Using mathematical skills to explore forces

Andy Markwick and **Jenny Hayward** explore how the application of mathematical skills in an inquiry-led approach deepens scientific understanding

Figure 1 Setting up apparatus to measure extension of an elastic band with different masses added

The synergy that exists between science and mathematics when integrated thoughtfully can support children's deeper understanding of scientific concepts (Markwick and Clark, 2016) and provide opportunities for children to apply their mathematical knowledge to new and authentic problems. This is particularly the case when learning is inquiry-focused, and children are encouraged to think scientifically (i.e. working scientifically, DfE, 2013a; Şamşek and Kabapınar, 2010). Force, which is a demanding concept for many learners, can be explored through investigating how the extension of an elastic band changes when masses are applied to it (Figure 1). Such an inquiry-led approach helps children to make sense of the scientific ideas in more meaningful ways and understanding deepens further when observations and measurements are quantified and visualised by applying mathematics.

The mathematics curriculum emphasises the importance of mastering mathematical concepts (DfE, 2013b) and there is no better way of assessing whether a pupil has mastered a mathematical concept than to see whether they can apply it within an unfamiliar context (NCETM, 2015; Markwick, 2019). For scientific concepts and knowledge, and mathematical knowledge and skills, that pupils might engage with in this activity see Table 1.

Effective inquiry-led learning needs to be driven by well-focused questions that support children's thinking. Not only must inquiry-focused questions provide information about the level and depth of a child's understanding for the teacher, they must also be used to show the learner what they know and what they might want to find out. Questions are also valuable tools for driving thinking during activities and to provide learners with clues about potential ways forward, acting like catalysts for progressing thinking (Artigue, 2012; Artigue *et al.*, 2012). The following account illustrates methods based on how this activity was introduced to a year 3 (age 7–8) class.

Introducing elasticity

To begin with, a simple demonstration of pulling on an elastic band was used, accompanied by foundational questions, such as *'If I pull the elastic band apart what happens to its length?', 'Why does the elastic band get longer when I pull it apart?', 'What happens to the length of the elastic band when I stop pulling it?'* Responses included *'It will get longer because you are pulling it apart', 'You are using a pulling force to make it longer', 'It goes back to its normal size'.*

These questions can lead to an understanding that applying a force will extend the length of a material. At this point, children can be introduced to the idea of extension, that is, making the length larger. This can be quite challenging for children and so it may be necessary to demonstrate this a few times by measuring the length before and after stretching and then calculating the extension. The demand of the questioning can be adapted for different learners so that they are challenged appropriately.

The method used

To start children thinking about the importance of elasticity and extension a video was shown that showed bungee jumping (e.g. www.bbc.co.uk/cbbc/watch/bp-richie-bungee-jump). Children were asked to discuss what

Mathematics ● **Enquiry** ● **Real-world science**

Table 1 The range of key skills developed in working scientifically and mathematically

Working scientifically statement (LKS2)	**Evidence**
Asking relevant questions and scientific enquiries to answer them.	*'I think the elastic will get longer with more mass'* and *'Let's see how much mass is needed to make it touch the table'.*
Setting up simple practical enquiries, comparative and fair tests.	Children were encouraged to set up their own practical inquiry to answer their questions.
Making systematic and careful observations and, where appropriate, taking accurate measurements using standard units.	Children worked together to measure mass and length.
Recording findings using simple scientific language, labelled diagrams and tables.	One person in the group agreed to record the group's data in a table.
Reporting on findings from enquiries, including oral and written explanations.	During and at the end of the activity children offered their thoughts and discussed what they had found out.
Using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions.	Children made predictions and were able to compare these with their data to draw conclusions.
Mathematics knowledge	**Evidence**
Compare and order lengths, mass (year 2, ages 6–7).	Children measured length in cm and mass in kg.
Measure, compare, add and subtract lengths (m/cm/mm) and mass (kg/g) (year 3, ages 7–8).	Children were able to calculate extension in cm.
Interpret and present data using bar charts, pictograms, and tables (year 3).	Children were able, with some help, to record data in tables and one group were able to draw a line graph.
Interpret and present discrete and continuous data using appropriate graphical methods (year 4, ages 8–9).	See above.
Solve comparison, sum and difference problems using information presented in tables (year 4).	Calculations enabled children to demonstrate their ability to work out difference.

they could see. Many focus on the person jumping, so the first question asked was '*What is happening to the rope when the person jumps?*'. Many children could see (once the clip was repeated) that the rope was flexible and getting longer at the end of the jump; it was stretching. To reinforce this, we can model how a normal piece of string and an elastic band respond to these pulling forces.

Next they were asked '*Why does the bungee rope stretch?*'. Children were able to suggest that this was due to the person's weight and some related this to the elastic property of the rope. They can be asked whether other materials, such as metal, glass and wood, might respond in the same way. Children were encouraged to use scientific vocabulary to explain why the bungee rope stretched, that is, it was elastic!

It is important that children relate the extension of the bungee rope to the mass of the person. To help them conceptualise the relationship between force (mass applied) and the extension of an elastic band we demonstrated how to set up possible equipment and ran through one example. It is also important to secure children's understanding of extension rather than just final length, that is the amount of stretch (*final length – initial length*). However, they may find it easier to just measure the final length when adding masses. Asking children to pose a research question can start them thinking about planning how they might carry out the inquiry.

For less-confident children we asked '*What might happen if I add more mass to the elastic band?*' For more-confident learners we asked '*What will happen to the extension of the elastic band if I double the mass hanging from it?*' Although we had thought that this might differentiate the concept of extension, all children were able to understand both ideas! Responses included '*It's going to get longer with more weight*', '*More weight makes it longer*' and '*If you double the weight, I think the stretch will double*'.

These responses suggested that children were able to understand that an applied force (additional weight) would result in stretching the elastic band and they were able to make predictions about the relationship between applied force and extension.

The important next stage asked children to plan how they would investigate the relationship between the extension of the elastic band and the amount of mass added to it. This may seem a straightforward idea, yet some children had not considered adding masses incrementally, but rather adding quite random amounts of mass. It was important to show how applying mathematics, that is systematic measurements, could help to explain the relationship between adding mass and the extension (Figure 2).

Figures 1 and 2 show how one group of children set up their equipment and measured lengths of the elastic bands. Figure 3 shows an example of how one group's data looked when plotted using *Excel* (by the teacher due to time constraints). It can be seen that children found that adding more mass increased the extension, with one child commenting '*Look more weight means it gets bigger*',

Figure 2 Measuring accurately and recording data

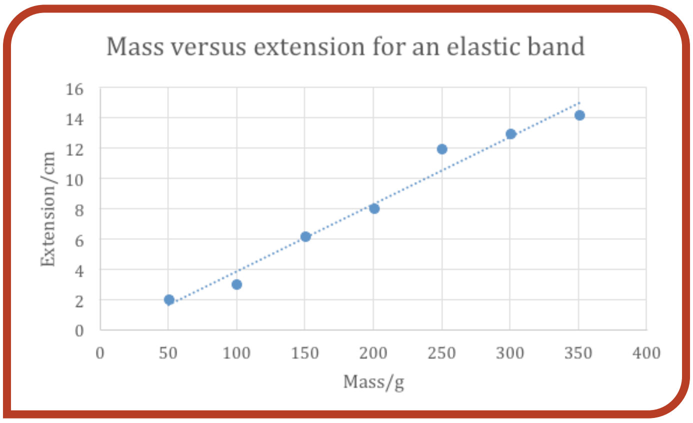

Figure 3 What the data looks like when plotted using *Excel*; this helped children to visualise how the increase in mass led to an increase in extension

and another stating that '*The band gets longer if I put on more weight*'.

Another question we asked was '*What would happen to the extension if you used two elastic bands for the same weight?*'. Children started to provide different responses, such as '*It will get shorter*' and '*It won't stretch as much because it's stronger*'; one group stated '*It's going to be half the length (extension)*'. When asked to explain this they said '*The bands are twice as strong and so won't stretch as much*'. These responses demonstrate that together children can make well-informed predictions and arrive at very plausible explanations.

Different levels of engagement

Applying more inquiry-led activities provides greater opportunity for children to think through problems for themselves with less direction from the teacher. Such an approach will often reveal a wider range in depth of understanding than more teacher-centred approaches and so for assessment we can get a much clearer picture of the children's true understanding of a concept/idea. Whether children are asking basic questions and making simple observations, noting how the extension changes with greater mass, or plotting a line graph and drawing conclusions as some groups managed to do, these all demonstrate considerable engagement and understanding of a challenging scientific concept.

The application of mathematical skills in this activity helped children to visualise and quantify the relationship between force applied to an elastic band and its extension by recognising patterns. This, and encouragement to collaborate with each other, helped them to construct sophisticated conclusions informed by their data.

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