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.

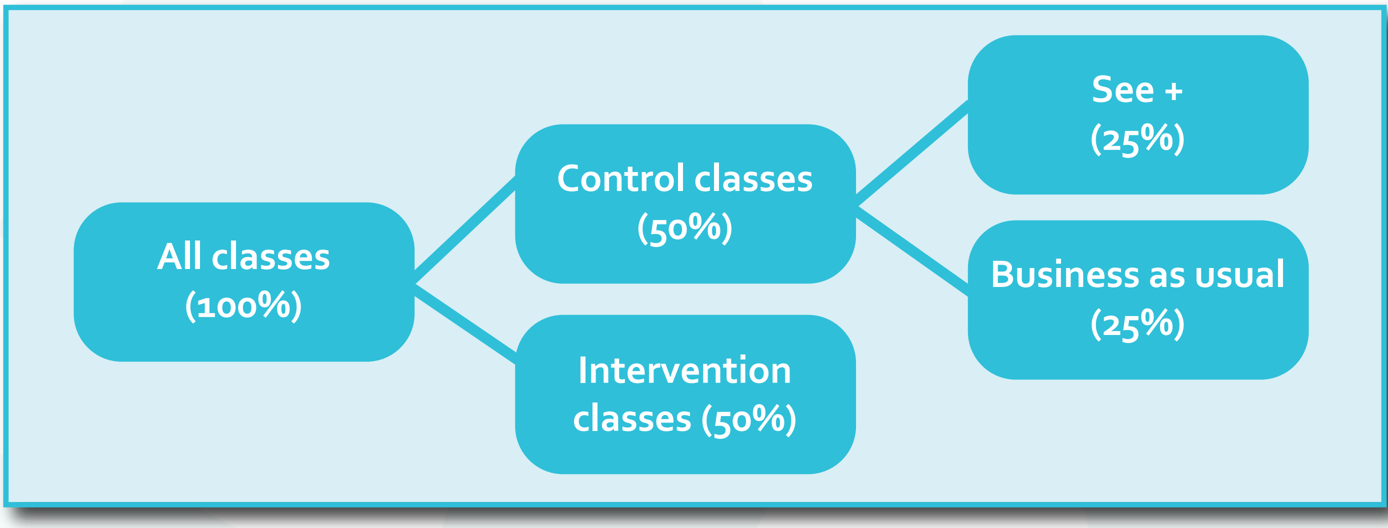
The trial involved 89 schools across England and 6,672 children, approximately half in Year 3 (age 6) and half in Year 5 (age 9). Approximately 16% of the children were eligible for free school meals (FSM). The randomisation was based on classes, so that 50% of the classes undertook the main intervention (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.

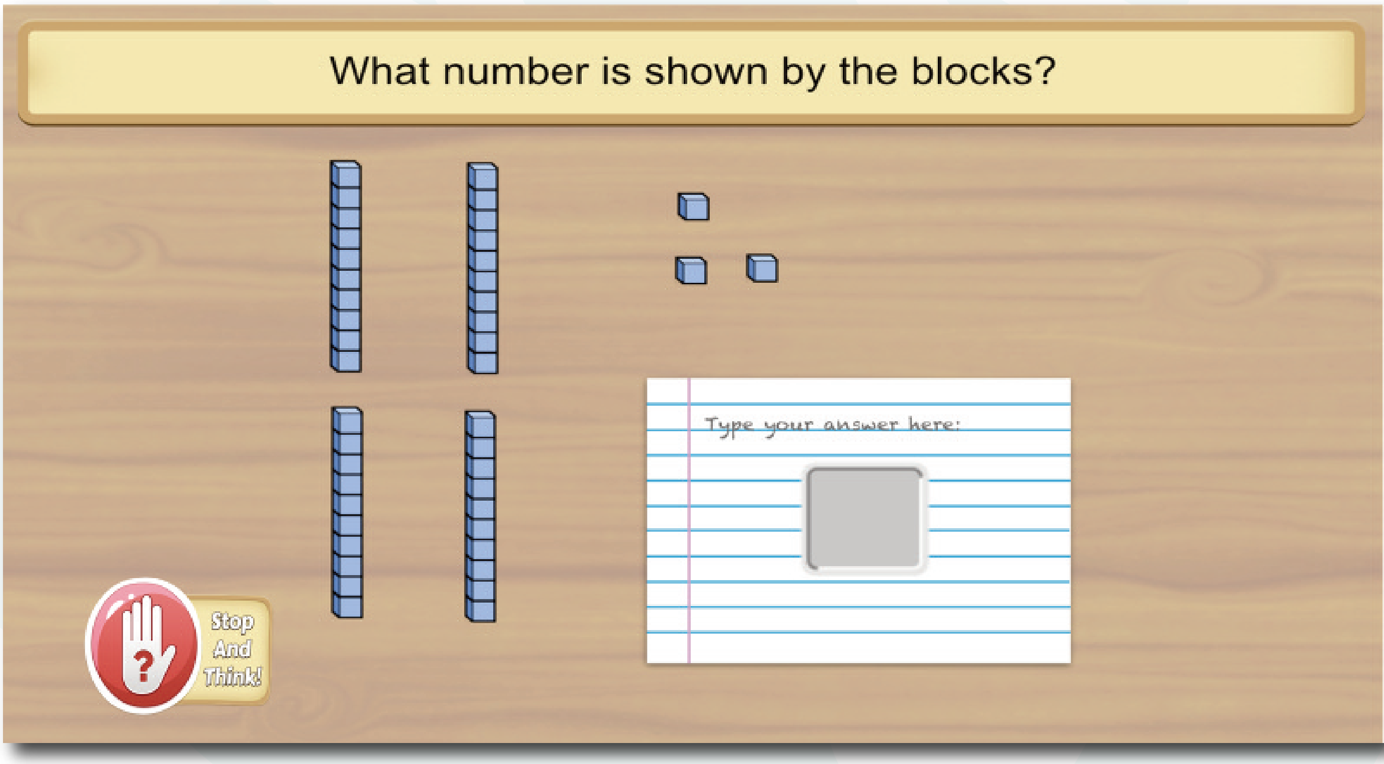
The effect size for science was statistically significant at $p < 0.05$, but that for maths was not. Unfortunately, this meant that the evaluators could not deem the trial successful overall because the pre-published hypothesis stated that significant progress would result in both maths and science. 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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The power of sound – can we hear air pollution?

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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?

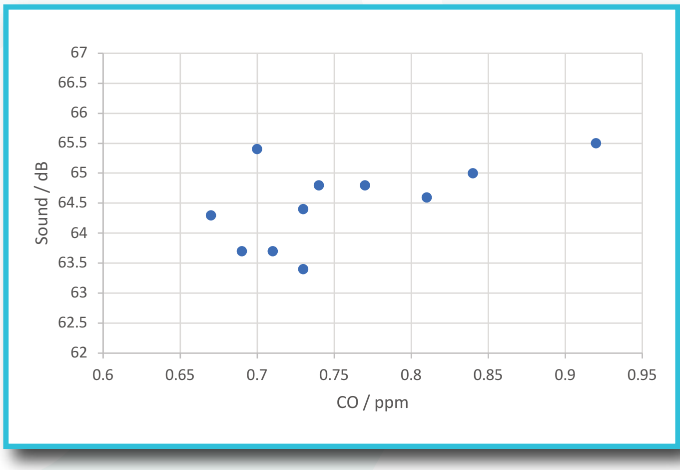
There is no doubt that air pollution is a serious problem in terms of health, particularly in cities (e.g. Harrison *et al*, 2020a, 2020b) and that key pollutants such as carbon monoxide (CO) and small particles such as PM_{10} can be measured using a range of pollution sensors, including hand-held ones. 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.

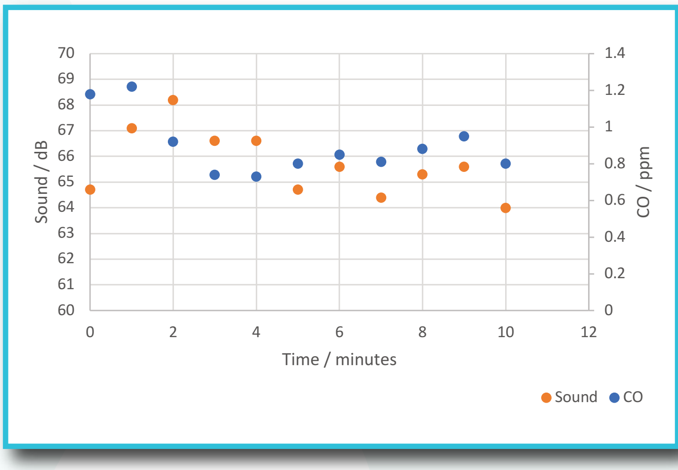
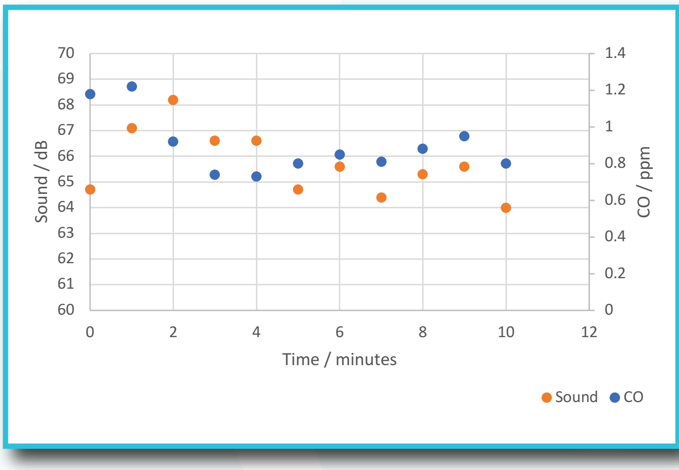


Figure 3. CO and sound levels during a circular walk from the school and back to the school.



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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