*Physics > Big idea PFM: Forces and Motion > Topic PFM4:Measuring and calculating motion > Key concept PFM4.3: Velocity-time graphs*

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| **Key concept (age 14-16)** |
| **PFM4.3: Velocity-time graphs** |

**What’s the big idea?**

A big idea in physics is force, because it is the key to explaining changes in the motion or the shape of an object. The motion of an object can be explained or predicted if you know the sizes and directions of all the forces that act on it. Understanding forces helps us to predict and control the physical world around us.

**How does this key concept develop understanding of the big idea?**

This key concept helps to develop the big idea by building on clear and accurate descriptions of motion, in order to develop an understanding of how these can be represented on speed-time and velocity-time graphs so that a more detailed analysis of changing motion is made possible.

****The conceptual progression starts by checking understanding of how to read values from the axes of a graph, including interpreting the meaning of the sign of the velocity in one dimension. It then develops a qualitative understanding of the meaning of a graph by translating from a graph to a narrative description, and vice versa, before translating between distance-time and displacement-time graphs, and speed-time and velocity time graphs. The progression then considers the meaning of the gradient of a velocity-time graph as the acceleration of an object, and the area under the graph between two times as the change in displacement, developing an understanding of the meaning of negative gradients and areas.

**Using the progression toolkit to support student learning**

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.

**Progression toolkit: Velocity-time graphs**

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| **Learning focus** | A velocity-time graph of an object moving in one dimension can be read to find the object’s velocity at any moment of time. The gradient of the graph at a given time gives the object’s acceleration; and the area under the graph between any two times gives the change in the object’s displacement, or the distance it has travelled. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Read values of speed or velocity off a speed-time or velocity-time graph, and interpret the meaning of a negative velocity.  **P** | Describe the motion of an object from a velocity-time graph, and identify the velocity-time graph from a description of motion. | Identify the velocity-time graph corresponding to a given displacement-time graph, and vice versa. | Calculate, and explain how to work out, the acceleration of an object from the gradient of a velocity-time graph. | Calculate, and explain how to work out, the change in displacement of an object, or the distance it has travelled, from the area under a velocity-time graph. |
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| **Diagnostic questions** | Reading the graph | Telling the story | From displacement to velocity | Speeding up | Are we there yet? |
| Choosing the graph | From velocity to displacement |
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| **Response**  **activities** | Drawing graphs | Drawing the story | Translating motion graphs | Using the gradient | Calculating displacement |
| Shaping the graph |

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| Key: | | | |
| **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning |

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| **Reading the graph** | | | | **Telling the story** | | **Choosing the graph** | | | | **From displacement to velocity** | | **From velocity to displacement** |
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| Linking ideas | | | | Simple multiple choice | | Linking ideas | | | | Linking ideas | | Linking ideas |
| **Speeding up** | | | | **Are we there yet?** | | **Drawing graphs** | | | | **Drawing the story** | | **Shaping the graph** |
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| Simple multiple choice | | | | Simple multiple choice | | Application and practice | | | | PEOE | | Application and practice |
| **Translating motion graphs** | | | | **Using the gradient** | | **Calculating displacement** | | | |
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| Talking heads | | | | Application and practice | | Application and practice | | | |

**What’s the science story?**

If we want to explain why objects move as they do, we first need to be able to describe motion clearly and accurately. Objects move in a particular direction. We therefore need to work with quantities, like displacement, velocity and acceleration, that have both a magnitude and a direction. These quantities are called vectors. Quantities that have a magnitude only, like distance and speed, are called scalar quantities.

Vector quantities can be represented on a graph if the motion is one-dimensional. In this case, the sign of the vector quantity indicates the direction in one dimension. A velocity-time graph describes the motion of an object by showing its velocity at any given time.

A velocity-time graph also contains information about both the acceleration of an object, and about changes in its displacement. The average acceleration between two times is given by dividing the change in velocity by the time interval over which this change occurs:

The instantaneous acceleration can be found from the gradient of a tangent drawn at a given time.

The change in the displacement of an object between any two given times is given by finding the area under the velocity-time graph between these two times.

Both the gradient of a velocity-time graph and the area under the graph can be positive or negative, reflecting the fact that both acceleration and displacement, like velocity, are vector quantities. The signs of the gradient and the area give the directions of the acceleration and the displacement, respectively, in one-dimension.

**Earlier development of understanding (BEST 11-14)**

When applying their understanding to novel situations, students of all ages often revert to earlier misunderstandings. Before moving forward it is worthwhile using diagnostic questions from earlier topics to check that students do not have any persistent misunderstandings that can form barriers to learning. Time spent consolidating the scientific understanding of earlier key concepts before moving forward can accelerate progression later.

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| **Key concept PFM2.2: Motion graphs**  **Learning focus:** Information about the motion of an object can be summarised on a distance-time graph: the plot shows the object’s distance from the start at a given time and the slope (gradient) at that point shows its speed.  This key concept:   * Develops the ability to read and to plot distance-time graphs. * Uses this understanding to describe the motion of an object from the graph. * Introduces the idea of speed as the gradient of a distance time graph. |

**What does the research say?**

**Students have a consistent set of difficulties with graphs of motion.**

The visual presentation of data in graphical form makes graphs valuable for analysing data and, perhaps more importantly, for showing relationships between data sets (Rogers, in Carson, 1999). It is common for teachers to assume students can readily extract information from graphs when this is not necessarily the case (Beichner, 1994). Misunderstandings and difficulties in interpreting graphs arise even when students have a good understanding of kinematic concepts (position, displacement, velocity and acceleration) and are evident amongst different student populations and across different academic levels (McDermott, Rosenquist and van Zee, 1987). Even when students have the necessary mathematical knowledge about how to plot and read graphs, and how to calculate gradients and areas, they may struggle with the same skills in a physics context (McDermott, Rosenquist and van Zee, 1987; Bollen *et al.*, 2016).

**Students may have difficulties interpreting the meaning of a negative velocity on a velocity-time graph.**

When asked to think about graphical representations of velocity, students often think only about speed (Goldberg and Anderson, 1989). They may be aware that velocity is a vector quantity, with both a magnitude and a direction, but see these as completely separate properties that are not combined in a graphical representation. For these reasons, they may struggle to read velocity-time graphs, especially those that include both positive and negative values of velocity. Some students may believe that a negative quantity on a velocity-time graph implies a speed that is less than zero, which makes no sense, rather than interpreting the negative sign as meaning “in the opposite direction”.

**Students may see graphs as pictures of the motion and fail to interpret them correctly. When asked to draw a graph to represent motion, they may draw a picture of the motion rather than the correct motion graph.**

A common error that some students make is to see a graph as a literal picture of a physical situation and, rather than viewing a graph as a mathematical representation of a motion, they may see it as a sort of ‘photograph’ that duplicates the motion (Clement, 1985; Leinhardt, Zaslavsky and Stein, 1990; Beichner, 1994; Bollen *et al.*, 2016). This can make it hard for them to describe qualitatively a motion represented by a graph, or to draw the shape of a graph from a description of a motion.

Students who struggle with this ‘iconic interpretation’ may believe that plotting different kinematic variables (displacement, velocity, acceleration) against time does not change the appearance of a graph. They can find it difficult to match distance-time graphs to corresponding speed-time graphs, or displacement-time graphs to corresponding velocity-time graphs, and vice versa (Beichner, 1994).

Clement (1985) identifies two types of iconic interpretation error: g*lobal correspondence errors* describe the misinterpretation of the overall shape of a graph, which some students may think corresponds to the overall shape of the motion; and f*eature correspondence errors* that are made when individual features of a graph are misinterpreted, such as what happens at the intersection of two lines plotted on the same axes that each represent the motion of a different object.

**Students may not always understand how the graph relates to what they are trying to measure and may read values off a graph (y-co-ordinate) instead of calculating a gradient. When calculating a gradient, they may divide values of a single point rather than dividing *changes* in velocity and time.**

In a study of 700 undergraduates in Ireland, Belgium and Spain (Bollen *et al.*, 2016), students demonstrated two misunderstandings associated with the gradient of a graph: ‘interval-point’ confusion, when students focus on a single point when they should be using a range of values (for example when calculating the gradient of a graph that does not pass through the origin); and ‘slope-height’ confusion, where students confuse the height of a graph with its slope when, for example, calculating acceleration from a velocity-time graph. In a study of several hundred undergraduates and high school students in the USA, McDermott and colleagues found the same misunderstandings (McDermott, Rosenquist and van Zee, 1987). These researchers found these misunderstandings even amongst students who demonstrated a good command of kinematical concepts, and who had a good grasp of how to plot and to read graphs and of how to calculate gradients from their study of mathematics, often misinterpret what the gradient of a velocity-time graph represents.

**Students may not recognise that the area under a velocity-time graph can represent a displacement or a distance. When calculating the area under a velocity-time graph, some do not pay due regard to the scale and units on each axis and some do not understand the significance of a *negative area*.**

Students do not always understand the meaning of the area under a speed-time or velocity-time graph, perhaps because they do not understand how an area can represent a length (a distance or displacement) (McDermott, Rosenquist and van Zee, 1987; Beichner, 1994; Billings and Klanderman, 2000). On graphs showing both positive and negative velocities, students may ignore the axis and fail to understand its role in defining positive and negative areas. They may not therefore associate a positive area (an area above v = 0) with a positive displacement, and a negative area (and area below v = 0) with a negative displacement (McDermott, Rosenquist and van Zee, 1987).

**Guidance notes**

Graphs are a part of the language of science, used not only to represent data visually but also to show the relationships between variables and, as such, they are an essential part of learning science. Students may have a good understanding of how to plot and read graphs, and of how to calculate gradients and areas from their study of mathematics, and they may understand kinematic concepts (displacement, velocity, acceleration) from their studies in science. However, interpreting graphs, linking what they represent to real physical situations, and relating graphs of one kinematic quantity to those of another (e.g. translating from displacement-time graphs to velocity-time graphs) are separate complementary skills that students need to spend time developing in their science lessons.

**References**

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