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

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| **Key concept (age 14-16)** |
| **PFM6.3: Changing momentum** |

**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 momentum and changes in momentum, in order to develop understanding of how the forces acting on an object are equal to the rate of change of momentum.

****The conceptual progression starts by checking understanding of momentum and supporting the development of an understanding of the conservation momentum. It then develops an understanding of how to determine a change of momentum in order to understand and apply the relationship between force, change in momentum and the time the force is acting.

**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: Changing momentum**

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| **Learning focus** | In a collision (or any closed system), momentum is conserved and the size of the forces are equal to the rate of change of momentum. | | | | |
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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** | | | | |
| Calculate momentum using p = m x v.  **P** | Describe what happens to the motion of objects colliding head on. | Determine changes in momentum, Δp. | Explain and use the relationship between force, change in momentum and time the force is acting. | Apply an understanding of F=Δp/Δt to explain how forces and momentum can be controlled.  **B** |
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| **Diagnostic questions** | Gaining momentum | Rugby tackle | Bouncing | Stop that! | Follow through |
| Boom! | Wet sand |
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| **Response**  **activities** | Crash test | | Wall game | Crumple zones | |

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

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| **Gaining momentum** | **Rugby tackle** | **Boom!** | **Bouncing** | **Stop that!** |
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| Simple multiple choice | Two-tier multiple choice | Confidence grid | Simple multiple choice | Two-tier multiple choice |
| **Wet sand** | **Follow through** | **Crash test** | **Wall game** | **Crumple zones** |
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| Simple multiple choice | Simple multiple choice | Application and practice – problem | Talking heads | Explanation story |

**What’s the science story?**

Forces arise because of interactions between objects and always come in interaction pairs. When one object exerts a force on another, the second object exerts a force back on the first object. The two forces are equal in size and act in opposite directions. This is Newton’s third law. The two forces act at exactly the same time and over exactly the same time interval.

Moving objects carry momentum. The momentum of an object is calculated using the equation:

Using symbols, this can be written as:

Both velocity and momentum are vectors, having both a magnitude and a direction. The direction of the momentum is the same as the direction of the velocity.

If a force acts on an object, its momentum changes. The change in the momentum depends on the time over which the force acts. The change in the momentum, the force, and the time interval over which the force acts are related by the equation:

In symbols:

When two objects collide or spring apart the objects exert equal and opposite forces on one another for equal times and so the momentum of each object changes, and the momentum changes are equal in size and opposite in direction. Therefore, the total change in the momentum of the objects, which is the vector sum of the separate momentum changes, is zero, provided that no other forces act on the objects. Momentum is said to be conserved in an isolated system, i.e. a system on which no external forces act, and the only forces are those between the objects in the system.

**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 PFM1.2: Describing forces**  **Learning focus:** Forces arise when two objects interact; the force on one object is always equal in size, and opposite in direction to the force on the other object; force arrows indicate the size, direction and location of each force.  This key concept:   * Develops the use of arrows to represent forces * Develops an understanding of forces in terms of interacting pairs of objects |

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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 the calculation of resultant forces 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 |

**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). 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 superficially resembles what a physicist means by momentum (Watts and Zylbersztajn, 1981).

Students often do not understand Newton’s third law and how it is related to momentum change and the conservation of momentum. Students who do know that forces occur in interaction pairs may not realise that forces are equal in size and act on *different* objects. They may think wrongly that two equal and opposite forces acting on a single object make up an interaction pair.

In a study of 78 high school students in the US, Brown (1989) found many students believed a moving billiard ball would exert a greater force on a stationary ball than the stationary ball would exert on the moving ball in a collision. These students argued that the moving ball ‘had’ more force than the stationary ball. The lack of understanding of forces as interactions ‘sabotages’ students conceptual reasoning and quantitative problem solving (Brown, 1989), and their understanding of momentum and momentum conservation.

Whilst most students readily accept that both mass and velocity have a direct impact on the damage that a moving object can cause when it collides with other objects, it is common for them to confuse ideas about momentum with ones about energy in a kinetic store (Bryce and MacMillan, 2009). These authors argue that thinking about the conservation of momentum without describing the external forces involved masks the universal applicability of this conservation law. Related to this is the difficulty students often have in defining what is meant by an ‘isolated system’, which may lead some to believe that the momentum of each object in a collision is separately conserved. Bryce and MacMillan (2009) also point out that in most textbooks the scenarios used for momentum calculations are usually friction free, which may leave students wondering about real world applications where objects perceptibly slow down.

Students also find it difficult to separate the concepts of energy in a kinetic store and momentum with respect to their scalar and vector nature, respectively (Singh and Rosengrant, 2003; Bryce and MacMillan, 2009). Students struggle to reason correctly about vector quantities even after studying vectors (Knight, 2004; Flores, Kanim and Kautz, 2004).

Students find questions involving impulse and change in momentum more difficult than the ‘special case’ questions where momentum is conserved (Lawson and McDermott, 1987; Pride, Vokos and McDermott, 1998; Singh and Rosengrant, 2003). In a study of over a thousand undergraduates in the US, only about 5% of students were correctly able to answer a question about momentum change caused by an impulse, regardless of the amount of instruction about the impulse-momentum theorem (Pride et al., 1998).

Students may be able to use Newton’s laws, including the third law, and ideas about momentum and its conservation, when performing calculations, but a superficial knowledge of the use of formulae may mask qualitative misunderstandings (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).

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

**Guidance notes**

Given students’ difficulties in differentiating between momentum and the energy in a kinetic store, it is important to ensure they have a good grasp of the latter. The diagnostic questions and response activities in BEST topic PFM5.1 can help to develop this understanding.

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