*Physics > Big idea PFM: Forces and motion > Topic PFM6: Forces make things change*

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| **Key concept (age 14-16)** |
| **PFM6.2: Force, mass and acceleration** |

**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 an understanding of the effect of a resultant force in order to understand the relationship between the resultant force, mass and acceleration of an object that is free to move.

****The conceptual progression starts by checking understanding of the effect of resultant force on objects of different mass. It then develops an understanding of the relationship between acceleration, mass and the resultant force on objects, in order to enable to determine the motion of objects that are accelerating.

**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: Force, mass and acceleration**

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| **Progression toolkit: Force, mass and acceleration**  **Learning focus** | The acceleration of an object is proportional to the resultant force acting on it and inversely proportional to its mass.  An object accelerates in the direction of the resultant force acting on it. | | | | |
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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** | | | | |
| Describe the effect of a resultant force on objects of different mass.  **P** | Describe the relationship between the resultant force on an object and its acceleration. | Explain the equation  F = m x a and use it to make calculations. | Use the equation F = m x a to determine and explain the motion of falling objects. | Apply an understanding of F = m x a for a changing mass.  **B** |
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| **Diagnostic questions** | Loaded lorry | Drag race II | Spaceships | Accelerating ball |  |
| Rearranging the equation | Stopping in mid-air |
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| **Response**  **activities** | Trolley pull | |  | Free-fall | Rocketing up! |
| Dropping forces | |

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

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| **Loaded lorry** | | | **Drag race II** | **Spaceships** | | | **Rearranging equations** | | **Accelerating ball** |
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| Simple multiple choice | | | Confidence grid | Simple multiple choice | | | Simple multiple choice | | Linking ideas |
| **Stopping in mid-air** | | | **Trolley pull** | **Dropping forces** | | | **Free-fall** | | **Rocketing up** |
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| Confidence grid | | | Predict, explain; observe, explain  (PEOE) | Explanation story | | | Talking heads | | Talking heads |
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**What’s the science story?**

Inertia is the tendency of objects to maintain their current motion (or lack of motion); inertia is proportional to mass. When the resultant force on an object is non-zero, the object will accelerate. The acceleration is proportional to the resultant force and in the same direction. The resultant force on the object, and its mass and acceleration are related through the equation:

Force = mass x acceleration

In symbols: **F** = m x **a**

Both force and acceleration are vectors and have both a magnitude and a direction. This relationship is known as Newton’s second law.

The force of gravity on an object is called its weight. A freely falling object in the Earth’s gravitational field accelerates as it falls. Air resistance on the object increases with speed until the resistive force is equal to the gravitational force. As air resistance increases, the resultant force on the falling object decreases, and therefore so does the acceleration. If the speed increases to the point where air resistance is equal in magnitude to force of gravity, the object falls with a constant velocity, called the terminal velocity.

**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 PFM1.1: What forces do**  **Learning focus:** A force makes things change: the speed, direction and/or shape of an object.  This key concept:   * Develops an understanding of forces as pushes and pulls * Develops this understanding to predict the changes caused by forces acting on an object |

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| **Key concept PFM1.3: Balanced and unbalanced forces**  **Learning focus:** The resultant force is the sum of the forces acting on the object, taking into account their direction. If there is no resultant force, the forces are balanced. Unbalanced forces change the speed, direction and/or shape of an object.  This key concept:   * Develops an understanding of how to calculate a resultant force from forces acting on an object in one dimension * Develops an understanding of how motion changes in one dimension due to the resultant force |

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| **Key concept PFM2.3: Changing motion**  **Learning focus:** A resultant force on an object can cause it to speed up or slow down, depending on the direction of the force.  This key concept:   * Develops the description how speed changes throughout the time a resultant force acts * Develops an understanding of why the presence of friction means that an opposing force is necessary to keep an object in uniform motion |

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| **Key concept PFM2.4: Drag**  **Learning focus:** The drag force on an object moving through a fluid increases with its speed and can be reduced by making the object more streamlined  This key concept:   * Develops an understanding that drag increases with speed * Develops an understanding of the forces, including drag, acting on an object moving through a fluid at constant speed. |

**What does the research say?**

Students struggle to understand forces and motion, and use a system of ‘gut dynamics’ based on everyday experience in their reasoning. Understanding motion in Newtonian terms is a major task for students, and students of all ages, including physics undergraduates, fail to understand Newtonian concepts of motion (Driver et al., 1994). Even experts may struggle with basic scientific concepts such as acceleration when analysing situations in which motion changes direction in two dimensions (Reif and Allen, 1992). Students may continue to hold mistaken beliefs even when confronted with phenomena that contradict those beliefs (Gunstone and White, 1981; Halloun and Hestenes, 1985).

Students have intuitive theories about forces and motion that resemble mediaeval ‘impetus’ theory (McCloskey, 1983). They may not see force as an interaction between two objects but rather as something that resides in a single object. They may use the terms ‘energy’ and ‘force’ in an undifferentiated way (Twigger et al., 1994) and may use ideas about force in a way that resembles what a physicist means by momentum (Watts and Zylbersztajn, 1981). They may believe that a force is required to maintain motion at a constant velocity, and that a greater force is required to maintain motion at a greater velocity, so that force is seen as being proportional to velocity rather than to acceleration as in the Newtonian view. Students may believe that objects at rest, even momentarily, have no net force acting on them. They may believe that objects come to rest because the force or ‘impetus’ ‘in’ an object runs out or is dissipated by external forces such as friction (Viennot, 1979).

When thinking about forces and motion, students treat motion in a horizontal plane and motion in a vertical plane differently (Lemmer, 2013). Some students do not see weight as a force, believing that gravity is the natural tendency of things to fall. If they think of weight as a force, they may think that the force of gravity is equal on all objects, and/or that heavier objects fall faster than lighter ones, regardless of air resistance (Gunstone and White, 1981). They may believe that the force of gravity increases with height or decreases with height, or that gravity does not act on objects resting on the ground. They may believe that gravity is due to air pressure, and does not act in space or where there is no air, for example on the Moon (Gunstone and White, 1981; Watts and Zylbersztajn, 1981; Minstrell, 1982; Galili, 2001). Students may believe that when objects rise and fall in a gravitational field, upward and downward motions need to be explained differently (Twigger *et al.*, 1994). Students may not see friction as a force, and may think that friction only acts on objects in motion, or only acts in a direction opposite to motion (Twigger *et al.*, 1994).

Students may be able to use Newton’s second law when performing calculations, but a superficial knowledge of the use of formulae may mask qualitative misunderstandings and misconceptions (Viennot, 1979; Clement, 1982). They may demonstrate rote learning of Newton’s laws without an understanding of how to apply them and may focus on superficial features of physical situations rather than applying general principles (Lemmer, 2013).

The research suggests that there is little evidence of any trends with age in students conceptions about forces and motion even following teaching about Newtonian mechanics (Twigger *et al.*, 1994), and that students’ ideas about forces may be applied inconsistently, with different ideas applied to different situations according to surface features (Finegold and Gorsky, 1991; Alonzo and Steedle, 2009).

Rearranging formulae is something that students can often find challenging (Boohan, 2016). The difficulty in students being able to use maths in physics may be that they can’t do the maths, but it could also be to do with students struggling with the way symbols in equations are used to make meaning differently in maths and physics (Redish and Kuo, 2015).

In physics each symbol in an equation is connected to a physical variable. Students are required to perform mathematical operations with the equation and then connect the mathematical operations and the results of calculations to their implications in the physical world (Redish and Kuo, 2015). To show mastery in physics students should be able to explain their equations in words, however at age 14-16 students often hide an incomplete understanding as they can calculate correct answers by treating equations just as mathematical operations without a good understanding of the physics that may be necessary for their future studies.

Redish and Kuo (2015) suggest for many students, the first step in physics calculations needs to be highlighting the physical meaning, which can later be tied to the formal mathematical laws. This can help students by giving meaning to equations, so analysis of problems is no longer a ‘brittle rote procedure’. It can also lead to conceptual short cuts that enable students to access more challenging problems. For many experienced physicists, physical meaning is gained by beginning with the mathematical relations that come easily to them, but their strategy is less effective for many learners.

Boohan (2016) describes four steps to rearranging formulae involving multiplication and division: first swap sides if necessary, so the variable to be made the subject of the formula is on the left; then multiply or divide both sides by the same variable(s) to leave the subject of the equation on its own; the third step is to cancel out these variables on the left hand side. Finally students should always check that the meaning of the new equation makes sense. Through this process, confident students might take shortcuts, but Boohan recommends that teaching always emphasises an understanding of the principles by carrying out all the steps.

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