*Physics > Big idea PMA: Matter > Topic PMA1: Heating and cooling*

|  |
| --- |
| **Key concept (age 11-14)** |
| **PMA1.2: Heating and cooling** |

**What’s the big idea?**

A big idea in physics is matter. Matter is a more formal word for ‘stuff’. Anything that can be stored in a container, or weighed, is matter. Scientific ideas can help to explain why a given material behaves as it does, and may help scientists to develop new materials with specific properties.

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

This key concept helps to develop the big idea by building on the understanding that heating increases the temperature of a substance or material, to develop an understanding that if two objects at different temperatures are in contact, energy will move spontaneously from the object at the higher temperature to the object at the lower temperature, and that the temperatures of both objects will change because energy is conserved.

****The conceptual progression starts by checking understanding of what happens when cups of water at two different temperatures are mixed. It then supports the development of ideas about the dissipation of energy as a hot object cools down in order to enable understanding of the law of conservation of energy.

**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: Heating and cooling**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Learning focus** | If two objects at different temperatures are in contact, energy will move spontaneously from the object at the higher temperature to the object at the lower temperature. | | | | |
|  |  |  |  |  |  |
| **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** | | | | |
| Make qualitative predictions about the resulting temperature when hot and cold water are mixed.  **P** | Make quantitative predictions about the resulting temperature when hot and cold water are mixed. | Describe how the temperature of very hot water changes as it cools. | Explain how energy dissipates as a hot object cools down. | Apply the law of conservation of energy to explain what happens to energy in novel situations.  **B** |
|  |  |  |  |  |  |
| **Diagnostic questions** | Mixing water | | Just cool? | Cooling tea | Hot house |
|  |  |  |  |  |  |
| **Response**  **activities** |  |  | Cooling curve | Warm scarf |  |

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Mixing water** | **Just cool?** | **Cooling tea** | **Hot house** | **Cooling curve** |
|  |  |  |  |  |
| Simple multiple choice | Confidence grid | focused cloze | Confidence grid | Predict, explain, observe, explain practical/demonstration |
| **Warm scarf** |  |  |  |  |
|  |  |  |  |  |
| Talking heads |  |  |  |  |

**What’s the science story?**

The temperature of an object is a measure of how hot it is. It can be measured using a thermometer (in degrees Celsius, oC). To raise the temperature of an object, energy has to be transferred to its thermal store (gained by it). To lower the temperature of an object, energy has to be transferred from its thermal store (lost by it).

The amount of energy stored in a hot object depends on its temperature – the hotter the object, the more energy is stored. Also if two objects made of the same material are at the same temperature, the bigger (more massive) object stores more energy.

If two objects at different temperatures are in contact, energy will move spontaneously from the object at the higher temperature to the object at the lower temperature. The ‘other object’ might simply be the surrounding air. The rate at which energy moves depends on the temperature difference and the nature and thickness of the material(s) between the two objects. Materials which significantly reduce the rate of energy transfer by heating are called thermal insulators.

If several objects and materials are left for some time in contact with one another, all of them will reach the same temperature (thermal equilibrium).

To keep an object at a steady temperature above that of its surroundings, energy has to be supplied to it at the same rate as it is losing energy to its surroundings. Similarly to keep an object at a steady temperature below that of its surroundings, energy must be removed from it at the same rate as it is gaining energy from its surroundings.

**What does the research say?**

It is important for students to understand that temperature is an indication of the concentration of energy in an object. If two objects made of the same material are at the same temperature, the bigger (more massive) object has more energy in its thermal store. In a study of 8- to 14-year-olds (n=324) it was found that one in six 13- to 14-year-olds, and half of 12-year-olds thought that larger ice-cubes had a lower temperature than smaller ones because they take longer to melt (Driver and Russell, 1982).

Students are usually good at predicting that when samples of hot and cold water are mixed, the temperature of the mixture is somewhere in the middle. When samples are mixed students need to use the idea that temperature is an intensive property in order to predict that the resulting temperature. Some students are likely to get this wrong because they confuse temperature with an amount of energy and adding more water adds more energy. When a value for the temperature of each sample is given some students add or subtract the temperatures, applying a mathematical process without appearing to think about what happens. (Erickson and Tiberghien, 1985; Driver et al., 1994; Millar, 2011)

The difference between temperature and a thermal store of energy is a crucial idea in the understanding of thermal concepts. When an object is warmed up its temperature rises, the amount of energy in its thermal store increases and the particles in the object move or vibrate more. All of these changes are interconnected and happen at the same time. More specifically, and at a level students may encounter later in more advanced studies, temperature is a measure of the average amount of energy in the kinetic store of the particles and the extra energy gained by the particles increases the energy in the thermal store (Institute of Physics). Out of a sample of 15- to 16-year-olds (n=178), 36% had the misunderstanding that temperature could be transferred from one object to another (Chu et al., 2012).

The conservation of energy is not something that can be conclusively demonstrated to students, but as it is *the* essential feature of our understanding of energy it must be strongly asserted.

It will make it easier for students to accept the idea of the conservation of energy if it is taught at the same time as the idea of dissipation of energy. Drawing students’ attention to examples of dissipation of energy and encouraging them to identify unintended transfers of energy by heating can help them to reconcile conservation with their everyday experience of energy being ‘lost’. Dissipation identifies what has happened to the ‘missing’ energy. (Fairhurst, 2018)

In teaching energy the BEST resources have adopted a framework based on ‘energy stores’ and ‘energy pathways’ which is advocated by, amongst others, (Boohan, 2014), (Millar, 2014) and (Tracy, 2014). As Millar (2014) says, this approach “is not perfect - but it is adequate and significantly better than [approaches] based on lists of ‘forms of energy’.” A clear guide to this approach can be found on the Institute of Physics’ website (Institute of Physics) and in BEST approaches: Teaching energy (Fairhurst, 2018).

The progression toolkit for *heating and cooling* reminds students that adding hot water to cold makes warm water and challenges them to make quantitative predictions about the resulting temperature of the warm water. By considering what happens to the temperature of hot water when the cup it is in is placed into a cold water bath, they start to explore how energy is dissipated from an object by heating the surroundings. Further activities give students the opportunity to explain how dissipation works and to apply their understanding of this to new situations. A bridging activity challenges students to explain how objects can be kept at a steady temperature that is higher than their surroundings.

**Guidance notes**

*Problems with ‘heat’*

The use of the word ‘heat’ as a noun in colloquial speech can cause problems because it implies that ‘heat’ is a substance that can flow. For example in the phrases: ‘close the door to keep the heat in’; or ‘the kettle has gained heat’ (Erickson and Tiberghien, 1985). For this reason is good practice to avoid using the word ‘heat’ when describing heating and cooling effects. More accurately when one object is *heating* another, energy is being transferred. The BEST key concept: *PMA1.4 Thermal store of energy* describes how this energy is transferred into or out of a thermal store by heating.

**References**

Boohan, R. (2014). Making sense of energy. *School Science Review,* 96(354)**,** 11.

Chu, H.-E., et al. (2012). Evaluation of Students' Understanding of Thermal Concepts in Everyday Contexts. *International Journal of Science Education,* 34:10**,** 1509-1534.

Driver, R. and Russell, T. (1982). An investigation of the ideas of heat, temperature and change of state of children aged between 8 and 14 years. Leeds: University of Leeds.

Driver, R., et al. (1994). *Making Sense of Secondary Science: Research into Children's Ideas,* London, UK: Routledge.

Erickson, G. and Tiberghien, A. (1985). Heat and Temperature. In Driver, R., Guesne, E. & Tiberghien, A. (eds.) *Children's Ideas In Science.* Milton Keynes and Philadelphia: Open University Press.

Fairhurst, P. (2018). Teaching Energy. [Online]. Available at: <https://www.stem.org.uk/best-evidence-science-teaching>.

Institute of Physics. *Supporting Physics Teaching (SPT): Energy* [Online]. Available at: <http://supportingphysicsteaching.net/EnHome.html> [Accessed July 2018].

Millar, R. (2011). Energy. In Sang, D. (ed.) *Teaching Secondary Physics.* London: Hodder Education.

Millar, R. (2014). Teaching about energy: from everyday to scientific understandings. *School Science Review,* 96(354)**,** 6.

Tracy, C. (2014). Energy in the new curriculum: an opportunity for change. *School Science Review,* 96(354)**,** 11.