How can enquiry-based science support pupil learning in mathematics?

Andrea Doherty and **John McCullagh** consider how a science enquiry approach can be used to develop mathematics and numeracy skills and help pupils realise the important role mathematics plays in solving real-life problems

Setting science lessons within the context of an enquiry task or investigation is well established as an approach likely to increase pupil engagement and therefore support cognitive development (Harlen, 2014). The everyday nature of the enquiry question or problem draws pupils into discussion and thus provides a means to access pupils' thinking and thought processes. Solving the problem or discovering the answer to the enquiry question brings a sense of purpose to learning, enhancing motivation and instilling a positive disposition to science.

While numeracy skills such as measuring and recording are often used during science investigations, the main focus of the teaching in these lessons can often tend to be directed towards the science concepts and skills. Pepin (2015) claims that, in general, science enquiry enhances mathematics through the use of an inventive environment, formulating more impactful curricular learning for pupils and leading to greater enthusiasm and attainment. Through our work with schools and student teachers, we have discovered that when the mathematics and numeracy are given a central, purposeful role within the science enquiry the impact on mathematics learning is notable.

Benefits of setting numeracy within science enquiry

Treacy and O'Donoghue (2014) note the value of placing the learning of maths within meaningful contexts, promoting the use of hands-on activities that link to real-world problems. In science enquiry, meaningful contexts are presented, allowing the mathematics to become a tool to solve problems (Brown and Bogiages, 2019) and to serve as a language for the science (Schmidt and Houang, 2007).

When the mathematics is purposeful and instrumental to the science enquiry, the following benefits for mathematics learning can be observed:

- **Maths concepts become less abstract.** The abstract nature of many mathematical concepts is the root cause of difficulty in their comprehension. Science enquiry, by its nature, requires pupils to handle, measure and observe actual materials and objects, and therefore presents the potential to bring meaning to typically abstract mathematical concepts such as dimension, distance, mass and volume (Rogers, Volkmann and Abell, 2007).
- **Maths skills are consolidated through application across different contexts.** According to Pepin (2015), many pupils struggle to recognise the same mathematical concept in two different contexts. When science enquiry is employed and pupils are engaged in exploring changes over time and cause and effect, they are also required to measure, record and carry out arithmetic operations like subtraction, addition or multiplication. Pupils use mathematics in a new context and explicit discussion of this will allow pupils to become more aware of the maths and the role it plays across the curriculum. In this way, the quality of pupils' mathematics understanding is enhanced because children are actively forming their own understanding of maths concepts in the science context, with less focus on memorisation of facts and rules (Lange, Brenneman and Mano, 2019).
- **Maths talk is promoted and of a higher quality.** Maths talk is a crucial component of any effective mathematics classroom. When pupils talk about their work, they can explain their thinking, listen to how

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others work, and ask and answer questions. In science enquiry pupils are regularly drawn into discussions about not only the method and procedures, but also about the data collected and what these suggest in terms of findings and conclusions. Debates about possible trends or patterns in the data – the 'story' of how the data are changing and why that might be – all reflect and promote the mathematics that is inherent in science enquiry. Carrying out the activity generates an associated narrative for the process of data analysis and is a shared experience that the teacher can make use of when scaffolding the ideas. The science enquiry enriches the maths talk through the introduction of an accessible context and the maths talk becomes richer and more purposeful.

- **Maths anxiety is reduced.** Teaching maths through enquiry science has the potential to reduce the impact of maths anxiety in the classroom (Geist, 2010) and develop positive dispositions to mathematics. As can be seen in Table 1, the various issues that cause maths anxiety can be addressed through the incorporation of science enquiry.

Alongside the benefits for mathematics and numeracy learning, one key benefit for science is that time is 'found' to teach science. According to McCullagh and Doherty (2022) the amount of science being taught in primary classrooms in Northern Ireland has reduced significantly due to curriculum overload. The lack of space and time for science in the primary classroom is evidenced by the performance of pupils against their peers in other countries; Northern Ireland pupils are significantly outperformed in their science ability (Perry and Irwin, 2015). Interestingly, however, according to the same report, Northern Ireland pupil performance in primary maths is among the best in the world. Therein lies an opportunity to 'find' time and space for more science teaching alongside mathematics and numeracy. According to Cross (2022), the skills, knowledge and procedures for success in maths and science are complementary and therefore their integration is intuitive.

Table 1 How science enquiry can reduce maths anxiety

Cause of maths anxiety	How science enquiry overcomes it
Fear of being wrong	Open-ended enquiry/open-ended solution – the problem can be solved in multiple ways; there are multiple solutions.
Low self-esteem/ confidence	Collaboration and teamwork are encouraged in enquiry; mixed-ability groupings can be employed to support peer teaching and learning.
Lack of relevance of maths	Playful science contexts create a purpose for the numeracy; pupils get affirmation from the mathematical task and ultimately develop their self-efficacy.
Past failures and worry	A new context, fresh and separate from previous potentially negative numeracy experiences.
Poor working memory and learning differences	Incremental nature of the task: repeated, supported and progressive.

Setting numeracy within a science enquiry

How many of your own feet tall are you?

At **foundation stage** (ages 3–5), Rolf Myller's book *How big is a foot?* provides an ideal context to develop children's understanding and practices of measurement. The playful narrative of the 'Silly King' who wants the carpenter to build a bed for his wife but who uses his foot size to provide a measurement, presents a fun but problematic context. The carpenter (a much smaller man) uses the King's directions for a six feet long bed but soon realises that the bed is too small for the Queen. The story raises fantastic questions around measurement, non-standard units and of course the need for standard units.

Children can be tasked with answering the question '*How long would your bed be?*' and '*How many of your own feet tall are you?*' Children need to use their mathematics knowledge and skills to select the appropriate methods and procedures to solve this task, and should be encouraged to select and use the appropriate and relevant resources independently. Children can cut out their footprints and align these along their body to support 1:1 correspondence in basic measuring (Figure 1). This science enquiry activity links to the popular topic 'All about me' and provides opportunities for discussion and learning to extend beyond the school environment, into the home.

Figure 1 Measuring height with cut-out footprints

Which kitchen roll is the best at soaking up liquids?

Within the topic of 'Properties of materials' in **key stage 1** (ages 5–7) pupils are likely to have tested household materials such as kitchen cloths, cling film, kitchen foil and sponges to find out if they will soak up water. At foundation stage pupils will have decided between 'yes' and 'no' and considered which materials are the best. At key stage 1 this can progress to squeezing out the soaked material and recording the volume of water. The various brands of kitchen roll provide pupils with the opportunity to investigate which absorbs the most water; pupils can present the data in a table and a bar chart. The task is ideal for developing planning skills, where pupils' emerging ideas for a method are prompted by measuring, showing them measuring cylinders, small water trays and funnels. The activity can be carried out in two ways:

- Measure the volume of water remaining in the tray after a sheet of kitchen roll is placed into 50 ml of water and then removed.
- A more direct method simply immerses a sheet of kitchen roll in a tray of water, removing it and squeezing all the water into a beaker before measuring.

The first method requires the operation of subtraction while the second method does not. If food dye is added to the water, the water directly absorbed by each type of kitchen roll can in turn be transferred to a measuring cylinder; when placed side by side, they take on the appearance of a bar chart (Figure 2). To ensure a fair test, the size of the sheets of kitchen roll needs to be the same, so this can allow for work on the area of a square or rectangle.

Figure 2 'Bar chart' created from measuring absorption results

An interesting extension activity for more-able pupils looks at value for money (a factor we often struggle with ourselves during the course of a weekly shop!): is a more expensive brand worth it?

The burning candle

The chemical history of a candle was the title of a series of six lectures on the chemistry and physics of flames given by Michael Faraday at the Royal Institution in 1848, as part of the series of Christmas lectures for young people still given there every year. While pupils will have experienced the burning and blowing out of candles in their lives, they are unlikely to have considered that candles require oxygen to burn. The following activity can be adapted for either key stage 1 or key stage 2 (age 7–11) pupils and because it involves a naked flame should be carried out by an adult or by key stage 2 pupils under strict supervision. (Please consult ASE's current edition of *Be safe!* for guidance on health and safety.)

Key stage 1

At key stage 1, gather the class around the candle, ensuring everyone has a clear view (a night light is ideal; light two so that you can use a splint to relight the candle conveniently). After lighting the candle invite the pupils to predict what they think will happen if a small glass jar is placed over it. Repeat the activity and then seek possible explanations for why the flame went out. Before confirming their responses, produce another slightly larger jar and ask the pupils what they think will happen if it is placed over the candle. Cover the candle again with this larger jar, and invite explanations for why the candle burned for longer. The use of the larger jar and resulting longer flame time may prompt pupils to make an association between the capacity of the jar and the burn time.

This idea can then be consolidated by inviting pupils to predict what will happen if we use an even larger jar (Figure 3). Some pupils may propose that when all the air in the jar is used up the burning candle will go out, as air is required for the candle to burn. This suggestion can be further refined by explaining that air is a mixture of gases and that it is a gas called oxygen, which makes up about a fifth of the volume of air, that is used up by the burning candle. Just as animals require oxygen to live, so does the candle. (In fact the candle will go out well before all the oxygen has been used up so the larger jar takes longer to get to this critical level of oxygen.)

Figure 3 Timing the burning candle

This activity allows younger pupils to use comparative language – large, larger and largest – to describe the jars and the observed burning times – long, longer and longest. For older pupils this can progress to recording the burning time for each candle and looking for a pattern in the data. The class could be challenged to predict how long a jar, with a capacity within the range of jars tested, will allow the candle to burn.

Key stage 2

At key stage 2 the activity can extend to include five jars and require pupils to firstly measure the capacity of each jar using water and a measuring cylinder. Pupils can then check to see whether a jar that is twice as large allows the candle to burn for twice as long. Each jar could be tested twice and an average value recorded, as it hones pupils' observation skills to decide the exact instant when the flame finally dies. The data could be recorded in a table and presented in a line graph. Using the scale on the

Table 2 More science enquiry activities that focus on mathematics

Enquiry title	Numeracy focus	Science activity
Meteorites and the dinosaurs	Measurement Recording Graphs	Pupils drop a large marble into a tray of smoothed sand/flour and record how the diameter of the crater varies with the height of drop, and the size of marble. 
What % of Earth is covered in water?	Recording Data handling	Pupils throw a large inflatable globe to each other and record whether the catcher's index finger is placed on land or sea/ocean on a tally chart. After 40 throws the data approaches the true figure (29% land, 71% sea).
Which sunscreen is best?	Recording Data handling	Pupils place photochromic beads in a transparent container and record and plot a bar graph using a reference scale of 1–5 to determine which sunscreen is best at blocking UV light. Video: https://edu.rsc.org/resources/mission-starlight/2073.article
How does the angle at which a rocket is fired affect the distance it travels?	Measuring Recording Geometry Data handling	Pupils make a rocket from foam pipe insulation and an elastic band. After testing the relationship between how far the elastic band is pulled back before firing and the distance travelled, pupils use a template of an enlarged protractor to investigate the relationship between distance travelled and the angle of projection. Resource: https://bit.ly/4fybF43
Can taller people reach further?	Measurement Data handling Recording Data interrogation	Pupils line up by height from smallest to tallest along a wall. Can they do this without talking? They are then each given a sticky note; standing flat-footed they raise one arm up straight, reaching as far as they can, and stick the note onto the wall above them. When pupils step away from the wall they can observe the data; they have plotted a graph of height against reach. What is the general trend? Can taller people reach further? Are there any anomalies in the data?
Can bigger hands hold more marbles?	Measurement Area Counting Calculation Recording	Pupils draw around their hand on squared paper and count the number of full squares. They then put their hand into a bucket of marbles and grab as many as they can. They transfer these marbles to a tray and count them. They repeat this three times and find an average. Compare hand sizes around the class and the number of marbles. Plot a class graph to explore the data set.
Where is our litter coming from?	Sorting Data handling	Pupils can do a litter pick around their school grounds, gathering as many items as they can. Be aware of health and safety! Can they sort the litter into various categories/sets? Can this information be used to inform their eco practices in school and at home?
What type of bird feeders are best in our school grounds?	Data handling	Pupils participate in a bird watch and record a tally of the types of birds in their school grounds. They can then research the diets of these birds and create appropriate and appetising bird feeders for them!
Take charge: Can you make a battery?	Recording Measurement Data handling	Pupils create their own battery using 2p coins, cloth, salt water and kitchen foil. They can use multimeters to measure how the voltage increases when more coins are used. RSC Take charge Global Battery Experiment: https://rsc.li/3Ac6UNp

x-axis (volume of jar) may be made easier by rounding the value for the capacity of the jar to the nearest unit of ten. Plotting the average burning time against the volume of the jar produces a reasonably straight line.

As an extension, the activity could be presented as a problem-solving task. The class is provided with five jars of different capacities, each with its actual volume written clearly on the jar. A sixth jar is presented (with a capacity falling about the midpoint of the range) without a label. Is it possible to determine the capacity of this jar, without using a measuring cylinder? The class is provided with a candle, matches, a timer, a sheet of squared paper, a pencil and a ruler and has access to water from the tap. After allowing pupils to discuss the problem, prompts can include asking the class how the burning time and jar capacity might be recorded in a table and then presented in a graph. The volume of the unknown jar can be determined by testing how long it kept the candle alight and using the graph to find what volume this corresponds to. To conclude the activity, provide pupils with a measuring cylinder and access to water to determine the volume of this jar. Pupils will feel a great sense of achievement when they discover the actual volume is very close to the value they obtained from their investigation. Pupils' understanding of the graph can be consolidated by questions such as '*What volume would a jar need to be to let the candle burn for 25 seconds?*' or '*How long would a 150 ml jar let the candle burn for?*', thus showing how the graph can be used to determine how long any jar within this range would let the candle burn.

Conclusion

Cohen and Waite-Stupiansky (2019) identified the integrated nature of science and mathematics and specifically noted the reliance of science experiments on mathematical processes. Too often, however, the importance of the mathematics is lost in practice. As shown in our discussion and in the examples above, when time is directed towards planning for mathematics within science enquiry, pupils' science and mathematics learning can be enhanced.

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