change or an intervention imposed upon them, which leads to long-lasting impact (Hubers, 2019). Without recognition, support or mandate from school leaders themselves, the science leader is likely to achieve little or be able to support their colleagues, so it is encouraging that provision to lead science and access to professional development have increased.

Improvement in primary science has been hard fought. To sustain the improvements, the science education sector must continue to support schools to invest in subject leaders (Wellcome, 2017a) and ensure that science isn't just for the brave, but underpins all of our daily lives.

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Louise Stubberfield, Primary Science Programme Lead, Wellcome Trust.
E-mail: l.stubberfield@wellcome.org

A window of opportunity: a neuroscience perspective on the gender stereotyping of science in the early years

• Gina Rippon

Abstract

21st century neuroscience research has revealed the link between key aspects of brain development and the very early emergence of social awareness in young children. This includes evidence of gender detection and processing in children as young as two years old, followed over the next three to four years by gender alignment and gender compliance. Increasing focus on the effects of gender stereotyping in these early years has led to consideration of the role of primary education in many aspects of gender socialisation and their potentially limiting consequences.

One such issue is the claim that the under-representation of women in STEM (Science, Technology, Engineering and Mathematics) is linked to the effects of certain gendered stereotypes about science and scientists, with evidence that the origins of gender imbalances in science subjects may be found in very early developmental experiences and expectations.

This paper outlines a temporal framework linking brain development to key stages of gender processing and of children's endorsement of gender stereotypes in science.

Keywords: Gender stereotypes, brain development, STEM (Science, Technology, Engineering, Mathematics), gender awareness, science stereotypes

Introduction

Worldwide, technological innovations mean that we have a greatly increased need for specialists in STEM (Science, Technology, Engineering, Mathematics) subjects. This demand is not being matched by supply (President's Council of Advisors on Science and Technology, 2012). The problem is compounded by the fact that women, 49.7% of the world's population, despite clear evidence of aptitude and ability for science subjects, are not choosing to study STEM subjects, are not being recruited into the STEM workforce, and are not staying in the STEM workplace. Globally, women account for less than a third (29.3%) of those employed in scientific research and development (Unesco, 2019).

Why don't women do science? Historically, an early explanation suggested that women were 'constitutionally' unsuited to the rigours of science education and practice and/or that they were innately deficient in key brain-based cognitive skills. Decades of research have, as yet, been unable to establish a consistent basis for such claims. Additionally, sophisticated performance measures have indicated that there are few or no sex differences in key measures of science-based skills, or that apparent innate sex differences are actually related to stereotype-driven differences in relevant learning or training opportunities. But the fact remains that girls *don't* do science, are *choosing* not to do science, as the statistics above indicate. Attempts to address this problem in the educational arena have commonly focused on secondary schools (WISE, Institute of Physics), but research indicates that determinants of this eventual choice can be found very early on in girls' educational journeys, involving key phases of brain development linked to the emergence of stereotyped beliefs and behaviour.

Gender[1] gaps? Blame the brain

A continuing challenge to any attempts to address gender stereotypes (in any arena, at any age) is the deeply embedded belief that gender gaps (in any arena, at any age) are actually a measure of innate processes, predetermined, inevitable and invariant (Eagly & Wood, 2013). Social and cultural differences have been afforded limited power in explanatory models of gender gaps; indeed, the more traditional biological determinist views suggest that such differences were actually a reflection of biological factors. In science, for example, the 'essentialist' view suggested that female brains did not endow their owners with the appropriate portfolio of cognitive skills or personal attributes; access to education was not considered relevant (Schiebinger, 1991).

This approach is dramatically undermined by the lack of any consistent evidence that the brains of women and men, of girls and boys, are, in fact, different. Despite decades of research into these alleged differences, it is clear that female and male brains are more similar than they are different, and that explanations of gender gaps (in any arena, at any age) need to look beyond simplistic, unidirectional models based on sex-determined differences in the brain (Rippon, 2019).

Developments in 21st century neuroscience now afford a more powerful role for *external* factors in determining brain development and function, by demonstrating that socially or culturally determined rules, experiences and expectations can bring about significant changes in the brain.

BrainWorks – the three Ps: predictive, plasticity and permeability (Rippon, 2020)

It is now known that brains function rather like '***predictive*** texters', proactively extracting patterns and rules of behaviour from the outside world to guide appropriate or successful behaviour (Friston *et al*, 2014). These can include social rules, such as an understanding or prediction of how people might react in a particular situation, or the characteristics associated with particular identities (including your own) (Frith & Frith, 2010; Tamir & Thornton, 2018). This predictive coding process in the brain is supported by intricately connected networks or circuits, formed during key periods of brain development, especially the early years (Gao *et al*, 2017). These periods of maximal connectivity development in the brain are therefore associated with the emergence of high levels of rule-gathering behaviour, including social behaviour (Gotts *et al*, 2012).

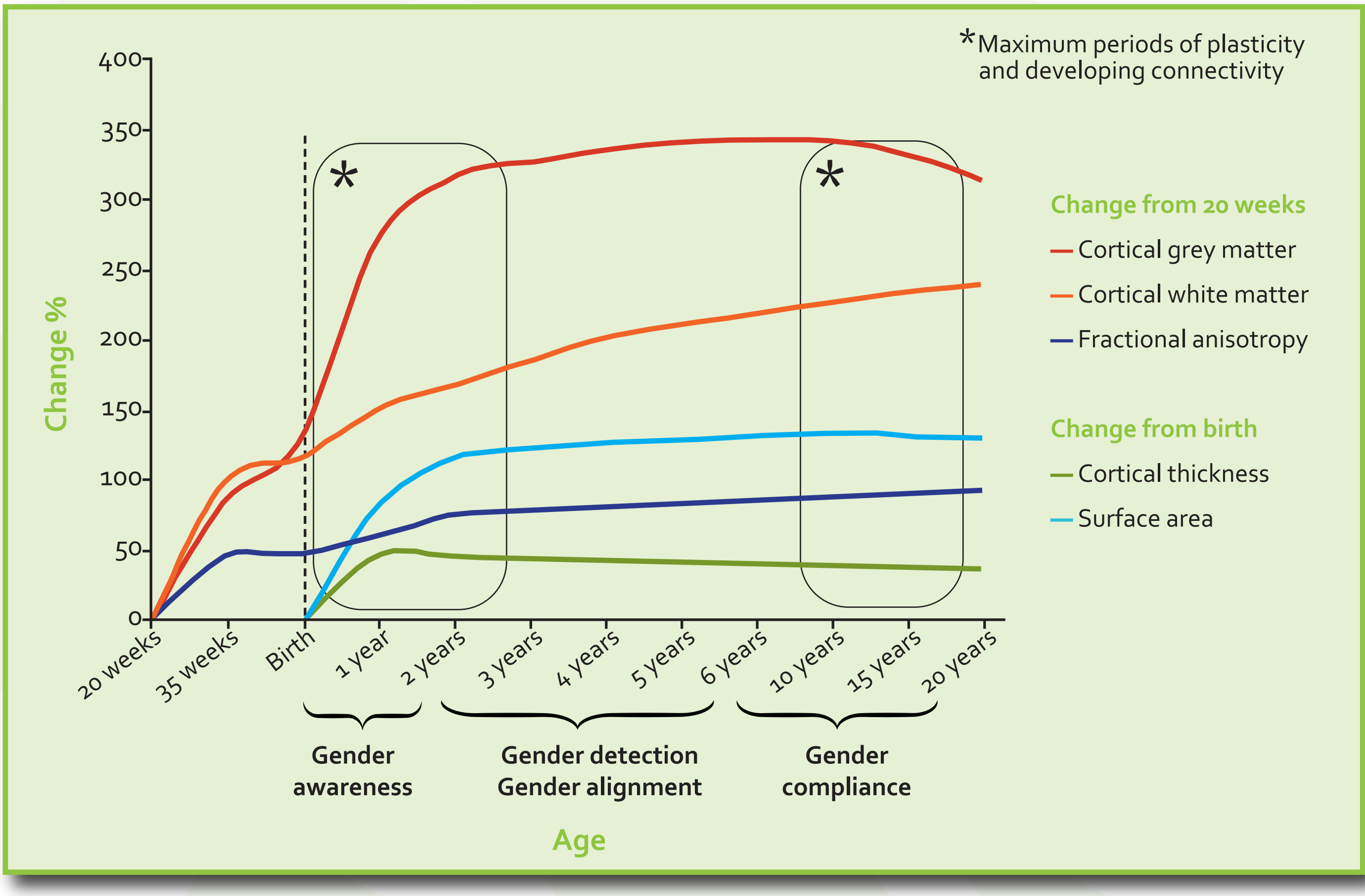
Similarly, these are periods of maximal ***plasticity***, of variation in key structural and functional development associated with variations in learning opportunities and experiences. An early focus was on marked developmental deficits associated with extremes of, for example, deprivation or disease (Chugani *et al*, 2001). But recent work has identified more subtle brain-based differences in typical development linked to early experience, such as opportunities for second language learning. Just as there are sensitive periods in sensory or motor development, it would appear that there are similar optimal periods associated with the benefits of more general, cultural opportunities (DeHaene, 2020).

In adults, the brain's ***permeability*** to social context, the attitudes and expectations associated with human social behaviour, have also been identified. Brain-imaging studies have shown that negative stereotyped beliefs associated with specific abilities (for example, females are poor at spatial thinking) are associated with lower levels of performance and altered brain activation (Wraga *et al*, 2007). In children, a similar effect has been demonstrated with specific negative self-beliefs, such as maths anxiety (Young *et al*, 2012).

This newer understanding of the interactive relationship between brains and external social factors can provide a framework for understanding the role of gender stereotypes in establishing (and maintaining) gendered patterns of behaviour in young children. Exposure of an exuberantly rule-gathering, experience-dependent brain to a firmly rule-based system of experiences and expectations provides a fertile substrate for the formation of potentially lifelong patterns of beliefs and behaviours.

[1]There is considerable debate concerning the appropriate use of the term 'gender' as opposed to 'sex'. The former is generally considered to be a cultural construct, referring to social norms and roles, whereas the latter is taken to refer to biologically determined characteristics of females and males. Although the entangled nature of these two concepts is acknowledged, the term 'gender' will be used here to refer to the processes being examined.

Figure 1. Figure 1 shows a mapping of periods of brain structural development against the emergence of key stages of gender processing (adapted with permission from Gilmore, J.H., Knickmeyer, R.C. and Gao, W. (2018), 'Imaging structural and functional brain development in early childhood', *Nature Reviews Neuroscience*, **19,** (3), p.123. Guilford Press).



Applying this model to the emergence of gender stereotypes with respect to science and scientists, specifically of stereotypes as to who does and does not do science, could identify key time windows in the origins of this problematic bias.

Brain development and social processing

As a result of 21st century developments in imaging brain development in babies and young children, we now have a detailed window into the nature and timescale of early structural changes in the brain. These can then be mapped against a timetable of behavioural changes/phases of interest, to identify potentially sensitive periods in the establishment of such behaviours, where identified relevant factors could be maximally effective.

Early on, links between early brain development and developing infant behaviour focused on emerging cognitive skills such as perception and language. More recently, attention has turned to early social skills, such as the differential recognition of a caregiver's face or voice or an understanding of different types of affective information (Simion & Giorgio, 2015). Accumulating evidence indicates that infants and young children are capable of highly sophisticated social processing, demonstrated by evidence of activation in key areas of the social brain, previously assumed to be functionally silent in very young children (Grossman, 2013). It is now known that such social processing can include, from a very young age, an awareness of gender differences and, only slightly later, their social significance (Martin & Ruble, 2004).

Gender processing: key stages

a. Gender awareness

With respect to early signs of gender awareness, children as young as six months have been shown to register normal gender differentiators, responding differently to 'gender inconsistencies' such as a high-pitched voice matched with a male face (Poulin-Dubois *et al*, 1994). By two years old, awareness of more socialised inconsistencies has been demonstrated, with toddlers' attention significantly captured by, for example, images of men putting on lipstick (Poulin-Dubois *et al,* 2002). Similarly, toy choice studies have shown that it is at this age that sex differences in response to gendered colour coding become evident, with boys actively rejecting pink toys (LoBue & DeLoache, 2011).

b. Gender rules – identification and alignment

By two years old, gender cues have been registered and are starting to affect behaviour (Martin & Ruble, 2004). This marks the onset of the 'gender detection' phase, linked to the emergence of gender identity, where young children appear to seek out ways of appropriately allocating a gender to whatever they find in their world, be it other children, adults, clothes, toys, games. This parallels the early stages of predictive coding in brain development as outlined above, where emerging patterns of connectivity support the development of rule-based perception and cognition.

The causal power of stereotyped gender cues in children's gender questing activity has been demonstrated in 3-5 year-olds by observing the effect of gender coding on previously neutral objects. Requested to sort objects such as melon ballers or garlic presses that had been painted pink or blue into 'for boys' or 'for girls' categories, the children firmly followed the pink-blue divide in their choices. Modelling had a similar effect – having watched videos showing either males or females using a range of neutral objects, children again sorted these objects according to who used the items, rather than what they were used for (Weisgram *et al,* 2014).

Gender detection is also commonly associated with gender alignment and can be a time of quite fierce gender policing around, for example, the dressing-up box. Girls in particular can demonstrate firm views as to what is appropriate for them to wear – labelled as the 'pink frilly dress' phenomenon (Halim *et al,* 2014). It is also a phase where naïve logic linked to occupational stereotypes can be observed, commonly reflecting everyday experiences (my bus driver is a man, so only men can be bus drivers), or in response to the kind of modelling effects demonstrated with toys; gender bias in images of males or females occupying different roles can lead to 'stereotype endorsement' of the 'women are nurses, men are scientists' kind. Such beliefs in the gender divide in adult occupations have been illustrated at this age by examining children's drawings of, for example, fighter pilots or nannies, and registering their astonishment when presented with counter-stereotypical examples (Redraw the Balance, 2016).

Research has shown that occupational stereotypes about scientists are a major part of the gender lexicon acquired by early years children. For example, the draw-a-scientist test has been a popular source of demonstrating clearly biased stereotypical views among young children (Finson, 2002). Such beliefs may be compounded by science educational resources themselves. A recent visual content analysis of over two thousand online primary science resources showed that, with respect to the depiction of science professionals, 75% of images were of males (Kerkhoven *et al,* 2016). In children's science books, women are significantly under-represented, particularly in physics and maths (Caldwell & Wilbrahim, 2018).

Stereotypical endorsement of different occupations is associated with the next stage of gender compliance, of children linking their gendered self-identity to a gender-related social stereotype in accordance with models such as Gender Schema Theory (Starr & Zurbriggen, 2017) or Social Role Theory (Eagly & Wood, 2016). By the age of about five and a half to six years onwards, there is evidence that children have categorised different occupations as female or male and align their future ambitions and expectations accordingly (Martin & Ruble, 2004).

This gender alignment effect divide can also be shown in children's views of their own relevant abilities and skill sets. By the age of seven, girls have been shown to be significantly less likely to support the notion that girls (i.e. their own sex) are 'really really clever' (Bian *et al,* 2017). Linked to the notion that science is only done by 'really really clever people', the stereotype of science as 'not for girls' can swiftly be established. Girls as young as 6-7 years old believe that maths is a 'boy thing' and that they would therefore be unlikely, in the future, to engage with maths or maths-related activities (Cvencek *et al,* 2011).

c. Gendered experiences – XX/XY or X-box?
Toys have proved to be a powerful battleground in research into explanations of emerging gender differences in children. The apparently fixed preferences among girls for dolls, pink paraphernalia and fantasy worlds, and among boys for mechanical objects, construction kits and guns, have been claimed as supporting evidence for both the 'nature' and the 'nurture' camp. The former claim that this gender bias is related to innately-determined and evolutionarily significant caring or nurturing roles for girls and constructionist, competitive roles for boys; the latter nominate socially-determined role stereotyping and/or market-driven forces firmly steering previously neutrally-minded children down a pink-blue divide (Fine & Rush, 2018). A detailed examination of the evidence in support of either side is beyond the scope of this paper, but the relevance of investigating a gendered toy divide in an understanding of science stereotypes is to note the differential training opportunities and experiences that play can give young children.

Cognitive neuroscience studies have shown that experience with games such as Tetris or Super Mario can not only improve spatial performance in young adolescents, but also alter associated brain structure and function (Haier *et al*, 2009; Kuhn *et al*, 2014). And apparent sex differences in spatial ability have been shown, in reality, to be a function of spatial experience with childhood toys and hobbies such as videogame playing (Terlecki & Newcombe, 2005). Given that spatial ability has been identified as a core competency in science (Wai *et al*, 2009), any gender bias in experience of or access to relevant 'training' opportunities, for example via play, can impact on the development of spatial skills. Using the Preschool Occupations, Activities and Traits scale in 4-5 year-olds, researchers showed that, even at this young age, there was evidence of stereotyped beliefs that boys would be more likely to play with LEGO blocks and would be better at using them (Shenouda & Danovitch, 2014).

d. Gendered attitudes – the not-so hidden truths
Noting the differential values associated with the different genders is also part of the rule-gathering activities of developing brains. The different attitudes and expectations, both conscious and unconscious, of adults about what is appropriate for, or expected of, girls or boys has been well documented. And children show a very early awareness of this. In a small-scale study, 3-5 year-old girls and boys were asked to identify toys as 'for girls' and 'for boys' and then asked which toys their parents would like them to play with (Freeman, 2007). There was clear agreement among the children as to which toys were for boys or for girls and, more significantly, of the level of parental disapproval of playing with cross-gendered toys – for example, only 9% of 5 year-old boys thought that their fathers would approve of them playing with a doll or a tea set. (A twist to this study was that the parents of these children were also being asked about their agreement or disagreement with gender stereotypes. One finding was that between 60% and 90% of parents indicated their disapproval of the gendering of toys or activities.)

With respect to parental attitudes about gender and science, endorsement of science as 'for boys' is also well documented (Mulvey & Irvine, 2018). More negatively, specific identification of science as 'not for girls' is also evident (Archer *et al*, 2013). A parallel thread to this is the relationship between the STEM-excluding consequences of maths anxiety, more common in girls, and the attitudes to maths found in parents, especially mothers (Gunderson *et al*, 2012).

It has also been shown that, in the early years, teachers' stereotyped beliefs can indirectly contribute to gender gaps in engagement with science. A longitudinal study examined the effects of teacher estimates of science ability at primary school level. Evidence of gender bias was clear, with teachers over-marking boys and under-marking girls. This bias score was then found to have a significant causal effect on subsequent choice of science subjects in later educational stages (Lavy & Sand, 2015).

Challenging stereotypes – the role of early years and primary science?

21st century developmental cognitive neuroscience indicates that early childhood is a key developmental window in which stereotypical beliefs and behaviours become established, in parallel with a heightened period of plasticity and connectivity in brain development. This underpins key processes in social behaviour, such as responsiveness to coded social rules, self-categorisation according to perceived social norms, and avoidance of stereotypically proscribed activities or events. An awareness of the differential values attached to stereotypically distinct groups or behaviours is also evident in these early years. In just the same way that the self-organising experience-dependent nature of the developing brain makes it vulnerable to gender stereotyping, its very plasticity and mouldability in the early years offers the opportunity to counteract the negative effects of such stereotyping. So, primary education offers an effective forum in counteracting the development of negative sets of beliefs about who can and can't do science, and why. Challenging the *status quo* and the rules, offering counter-stereotypical examples and experiences, and carefully monitoring negative attitudes can all have a moderating effect and prevent stereotypes from becoming fixed and unchangeable (Olsson & Martiny, 2018). Hopefully this can set firm foundations for later initiatives to encourage greater engagement with science.

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Professor Gina Rippon, Aston Brain Centre, Aston University.
E-mail: g.rippon@aston.ac.uk

UnLocke-ing learning in maths and science: the role of cognitive inhibition in developing counter-intuitive concepts

● Derek Bell ● Denis Mareschal ● The Unlocke Team

Abstract

Children (and adults) all hold misconceptions that often interfere with learning and are particularly challenging in developing counter-intuitive concepts in science and maths. In this paper, we first draw on findings from educational neuroscience to provide insights into the role of cognitive inhibition in relation to overcoming misconceptions. Then we report on the UnLocke (Stop and Think) Project, which aimed to develop a computer-based intervention to encourage children to engage their inhibitory control and improve their performance in maths and science. It was important that the intervention should be accessible and workable in the classroom as part of 'normal' teaching. The main trial was a randomised control trial and, based on an independent evaluation, revealed that children in the Stop and Think intervention group made on average the equivalent of one additional month's progress in maths and two additional months' progress in science compared to children in the control group. Implications and limitations of these findings are discussed.

Keywords: Counter-intuitive concepts, cognitive inhibition, inhibitory control, mathematics achievement, misconceptions, science achievement, technology-enhanced learning

Introduction

Teachers of young children are very familiar with the idea of 'misconceptions'. Almost on a daily basis, pupils express ideas that might be considered 'wrong' or 'illogical', or both. These ideas are commonly experienced in science and mathematics where many of the concepts are counter-intuitive. Helping children to develop their understanding of such concepts is a significant challenge.

There is a vast array of research that has explored children's and young people's ideas in relation to concepts in science and maths (e.g. SPACE Project, 1991-1994). The majority of studies, particularly earlier ones, focused mainly on identifying the types of responses that children give to particular tasks and questions. The interesting thing about the findings is that, regardless of age, we all hold misconceptions and this isn't only in science and maths. Moreover, many of the misconceptions expressed are quite consistent across age ranges and cultures. Such findings raise many questions, but principally four in the context of this paper:

- What causes misconceptions?
- How does the brain deal with misconceptions?
- What happens to misconceptions when children have been 'taught' the 'right' answer?
- How might teachers help children (of all ages) to overcome their misconceptions?

Drawing on research into the way the brain functions with regards to the mechanisms of learning counter-intuitive concepts (Mareschal, 2016), we address the first three questions. We then present the findings of the UnLocke (Stop and Think) Project, which was designed to investigate the fourth question.

What causes misconceptions?

In broad terms, a misconception is an explanation of an idea, which, at least on the surface, appears to be incorrect and does not align with the accepted explanation or answer to a question. Young children, for example, will often think of 'fire' as being 'living' because of the way it moves. Similarly, they might think of one quarter (1/4) as being bigger than one half (1/2) because '4' is bigger than '2'. More sophisticated misconceptions occur as children encounter new events, phenomena and ideas. For example, when two objects of the same size and shape are dropped together from the same height, many children (and adults) would say that the heavier one will hit the ground first. In fact, the objects will do so at the same time.

Misconceptions can arise from several sources. Those resulting from the application of everyday experiences and observations to explain phenomena are often referred to as 'preconceived'. For example, although we know the Earth is a sphere and therefore the surface is curved, to the naked eye standing on a football pitch it appears to be flat. To make the leap from 'flat' to 'round' requires a change in thinking and perspective. Vernacular misconceptions tend to come from the use of everyday language leading to misunderstanding in the use of words and phrases in relation to subject-specific contexts. Perceptual misconceptions result in large part from the lack of careful observation and perception of the way in which objects interact. Much more difficult, conceptual misconceptions arise with more abstract ideas and understanding of concepts, such as why the two objects hit the ground at the same time.

What is particularly important to recognise is that misconceptions are a part of the learning process. Whilst they may be regarded as 'incorrect' or 'illogical', they are in fact steps along the way of children (and adults) making sense of phenomena and ideas with which they are unfamiliar. This is one of the reasons why other terms such as 'naïve theories' (Gelman & Noles, 2011) and 'alternative frameworks' (Nussbaum & Novick, 1982) are used by some researchers.

How does the brain deal with misconceptions?

Learning takes place through the formation of networks of cells in the brain. Each experience triggers brain activity and, when repeated, this same activity reinforces the pathways and connections in the brain. Thus, it develops memory and the ability to carry out a range of tasks, both physical and mental, as part of the learning process. In young children many connections are made as they explore their environment and begin to relate things to one another. As their level of exploration deepens, children begin to: build up a bank of evidence and knowledge of the world; understand the processes involved in generating the evidence and knowledge; and develop conceptual frameworks that enable them to better understand phenomena, ideas and the relationships between them. Ultimately, this is what education is trying to support children to do – we call it learning!

Learning in science and maths, as in other subjects, depends on the use of the executive functions (EFs), which are associated with the pre-frontal cortex (PFC) of the brain and relate to three core processes: inhibitory control, working memory and cognitive flexibility (Diamond, 2013). All these activities contribute to the process of reasoning, which helps to, for example, make sense of perceptual observations in relation to existing ideas, and develop and test hypotheses through interpretation of evidence in the light of existing theories. Although the PFC is the last part of the brain to mature fully, usually in late adolescence or early adulthood, young children with support start developing their reasoning skills from an early age.

Evidence from brain-imaging studies suggests that, when the new evidence or idea is consistent with existing knowledge, it is handled through one type of neural pathway. However, if the new evidence is inconsistent with existing knowledge, another pathway is triggered that involves two particular areas of the brain: the anterior cingulate cortex (ACC), which identifies the inconsistency, and the dorsal lateral pre-frontal cortex (DLPFC), which, through the use of EFs, attempts to resolve the problem. A key element in the resolution is the process of cognitive inhibition (or inhibitory control), which is also an important factor in cognitive development more generally. Inhibitory control is used to suppress the inaccurate prior knowledge and/or the intuitive responses that are in conflict with the new evidence (Brault Foisy *et al*, 2015). This suggests that, in order to help children overcome their misconceptions, they need to be supported to engage their inhibitory control, begin to recognise possible inconsistencies in their reasoning and consider alternative explanations.

What happens to misconceptions when children have been taught the right answer?

At first sight it might appear that addressing misconceptions is straightforward: identify the incorrect idea and then correct it by explaining the 'right' answer. However, as teachers well know, it is not as easy as that. So, what happens to misconceptions?

Initially it was thought that once the 'correct' explanation was 'learnt' the incorrect idea disappeared from memory. This view became modified to suggest that the misconception is altered in some way so that it is closer to the 'correct' answer. However, there is now convincing evidence that misconceptions are very resistant and are largely retained. This is why we, without thinking, occasionally give the 'wrong' answer when we know it is not correct. The evidence comes both from behavioural studies (Shtulman & Valcarcel, 2012) and, importantly, brain-imaging work (Masson *et al*, 2014). The latter demonstrates that, when faced with counter-intuitive situations, experts in the field show significantly more activity in those areas of the brain that are associated with cognitive inhibition than do novices. In other words, misconceptions do not go away, but inhibitory control is required to suppress the pre-existing ideas, even in the minds of experts in the field, in order to come to a 'correct' answer.

How might teachers help children (of all ages) to overcome their misconceptions?

The UnLocke (Stop and Think) Project (see www.unlocke.org for more details) was one of six projects funded by the Education Endowment Foundation and the Wellcome Trust to explore insights from neuroscience on learning (EEF, 2014). The challenge was to develop an intervention that would be accessible and workable in the classroom as part of 'normal teaching'. Importantly, the emphasis was on developing an approach that encouraged children to use their inhibitory control in the context of a particular subject domain. It was not attempting to 'teach' cognitive inhibition *per se*. This was because the evidence indicates that teaching EF such as inhibitory control in isolation may improve performance in the specific context, but there is then little or no transfer of that ability to other situations (Diamond & Ling, 2016). Therefore, UnLocke encourages children to use their inhibitory control skills (whatever level that may be) in the context of solving maths and science problems.

❐ *The UnLocke project: design and method*

The UnLocke Project was conceived as a randomised control trial to test specially designed software that aimed to improve pupils' ability to inhibit irrelevant prior knowledge when faced with a range of problems and concepts in maths and science. The project went through 3 main phases: the first to develop the software, assess the logistics of a large-scale trial and pilot the data collection processes (Wilkinson *et al*, 2019); the second was the main trial; and the third, analysis of the findings. A key requirement of the design was that the outcome of the project was assessed by an external evaluator and not the researchers themselves. This was to maintain the highest possible transparency of the findings.

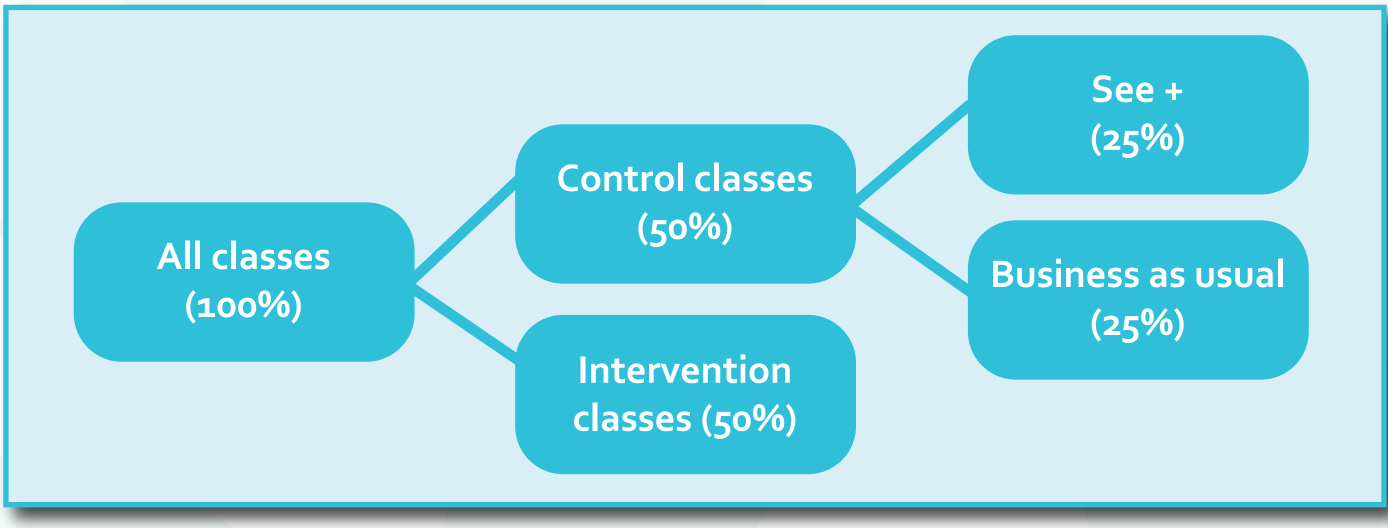
The trial involved 89 schools across England and 6,672 children, approximately half in Year 3 (age 6) and half in Year 5 (age 9). Approximately 16% of the children were eligible for free school meals (FSM). The randomisation was based on classes, so that 50% of the classes undertook the main intervention (Stop and Think – SaT) and the other 50% were control classes. The control classes were then divided between a 'passive' (Business as Usual – BaU) control (25% of the total) and an 'active' control (SEE+) (25% of the total) (Figure 1 on page 22). BaU classes simply followed their normal science and maths lessons, whereas the SEE+ classes undertook a computer-based activity that related to PSHE. The reason for the active control was to account for what are known as the Hawthorn and Placebo Effects to minimise the risk of identifying an impact simply due to children being engaged in a novel computer-based activity.

Allocation of classes was done by the evaluator in such a way as to ensure that every school had at least one class involved in an active intervention, either SaT or SEE+. This aimed to ensure that schools remained in the trial and completed the necessary data-gathering activities.

The main trial was run over a period of 10 weeks in which the teacher-led interventions were undertaken 3 times a week for 12 minutes, at the beginning of a maths or science lesson.

The software was designed around the concept of a TV game show, hosted by a character called Andy, with 3 contestants (Figure 2a on page 23).

Figure 1. Randomised allocation of classes.



NB: The percentages relate to the proportion of the total number of classes involved in the trial. Allocations were done by the evaluator so that all schools had an active class, e.g. Year 3 intervention but Year 5 Business as Usual; Year 3 Business as Usual but Year 5 intervention; Year 5 intervention and Year 3 See+.

A series of pre-determined questions were posed based on known misconceptions in science and maths. The topics were drawn from the appropriate stages of the English National Curriculum. Led by the teacher, children engaged with Andy who asked a question, at which point the software was locked and a symbol (Stop and Think Hand, Figure 2b on page 23) appeared so that children were prevented from answering for 4 seconds. Once released, the teacher took answers from the class and then returned to Andy who asked the three contestants for their answer and reason (Figure 2c on page 24). The 'right answer' was displayed. If the children agreed, then they could move to the next question. If not, they could try again with another question. They could also engage in a 'bonus round' in which they attempted more challenging questions. The software then moved on to the next topic. Two things should be stressed here: the intervention was not trying to teach the children the science or maths directly. Nor was it necessary to obtain the right answer. The purpose of the intervention was to get children to 'Stop and Think' about their answer before responding, in other words, to use their inhibitory control in coming to their answer.

The UnLocke Project: findings

At the end of the 10 weeks, half the children from all conditions took a GL Assessment Progress Test in maths and the other half took the test in science. They also took a Chimeric animal inhibitory control task.

The main analysis, which provides the basis for what follows, was conducted by the evaluators and is fully explained in the EEF report (Roy *et al*, 2019).

The overall findings, shown in Table 1 on page 24, revealed that children in the SaT intervention group made on average the equivalent of one additional month's progress in maths and two additional months' progress in science compared to children in the control group.

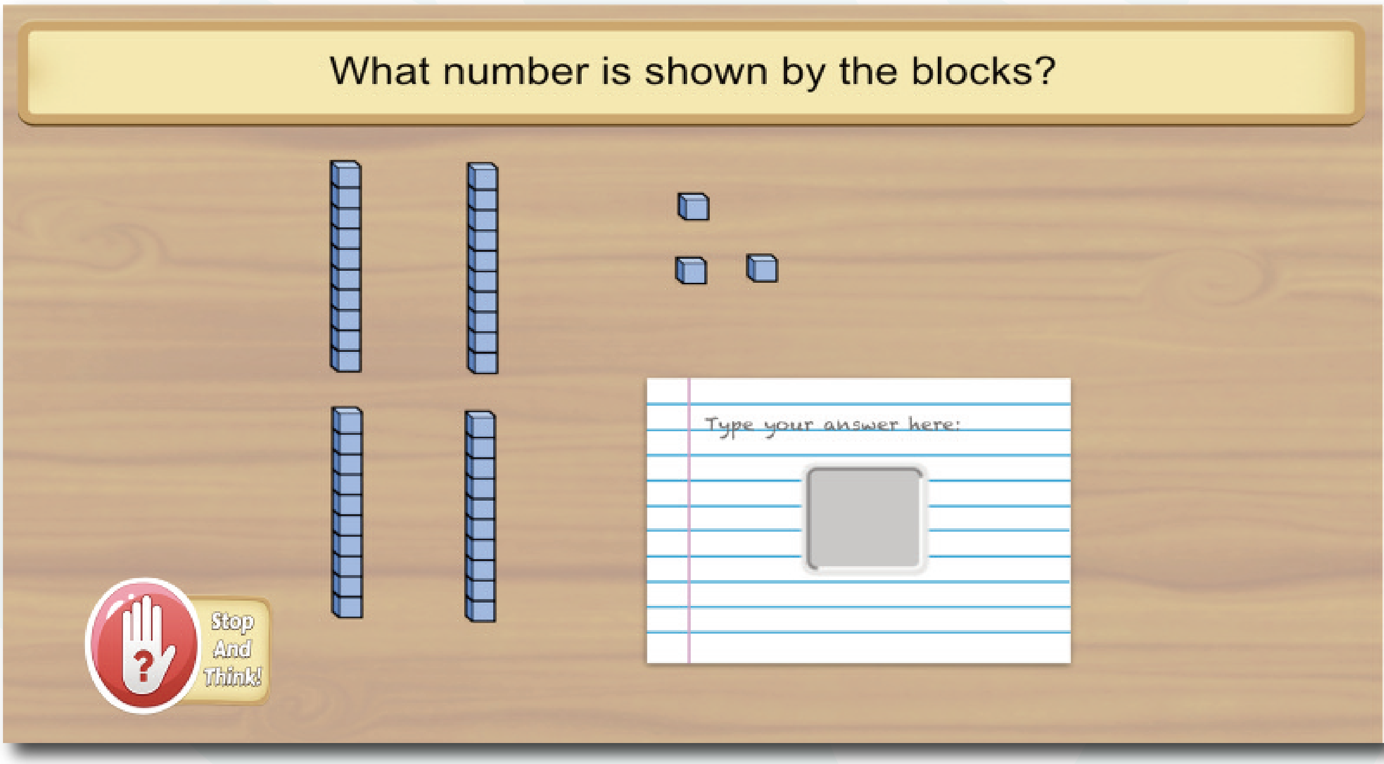
The effect size for science was statistically significant at $p < 0.05$, but that for maths was not. Unfortunately, this meant that the evaluators could not deem the trial successful overall because the pre-published hypothesis stated that significant progress would result in both maths and science. Despite this, the results have a high trial integrity rating (EFF padlock rating) and are, overall, considered promising.

Secondary analysis of the data highlighted several other insights that indicated additional encouraging findings. In particular, there were significant improvements for Year 5 in both maths and science, when compared to active control only. Although more research would be required to test the hypothesis, this might be an effect of children's underlying cognitive development.

Figure 2. Stop and Think' game show activity.

a. Andy and the contestants.

b. Example maths question showing 'Stop and Think Hand'.



Similarly, there was evidence of a greater effect in Year 3 maths for children eligible for free school meals. Unfortunately, the sample size was underpowered to test for statistical significance, but it is nonetheless worth further investigation.

This suggests that an activity such as SaT might be encouraging disadvantaged children to gain familiarity with a broader range of experiences and practice in considering a wider range of factors when tackling problems.

c. (c) Stop and Think – contestants' answers.

It is worth noting that the project found no evidence that the Stop and Think programme had an impact on pupils' general inhibitory control as measured by pen and paper task. This is consistent with the view that the SaT software was not designed to 'teach' cognitive inhibition *per se.*

❒ *The UnLocke project: teachers' perceptions*

An important aspect of the trial were the teacher perceptions of both the activities and the impact on the children. Overall, the feedback was positive. However, it was felt that the SaT should not be rolled out in its current form due to issues with the technology and improvements that could be made to the software. For example, it was suggested that teachers should be able to select which questions to use and align them more closely with schemes of work. Importantly, most teachers thought that 'Stop and Think' had a positive impact on the mathematical and science abilities of the pupils in their class, as the quotes overleaf illustrate:

Outcome / Group	Effect size (95% confidence interval)	Estimated months' progress	No. of pupils	P-value	EEF security rating	EEF cost rating
Maths (Year 3 & Year 5 combined) vs control	0.09 (-0.01 . 0.19)	1	2702	0.087	🔒🔒🔒🔒🔓	£££££
Science (Year 3 & Year 5 combined) vs control	0.12 (-0.02 . 0.22)	2	2735	0.018	🔒🔒🔒🔒🔓	£££££

Table 1. Summary of impact on primary outcomes of maths and science (GL test scores).
NB: Redrawn from EEF Evaluation Report (Roy et al, 2019)

'The Stop and Think game show contestants and animations in the programme encouraged pupils to reason more, which enhanced their learning.'

'Some pupils took the Stop and Think idea into other lessons, that is to say, pupils were taking time to consider questions before answering.'

Moreover, many teachers reflected that it had influenced their own thinking:

'It gave me an insight into how children's ideas can change when given thinking time and how they are able to reason as to why something is right or wrong.'

Discussion

Taken together, the findings from and reaction to the UnLocke (Stop and Think) Project are promising and, currently (November, 2020), the EEF has commissioned a large-scale effectiveness trial, involving 175 schools and 8,750 pupils, using an improved version of the software (EEF, 2020). In the meantime, there are some lessons that might be drawn from the work to date.

The first is that, despite much of the basic research into inhibitory control mechanisms being carried out with adolescence and adults, the UnLocke findings add to the battery of evidence demonstrating the importance of inhibition as part of learning. Focusing on the need to 'Stop and Think', although it was only for 4 seconds, underlines the value of much older behavioural studies into 'wait time' (Rowe, 1986) that demonstrated how children's responses to questions can improve as a result of such a pause.

As such, the UnLocke Project provides an example of the potential of building on understanding of brain mechanisms and taking it through to classroom-based activities. Although there remain more questions and research to be undertaken, we would argue that there are implications for pedagogy that are worthy of consideration.

A key principle in the design of 'Stop and Think' was that it should be part of normal teaching, not treated as an add-on. This can be extended in that the principles underlying SaT should not be restricted to the time using the software. Rather, they should be an integral part of a wider pedagogy across subjects, encouraging children to consider alternative ideas before responding to questions. This requires taking children's ideas (including their misconceptions) seriously and helping them to engage in activities, e.g. use of Concept Cartoons, which require them to consider alternative ideas (Naylor & Keogh, 2000). It is also supported by providing children with opportunities, such as 'pair-share' activities, to explain and discuss their ideas with peers before 'going public' in front of the whole class. Beyond making the 'Stop and Think' process explicit, it is also important to help children to recognise that it does not simply apply to learning in science and maths. It can be used across all subjects, but transfer of knowledge and the underlying cognitive processes from one context to another do not occur easily. Thus there is a need to help children to make the necessary connections through providing appropriate guidance, the use of well thought out examples and carefully worded questions.

Conclusion

Without doubt there is strong evidence that inhibitory control is an important component in the development of learning. The UnLocke Project endeavoured to take this a step further and transfer the research findings into the classroom. Whilst the findings of the randomised controlled trial are mixed, they are also promising in providing evidence that, by attempting to develop, rather than teach, children's inhibitory control within the context of a subject domain, science and maths in this case, improvements in overall performance are possible.

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Derek Bell is Director of Learnus and a former Chair and CEO of ASE.
E-mail: Derek@learnus.co.uk

Denis Mareschal is Professor of Psychology in the Centre for Brain and Cognitive Development at Birkbeck College and Project Leader of the UnLocke Project.

The UnLocke Team, in addition to the named authors, includes: Michael Thomas, Andy Tolmie, Emily Farran, Iroise Dumontheil, Kaśka Porayska-Pomsta, Sveta Mayer, Hannah Wilkinson, Claire Smid, Su Morris, Wayne Holmes, Annie Brookman-Byrne, Roshni Modhvadia and Dilini Sumanapala.

The power of sound – can we hear air pollution?

● Jeannette Morgan ● Dudley E. Shallcross

Abstract

Reducing air pollution sources and air pollution exposure is an important challenge, particularly for the very young and very old, who are more susceptible to the health effects of such pollution. However, air pollution sensors can be expensive (for primary school budgets) and hard to interpret, whereas data from a sound (loudness) sensor can be interpreted much more easily and sound sensors are much cheaper. In this study we compare a carbon monoxide (CO) pollution sensor with a sound sensor in a number of investigations around an urban primary school, and find that the sound sensor is a very good proxy for CO (a marker of air pollution). Therefore, we propose that a sound sensor can be used in an urban primary school setting to investigate polluted and non-polluted environments.

Keywords: Sound, air pollution, data loggers, outdoor learning, science enquiry, climate science

Introduction

Before moving on to the application of sound sensors as a proxy for measuring air pollution, we will provide a short introduction to the science of sound. Sound is a form of energy that travels through a medium. Sound waves are transferred by a particle in that medium passing the energy on to another particle. Sound travels differently depending on how tightly packed the particles are. In a solid, particles are very close together and so sound can travel through that medium very efficiently. In a liquid, where the particles that comprise it tend to be further apart, sound can travel through this medium, but not as efficiently as it can in a solid. Therefore, in a gas, where particles are much further apart than in a solid or a liquid, we would expect sound to travel least efficiently. Sound cannot be transferred in a vacuum because there is an absence of particles to travel through.

Table 1 demonstrates that the speed of sound is slowest through air. The structure of the solids must be different, because sound travels much faster through steel than through wood. Wood is an example of a polymer (e.g. Shallcross *et al*, 2016), which consists of long chains of particles, whereas steel is a metallic solid and consists of a regular structure, which makes it easier for sound to be passed on from particle to particle.

In the animal kingdom, there are variations in the range of sounds that can be heard, as shown in Table 2. The human hearing range is between around 64 Hz (low frequency or pitch sound) and 23,000 Hz or 23 kHz (high frequency or pitch sound). Interestingly, dogs have a similar lower frequency level to, but a much higher upper frequency threshold than, humans, and anyone who has had a dog will know that they can hear sounds that humans cannot. Bats have a high frequency threshold, which they use

Material	Speed of sound / ms^{-1}
Air	332
Water	1501
Wood (oak)	3850
Steel	5960

Table 1. Speed of sound in different materials at 300 K or 27° C (data from Kaye and Laby, 1986).

Table 2. Hearing range (frequency or pitch of sound) for a variety of animals (Fay & Popper, 1994).

Species	Lower end/Hz	Upper end/Hz
Human	64	23,000
Dog	67	45,000
Elephant	16	12,000
Bat	2,000	110,000
Beluga whale	1,000	123,000

for eco-location, i.e. they use sound to navigate. Beluga whales can hear sounds from many hundreds of miles away, since sound travels more efficiently in water.

The loudness of sound is measured using the decibel (dB) scale, with sounds above 85 dB thought to be harmful to humans. Leaves rustle at around 30 dB, heavy traffic is around 80-90 dB, an elephant's trumpeting is around 117 dB and a bat is up to 140 dB (but can often not be heard by humans, being above our high frequency range). The loudest animal on Earth is the Blue whale at 230 dB (Fay & Popper, 1994).

Ways of using sound sensors in investigations

In primary schools, the loudness of sound can be measured using a sound sensor, data logger or sound app. In a previous article, we described the use of data loggers that measured sound levels (loudness) and how these could be used on a sound trail (Morgan, 2016; Morgan *et al*, 2017), utilising the benefits of learning outdoors (Grimshaw *et al*, 2019). A sound sensor is inexpensive, and children can calibrate it themselves; they do not need to understand the decibel scale, but can generate a sound from a range of sources and see what loudness level is recorded by the sensor. Use of sound sensors can give rise to open-ended investigations, with children investigating how sound levels change around their school grounds. Sound levels can easily be measured over a period of time, allowing the children to analyse changes over time and interpret why these changes occur. A sound sensor could be left in a 'secret position' in the school for a day, with children then asked to interpret the line graph produced and discuss where the sensor could have been left.

Hearing air pollution?

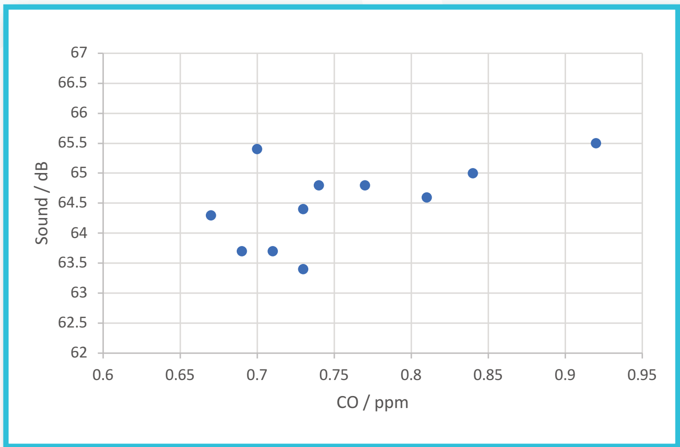
There is no doubt that air pollution is a serious problem in terms of health, particularly in cities (e.g. Harrison *et al*, 2020a, 2020b) and that key pollutants such as carbon monoxide (CO) and small particles such as PM_{10} can be measured using a range of pollution sensors, including hand-held ones. These sensors are becoming cheaper, and some reliable ones that can be used in schools exist, but data interpretation is not straightforward. A data reading from a pollution sensor, assuming that it is calibrated properly, can be almost meaningless because of its complexity. So how can a sound sensor help to measure pollution? We argue in this article that pollution sources such as vehicles, construction, etc. generate noise and so there is the potential that a sound sensor may work as a proxy for measuring air pollution. Several studies have shown that there is a correlation between air pollutants and noise levels in urban settings, since sources of pollution such as vehicles also generate noise (e.g. Kim *et al*, 2012; Shu *et al*, 2014). For this study, we used a carbon monoxide sensor and a sound sensor to explore their potential use in different investigations around school, with a mix of children from Key Stage 2 (aged 7-11). Three investigations are described below, with examples of data presented in Figures 1-3.

Fixed sensor

Figure 1 shows an example of data from two sensors co-located at a fixed location (~ 1.5 m from the ground attached to the perimeter railings) near the entrance to school, around the time of the children arriving at school in the morning. There is some correlation between the CO and sound levels; typically, there is not a perfect correlation but a consistent positive one, i.e. as CO increases, sound levels increase.

Data were collected over a number of days, with similar findings suggesting that the sound sensor could be used as a proxy for measuring pollution. In addition, counting the number of vehicles and the sound levels gave a good correlation, i.e. more vehicles corresponded with louder sound sensor data. Therefore, we argue that the sound sensor alone could be used as a proxy for measuring pollution and the number of vehicles arriving at the school. If schools are trying to monitor and manage vehicle numbers and their impact in and around the school environs (e.g. at the start and the end of the day), then a sound sensor is a cheap, easy-to-interpret way to gather data. However, there are times when the sound sensor will give elevated levels when pollution levels can be lower, e.g. during heavy rainfall or when children (and adults) shout near the sensor (though this causes a short-lived signal), and so careful thought to the location is needed and some trialling of location is recommended, together with perhaps keeping a weather log.

Figure 1. CO and sound data collected in a fixed position as the school drop-off begins.



Around the school grounds or outer perimeter

Figure 2 shows an example of CO and sound levels when walking around the outside of a school grounds during the morning when the children are being dropped off. Data collected show a similar general trend to above, in that elevated sound levels correlate with elevated levels of CO (apart from in situations such as heavy rainfall or children talking into the sound sensor).

The change in sound levels between busy roads and roads where there is much less traffic is consistent. It is possible to generate sound maps around the school and further afield to suggest walking or cycling routes to school that have lower levels of pollution (quieter routes).

Figure 2. CO and sound levels during a walk around the school perimeter.

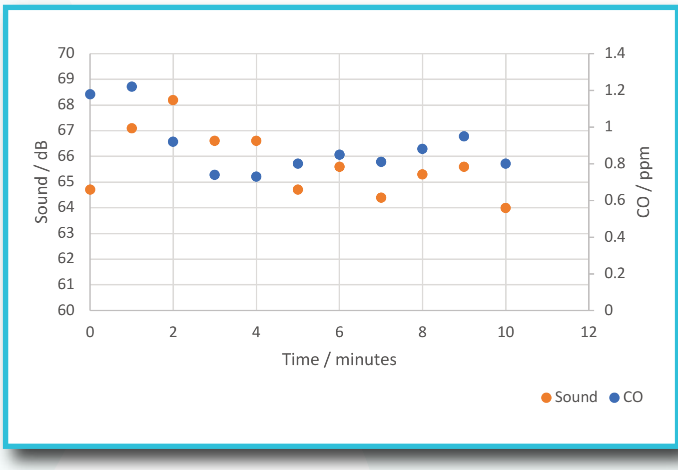
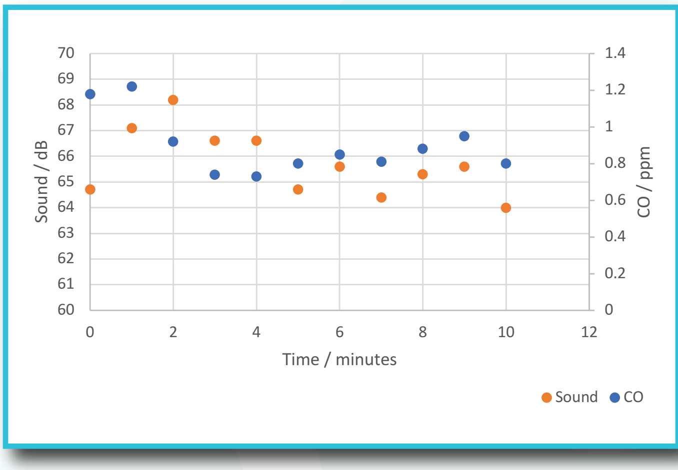


Figure 3. CO and sound levels during a circular walk from the school and back to the school.



Interesting data on walks from school and back again

Figure 3 shows a walk from the school, around a route and back to the school. Other walks show correlations like those seen in Figure 2, but some were similar to those in Figure 3. These more unusual findings could provoke discussion: what was happening between ca. 5-10 minutes from the start of the walk? The walk followed a route through a park during this time and the level of pollution, as measured by the CO sensor, dropped, but the sound levels went up. On most occasions, the sound level dropped too, but sometimes the children on the walk became excited and started making a lot of noise. In Figure 3, the increase in sound levels was due to natural sounds such as birds chirping, dogs barking, etc. and so using the sound sensor as a proxy here would suggest that pollution levels went up. However, by taking notes on the walk, it is possible to resolve the differences. Comparing the CO sensor with the sound sensor consistently showed that pollution and sound levels were lower in parks and similar areas away from main roads, and so routes through these environments can be assumed to be cleaner than those along main roads. This has been verified many times in the literature (e.g. Kaur *et al*, 2007). Studies show that both air and sound pollution levels drop in green spaces (Gozalo *et al*, 2018; Bunds *et al*, 2019; Xing & Brimblecombe, 2020).

Future developments

The sound sensor used in this study measured loudness but, if future sensors also measure the frequency or groups of frequencies of the sound, this would help the user to distinguish between vehicles such as cars (estimated to be 100-600 Hz) and trains (30-200 Hz), and natural sounds such as dogs barking (1000-2000 Hz) or birds chirping (1000-8000 Hz); i.e. human-induced sounds tend be at a lower frequency than natural ones (that we might encounter in the UK). Therefore, in addition to measuring the loudness, measuring frequency could help to make a sound sensor even more useful.

Summary

It has been noted that both air and noise pollution can affect health, especially that of children (Gupta *et al*, 2018). Studies on journeys through urban environments show strong correlations between various air pollutants and noise levels (e.g. Engel *et al*, 2018). A sound sensor can be used as a proxy for measuring air pollution levels around a school in an urban setting and its environs, although this may be less useful in rural settings. Sound sensor positioning and non-traffic sources of sound (e.g. children and rain) will need to be considered. Determining 'clean' routes to school, i.e. quieter ones, can reduce air pollution exposure. In the future, it is envisaged that clean electric vehicles will replace the fossil fuel-generated ones, noise levels will drop (Pardo-Ferreira *et al*, 2020) during this transition and so a sound sensor could be a useful sensor with which to investigate this transition.

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Jeannette Morgan is a primary school teacher, winner of the Primary Science Teacher of the Year Award (2012) and a Fellow of the PSTT College.

Professor Dudley Shallcross is a Chair of Atmospheric Chemistry at the University of Bristol.
E-mail: dudley.shallcross@pstt.org.uk

Exploring ways of defining the relationship between research philosophy and research practice

- Lynne Bianchi

Abstract

Without thoughtful reflection about who we are as researchers and our research 'frame' – how we act and think as researchers – we risk making superficial choices about methods and could fail to expose the inherent biases that impact on our analysis when communicating our research. This article examines the relationship between research philosophy and research practice in science education settings, taking stimulus from the 'Research Onion' (Saunders et al, 2019) to devise and describe how research is framed. This paper aims to explore the process of constructing a research frame, rather than the contents of the frame itself. In doing so, it explores the philosophical, theoretical and analytic approaches of the Science & Engineering Education Research and Innovation Hub (SEERIH), with the aim of prompting those involved in small or larger research practice to reflect on their own standpoints.

Keywords: Research paradigm, analytical frameworks, research methods

Introduction

Evidence-based practice is a term that has become increasingly commonplace within educational settings, where senior leaders and teachers seek to conceptualise the nature of effective pedagogies that have a recognised or reported track record of success (Hattie, 2008; Sotiriou *et al*, 2017). Evidence can be gathered via both evaluative and research methods that require engagement in schools and classrooms, involving teacher and/or pupil feedback such as observation, diaries, interviews, etc. This article describes the influences on how evidence is gathered in research, and how explicit reflection and description of these influences, including the philosophical, theoretical and analytical paradigms, should guide the planning, undertaking and analysis of research in schools.

Since 2014, the Science & Engineering Education Research and Innovation Hub (SEERIH) at The University of Manchester has designed programmes of professional learning for in-service teachers and led on innovative school engagement projects to enhance participation in science and engineering in primary schools. It has also pioneered research activity to scrutinise and understand teacher professional development and pedagogical approaches in STEM education.

This article is written to attempt to define the ways in which we have collectively worked to develop a research frame that theorises the pragmatic research elements of our projects. With the support of Professor Debra McGregor (Oxford Brookes University), we have worked to articulate our research frame in order to explain the choices we make about data collection and analysis during a research programme. This involved reflecting on:

- our philosophical position in relation to our research activity;
- the main research paradigms that are significant to SEERIH's practice; and
- the way in which we develop theory from practice, distinguishing between deductive (theory testing) and inductive (theory building) practices.

To guide this examination, we reviewed the work of Saunders *et al* (2019), who explain the research process through the 'Research Onion'. Through an iterative dialogue, infused with professional challenge, we have identified and described our approach to research through the SEERIH Research Frame. This article prompts those involved in research to professionally reflect on their own choices when undertaking research in schools, whether that be small tests of change through to more in-depth academic research activity.

Saunders *et al's* Research Onion (2018)

Figure 1 presents the multi-layered diagram that places how we collect and analyse data at the heart of the 'Onion'. By focusing on the techniques, tools and procedures that we use, the Onion allows us to examine the decisions and choices that have led to the selection. This selection can be influenced by many factors, some of which are upfront and visible, e.g. the time available to collect data or the access we have to participants. Others are often implicit, e.g. our philosophical positions that we hold as researchers or our approach to analysing data and building meaning. Without thoughtful reflection about who we are as researchers and our research 'frame' – how we act and think as researchers – we risk making glib choices about methods and we fail to expose the inherent biases that impact on our analysis when communicating our research. Further to this, the selection of research tools and approaches could also be fundamentally at odds with the paradigm within which we are working, e.g. random sampling of participants when, in strictly qualitative terms, they should have a clear rationale for selection.

In its simplest terms, Saunders' Research Onion prompts us to reflect and describe six layers of influence in our research approach:

- ***What is your research philosophy? (Outer layer)***

Here we seek to unearth what shapes how we do and understand our research: the assumptions we hold about reality, the contexts and people we

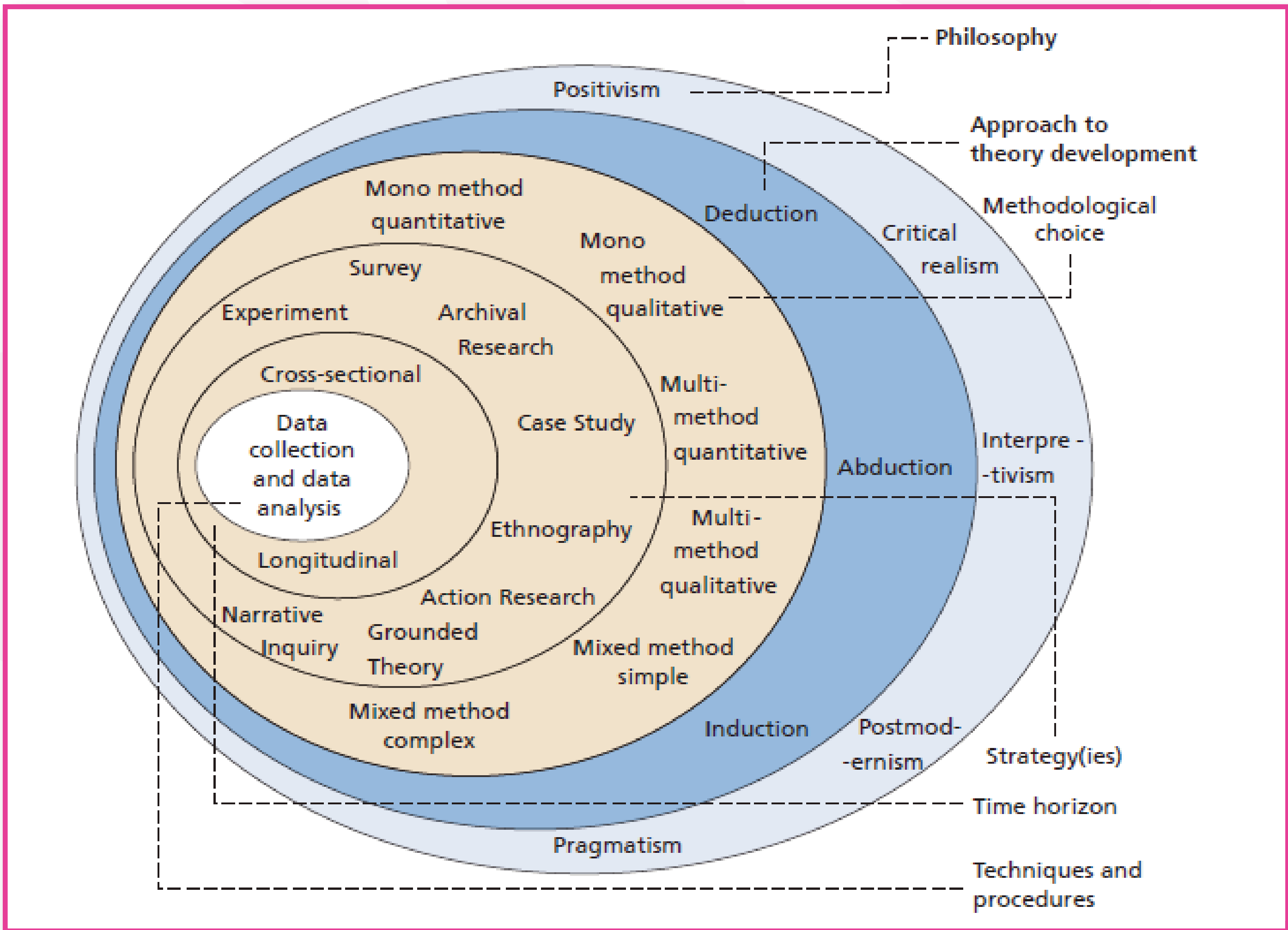

Figure 1. The 'Research Onion' (Saunders *et al*, p.130).

engage with (ontological assumptions). This is an area of thinking that makes us reflect on our assumptions about knowledge and what people can know (epistemological assumptions), and the extent to which our own values, political or ideological positions influence our research (axiological assumptions). This leads us to consider our positioning – examples of philosophical standpoints include positivism, critical realism, interpretivism, postmodernism and pragmatism.

Raising these large concepts here we hope will stimulate you to read more, using authors such as Saunders *et al* (2018), Williams (2016) or Scott (2008) to support your reflection.

- ***What is your approach to theory development? (Second layer)***

This decision will be influenced by whether we seek to theory test or theory build. It has a significant implication for the way in which we design the research, guiding us towards the selection of research techniques and tools: for instance, surveys versus focus group discussion. The two commonly used approaches towards reasoning and meaning-making are referred to as deductive (the process of reasoning where a conclusion is tested in reality – theory testing) or inductive (conclusions are derived from specific observations – theory building).

- ***How does your research paradigm influence methodological choices? (Third layer)***

Here we are encouraged to consider the qualitative or quantitative methods that can support evidence gathering. These choices will be reflective of a deductive or inductive approach. More typically qualitative techniques will align to inductivist approaches.

- ***What research strategies suit your methodology?***
- ***What is the timescale of your data collection?***
- ***What will you select as your data collection and analysis techniques and procedures?***

The final 3 questions lead us to the specifics of the research design and will be impacted by the philosophical and analytical standpoint. Here we consider the nature of the research strategies to be employed with participants, the duration of the research and how often within that timescale evidence will be collected. At this point the choice of analysis technique and procedures will reflect whether the research data would be considered through a deductivist or inductivist frame.

Exemplifying practice

Figure 2 outlines SEERIH's Research Frame, showing how Saunders *et al's* work has been translated to apply to our research activity. Although initially scoped using the 'Onion' model, we have found that a tabular format was preferable to visualise our approach, encompassing the key features of the original model in Figure 1. This is offered for exemplification and includes additional elements that were found to strengthen the frame. This paper aims to explore the process of constructing a research frame, rather than the contents of the frame itself. Further reading about the SEERIH theoretical model can be found at Bianchi (2017).

Firstly, the research context, purpose and setting are identified in order to describe and position our research and to identify ourselves as researchers in the field of science and engineering education, with a core focus on constructivist pedagogies. Our commitment to mainstream education influences our practice and the focus on primary and early secondary education impacts on what and where we publish its outcomes. When reflecting on this frame, it is worth noting that SEERIH has a wide range of activities, which are different in type and purpose; therefore, individuals or smaller research teams are likely to contain fewer elements within their frame.

Bianchi (2017) explains our theoretical model for teacher engagement using the Trajectory of Professional Development, which describes a 5-step model to teachers' socially-constructed professional learning – pre-engage, participate, collaborate, co-create and connect. This model impacts on many aspects of research design, in particular with regard to the expectations for teacher professional engagement within the research process (e.g. their level of participation): the way in which we review and describe their engagement and, in supporting them, to recognise and articulate impact of the research on their

Figure 2. SEERIH Research Frame.

<table>
<tr><td>Context</td><td colspan="5">Creativity in Science & Engineering Education</td></tr>
<tr><td>Purpose</td><td colspan="5">Enhancing children's opportunities to think and work as scientists and and engineers
Inspiring teachers into professional learning to innovate and reflect with constructivist pedagogies within science and engineering education
Improving pupils' identity, agency and engagement in science and engineering education</td></tr>
<tr><td>Setting</td><td colspan="5">Primary and KS3 classrooms in the UK. Higher Education STEM learning</td></tr>
<tr><td>Theoretical model of teacher engagement</td><td>Pre-engage</td><td>Participate</td><td>Collaborate</td><td>Co-create</td><td>Connect</td></tr>
<tr><td rowspan="2">Philosophical position</td><td colspan="3">Positivism</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="3">Interpretivism</td></tr>
<tr><td>Methodological choice</td><td colspan="2">Mono-method Quantitative – based on Guskey (1986)</td><td colspan="3"></td></tr>
<tr><td>Data collection technique</td><td colspan="2">Online quantitative standardised surveys</td><td colspan="3"></td></tr>
<tr><td>Methodological choice</td><td colspan="2"></td><td colspan="3">Multi-method – illustrative cases developed with participants aligned to specific research questions</td></tr>
<tr><td>Data collection technique</td><td colspan="2"></td><td colspan="3">Qualitative, semi-structured interviews, focus groups, diaries/portfolios, case study</td></tr>
<tr><td>Timescale</td><td colspan="2">Cross-sectional
(one-off moments in time)</td><td colspan="3">Phased-periodic
(insights over time, e.g. 6-12 months)</td></tr>
<tr><td>Analytical approach – theory development</td><td colspan="2">Deductive</td><td colspan="3">Inductive & Deductive Examining 'why and so what?' with a view to describing an outcome/theory</td></tr>
<tr><td>Analytic techniques and tools</td><td colspan="2">Excel data-sorting, processing, management and graphing/tabulation</td><td colspan="3">Thematic analysis (Braun & Clarke, 2006) Hand coding, Electronic coding (NVivo)</td></tr>
<tr><td>Publication</td><td colspan="2">Internal reports (e.g. funder/ stakeholder reports)
Verbal and written presentations</td><td colspan="3">Public access published reports.
Peer-reviewed academic papers.
Academic conference presentations and posters</td></tr>
</table>

practice. This is closely associated with our philosophical positioning and how we move from positivist to interpretivist paradigms.

The frame makes visible how SEERIH shifts from a positivist approach, where we are seeking to identify an observable social or educational reality (wanting to find out how much of something happens), for instance when researching the frequency of opportunity that children have to ask their own scientific questions in the classroom, to an interpretivist approach where we are seeking to understand and create meaning by working *with* teachers, therefore placing emphasis on them as professionals. Here we would work to study classroom practice and the classroom as a social setting for science learning, through which we can create new, richer insights exposing organisational realities.

We have found that the shift in engagement when teachers collaborate, co-create and connect enables a shift towards interpretivism. This offers the opportunity to include teachers' lived experiences and the voices of those within schools alongside our own interpretations. In this way we can gather deeper meaning, for instance about the levers and barriers to encouraging children to ask their own scientific questions and the implications that this has for the classroom.

Timescales for data gathering then influence the choices of methodological approaches and techniques applied. Here we notice the use of deductive and inductive forms of analysis. Where one-off quantitative methods such as a survey or questionnaire are used, the analysis is deductive, following the positivist philosophy as we seek to examine 'how much?' of something is taking place. When data are increasingly qualitative, the analytical approach that leads to a theory being put forward must shift towards meaning-making and, for us, we have selected the Braun and Clarke (2006) 6-step model of Thematic Analysis to guide this process, and notably move to a mixed methods approach.

Our work context is such that publication is required in different formats; therefore, we have added this to our research frame, so that, as a group, we are clear in how our choice of methods supports dissemination. It should be noted that our current academic publications are mainly drawn from the work we do with teachers when working within an interpretivist-inductive frame, where new ideas emerge and forge new contributions to knowledge in the field. It should not be assumed from our representation that academic publications cannot be developed from our quantitative data; it is just not the focus of our current research publications.

Conclusion

What has become clear through this introspection is the benefit and influence of articulating our research philosophy. Engaging in shared reflexive dialogue, with professional challenge, has led to us asking ourselves many questions about why we do things and expose the beliefs and assumptions that we hold. We have scrutinised these positions and debated to the extent that we have come closer together as a research team and more rigorous in our research practice.

The thoughtful deconstruction of what underpins how we engage with teachers and schools on SEERIH research projects has undoubtedly unearthed deeply held philosophical standpoints about learning within the research team. It has also stimulated dialogue about how best to involve participants in research, questioning their depth of engagement and stimulating consideration of whether they should have further engagement in the analysis of outcomes. In particular, by working through a guided process of reflection, we have made visible where our biases impact on meaning-making from research, therefore strengthening the way we present and discuss data within academic publications. Indeed, the cumulative effect is that research proposals also become more critical and justified, as we can write collaboratively with a common understanding of research purpose and design – in essence, the research frame clarifies the language for research practice across the team.

If you are embarking on research, or are already involved in research activity, I would urge you to reflect on your research frame, as this may offer you additional insight into your practice.

As with all such endeavours, the mere act of critical reflection can itself stimulate refinement.

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Acknowledgments

Dr. Amy Bonsall, Research Associate, The University of Manchester.
SEERIH's research activity is gratefully supported by the Comino Foundation, Primary Science Teaching Trust, Royal Academy of Engineering and the SHINE Trust.

Lynne Bianchi, The University of Manchester.
E-mail: lynne.bianchi@manchester.ac.uk

Contributing to JES

About the journal

The *Journal of Emergent Science (JES)* is an 'open access' biannual e-journal designed to bridge the gap between research and practice. It complements the ASE's professional journal, *Primary Science*, and is supported by the Primary Science Teaching Trust (PSTT). *JES* focuses on research and the implications of research for practice and provision of science (including health, technology and engineering) for young children from birth to 11 years of age. *JES* welcomes contributions from its audience of early years practitioners, primary school teachers, teacher educators and researchers.

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- Include a reference list (examples below), set out in alphabetical order.

Referencing examples:

Book

Russell, T. & McGuigan, L. (2016) *Exploring science with young children.* London: Sage.

Chapter in book

Johnston, J. (2012) 'Planning for research'. In Oversby, J. (Ed) *ASE Guide to Research in Science Education.* Hatfield: Association for Science Education.

Journal article

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