*Physics > Big idea PFN: Forces and motion > Topic PFM3: More about force*

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| **Key concept (age 11-14)** |
| **PFM3.1: Mass and weight** |

**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 distinguishing between mass and weight, in order to develop understanding of how gravitation force and acceleration combine to give the ‘measured weight’.

****The conceptual progression starts by checking understanding of weight and mass. It then supports the development of the relationship between mass and weight caused by a gravitational force in order to enable understanding of increased weight and weightlessness within a gravitational field.

**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: Mass and weight**

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| **Learning focus** | Mass is a measure of the amount of matter an object or substance is comprised of and weight is the force needed to support the object or substance. | | | | |
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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 weight as the force needed to support an object or substance. | Describe mass as a measure of the amount of matter in an object or substance. | Explain the relationship between the weight and mass of an object that is caused by a gravitational force. | Explain why the measured weight of an astronaut changes as they take off in a rocket.  **B** | Explain why an astronaut orbiting the Earth is weightless.  **B** |
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| **Diagnostic questions** | Which weighs more? | The biggest mass | Weight on the Moon | Blast off! | A very tall tower |
|  |  | Moon food |  | Falling weight |
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| **Response**  **activities** | Weight | Mass cans | Bathroom scales | Moving weight | |

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| Key: | | |
| **B** | Bridge to later stages of learning |

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| **Which weighs more?** | **The biggest mass** | **Weight on the Moon** | **Moon food** | **Blast off!** |
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| Confidence grid | Two-tier multiple choice | Two-tier multiple choice | Simple multiple choice | Two-tier multiple choice |
| **A very tall tower** | **Falling weight** | **Weight** | **Mass cans** | **Bathroom scales** |
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| Talking heads | Two-tier multiple choice | Simple multiple choice | Predict, explain; observe, explain | Focused cloze |

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| **Moving weight** |  |  |  |  |
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| Predict, explain; observe, explain |  |  |  |  |
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**What’s the science story?**

*Mass and weight*

Mass can be thought of as the amount of matter in an object – the sum of all the atoms that make it up. Mass is measured in kilograms. The mass of an object is always the same, no matter where the object is.

The weight of an object (the force needed to support it) is proportional to its mass. Near the Earth’s surface, the weight of a stationary 1 kg object is roughly 10 N. Most of this resultant force is caused by the Earth’s gravity. The gravitational field strength *at the surface of the Earth* is therefore 10 N/kg.

More generally, the gravitational force of attraction between any two objects is proportional to the masses of each of them, and decreases with the distance between them. So the weight of a stationary object will get less with distance from the centre of the Earth, and would be different on another planet or on the Moon.

The mass of an object is also a measure of its resistance to any change in its motion. For a given force, the larger its mass, the smaller the change of motion that results.

**What does the research say?**

*Teaching weight to avoid introducing misunderstandings*

In most text books (Galili and Kaplan, 1996; Tural, Akdeniz and Alev, 2010; Stein, Galili and Schur, 2015) and in many syllabuses and curricula (Department for Education, 2013; Department for Education, 2014) weight is defined as the gravitational force acting on a mass. The equation *weight = mass x gravitational field strength* (w = mg) clearly shows that an object with more mass feels heavier and has more weight. This is logically correct because ‘bigger mass’ describes an object which contains more matter which requires more force to lift.

There is however a problem with this definition in that it also suggests that an astronaut will be weightless only when there is zero gravity; and this is not the case. On the International Space Station (ISS) astronauts clearly experience weightlessness, yet the ISS orbits so close to the surface of Earth (about 400 km) that the gravitational force on it and on the astronauts inside is still 89% of what it is on the Earth’s surface.

Defining weight as the gravitational force on an object does not work in all situations and reinforces the misunderstanding that there is no gravity in space (Stein et al., 2015). An alternative definition of weight that is often used by teachers is: weight is the force needed to pick up an object; or alternatively weight is the force which an object pushes down on a surface. This definition works well to explain what is happening to the astronaut in the ISS. The ISS and the astronaut are both orbiting at the same speed and are following the same path, so as the astronaut falls - the ‘floor’ of the space station falls away from her at exactly the same speed. The experience of the astronaut is explained, but the equation w=mg does not work.

Weightlessness in the ISS is better explained using Newton’s second law, which states that force = mass x acceleration. If the force being measured is the force to lift a mass the equation becomes W = ma, and it is evident that the ‘g’ in W = mg is equal to an acceleration. This means that at the surface of the Earth ‘g’ is equal to the acceleration of an object in free fall; and in the space station where the acceleration of a falling astronaut is zero, W = m x zero confirms the astronaut has no weight.

What Newton did in defining weight was to (wrongly) equate the acceleration of freefall to the gravitational force (Galili, 2001; Stein et al., 2015). At the surface of the Earth these have almost exactly the same value, but they are not the same thing. For example, the acceleration of free fall of an object at the Equator is less than the gravitational force on the object - because the Earth is spinning.

The equation w = mg (where g is the force needed to lift one kilogram of mass) is sometimes said to give the ‘real weight’ of an object. The ‘measured weight’ is the weight experienced by an observer, and according to Einstein’s principle of equivalence it is impossible for the observer to determine how much of the measured weight is caused by a gravitational force and how much by the objects’ state of motion. For Einstein, gravitational force is *different* to weight force (Stein et al., 2015).

Students aged 11-14 are typically taught that weight is a force and that a particular mass will weigh different amounts on different planets or moons because of changes in the gravitational force. This is true, but teaching that weight is caused by *just* the gravitational force (whether explicitly or implicitly) leads to misunderstandings that prevent students developing a good understanding of weightlessness, of how gravitational forces extend into space, and about other related ideas they encounter later in their studies (Gonen, 2008; Stein et al., 2015). For example, Sharma et al. (2004) found that half of physics undergraduates (n=200) wrongly defined weightlessness as an absence of gravity.

To avoid teaching students about weight in a way that leads to misunderstandings, it is important to distinguish between weight caused by a gravitational force and weight caused by relative motion (Galili, 1995; Tural et al., 2010). At an introductory stage it is sufficient to teach that the weight of a mass is equal to force needed to support the mass (Galili and Kaplan, 1996; Stein et al., 2015). For a stationary mass at the surface of a planet its weight is almost entirely determined by the gravitational force between it and the planet. This is the special situation for which weight = mass x gravitational field strength is (about) the same as the measured weight. It is however important to also teach that measured weight, the weight that is experienced, can be changed by the way in which we move.

*Students’ understanding of mass and weight*

From an early age children develop a notion of the heaviness of an object by feeling how much it appears to ‘press down’. ‘Felt weight’ is typically conceived as a characteristic property of an object. The object’s mass is often associated with ‘massive’ because the words are similar. Ideas about mass can then be conflated with size or volume and some students will judge mass based on the size of an object (Mullet and Gervais, 1990; Driver et al., 1994; Galili and Bar, 1997; Stein et al., 2015).

A mass of one kilogram is properly defined by Newton’s second law, as the mass one Newton of force will cause to accelerate at the rate of one metre per second squared. At this stage it is sufficient to define mass of an object or substance as the amount of matter it contains.

Galili and Bar (1997) detected two common ways in which students aged 5-11 think about weight. Some misunderstood that “weight is a pressing force that some objects have (stones, sticks, etc.) and some do not (air, dust, etc.)”; others misunderstood that “weight is the amount of matter” that an object contains. The latter misunderstanding is understandable as teachers are often advised not to distinguish between weight and mass in presecondary teaching (National Academy of Sciences, 2012).

Driver et al. (1994) note several studies that show students do not generally think of weight as a force of gravity (Stead and Osborne, 1980; Ruggiero et al., 1985; Watts, 1982) instead this is a concept that is introduced through teaching. Watts (1982) found secondary students do not use the concept of gravity consistently, applying gravity differently to different objects and not always in the same way at all times to a particular object. When weight is defined as equal to mass multiplied by gravitational field strength and students understand that mass is unchanging, then it becomes necessary for them to apply a non-scientific and flexible approach in order to make sense of situations such as the weightlessness of an astronaut in Earth orbit.

Stead and Osborne (1980) found in a study of 11- to 14-year-olds that it is common for eleven-year-olds to think that gravity only relates to the Earth. At age thirteen (n=258) 44% do not think there is gravity on the Moon, and they commonly think that not all planets have gravity. 81% of 13-year-olds and 75% of 14-year-olds in the study did not think that there is gravity in space (Driver et al., 1994). Similarly, Galili (1995) found that the majority of students aged 14-15 (n=34) understood weightlessness to depend solely on an object’s location (a place with little or no gravity).

**Guidance notes**

There are different ways to think about weight. The equation: weight = mass x gravitational field strength defines weight as the force on a mass caused by a gravitational force. This is sometimes called ‘real weight’ and is the definition used most often in text books.

A second definition of weight is: the force needed to support an object. This is sometimes called ‘measured weight’ or ‘apparent weight’.

BEST resources use the second definition because it is more consistent with students’ experience, and does not introduce misunderstandings, that w=mg does, about weightlessness and the presence of gravity in space. It is also more consistent with Einstein’s theory of gravity.

BEST resources do allow the teaching of w=-mg as weight *caused by a gravitational force*.

The progression toolkit begins by clarifying the distinction between mass, the amount of matter in an object or substance, and weight which is the force needed to support the object or substance. This distinction is likely to be new to many students. Students then consider the connection between mass and weight caused by a gravitational force, but the equation w=mg is not used as a definition of weight. Instead students are challenged to interpret a situation in which measured weight is increased by an acceleration, and to explain the weightlessness of astronauts in Earth orbit where gravity is still large.

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