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

|  |
| --- |
| **Key concept (age 11-14)** |
| **PMA1.3: Thermal conduction** |

**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 makes the particles in a material move more quickly, to develop a more general understanding of how the particles throughout a material are caused to vibrate more quickly by the process of conduction.

****The conceptual progression starts by checking understanding of which materials are thermal conductors or insulators. It then supports the development of ideas about vibrating particles to explain heating by conduction, in order to enable understanding of how insulators can be used to slow down heating and cooling.

**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: Conductors and insulators**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Learning focus** | Heating makes the particles in a material move more quickly. Heating raises the temperature quickly throughout a good thermal conductor, and very slowly through a good thermal insulator. | | | | |
|  |  |  |  |  |  |
| **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 speed at which the temperature increases along a thermal conductor compared to a thermal insulator. | Identify materials that are good thermal conductors or good thermal insulators. | Use the idea of vibrating particles to explain heating by thermal conduction. | Explain how insulators can be used to slow down heating and cooling. | Explain why it is common for thermal insulators to feel warm and thermal conductors cold.  **B** |
|  |  |  |  |  |  |
| **Diagnostic questions** | Hot soup | Conductor survey |  | Ice melt | Warm feeling |
|  |  |  |  |  |  |
| **Response**  **activities** |  | Hot rods | Hot vibrations |  | Cool rod |

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

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Hot soup** | **Conductor survey** | **Ice melt** | **Warm feeling** | **Hot rods** |
|  |  |  |  |  |
| Focused cloze | Confidence grid | Two-tier multiple choice | Confidence grid | Predict, explain, observe, explain practical/demonstration |
| **Hot vibrations** | **Cool rod** |  |  |  |
|  |  |  |  |  |
| Sequencing | Talking heads |  |  |  |

**What’s the science story?**

If different parts of a metal object are at different temperatures, energy moves spontaneously (and quite rapidly) from the region at higher temperature to the region at lower temperature. This process is called thermal conduction. Non-metals are, in general, less good thermal conductors. Some, such as materials that contain trapped air pockets, are good thermal insulators.

At room temperature, thermal insulators feel warmer to the touch than conductors (such as metals, glass, stone and ceramics), because they do not allow energy to be transferred as quickly from our body (the core of which is at 37oC – well above room temperature).

**What does the research say?**

Although it is a misunderstanding, it can make sense to think that because a plastic chair feels warmer than a metal one it contains more energy in its thermal store. This is a view that Chu et al. (2012) found was held by over 35% of 14- to 16-year-olds (n=344). They also found a similar proportion of 14- to 15-year-olds (n-=178) thought that objects taken out of a fridge felt colder because they contained more ‘cold’. Students aged 12-to 15-years-old do not tend to examine temperature differences and explain phenomena in terms of the direction of energy flowing between thermal stores. Instead they often link properties of an object with what will happen: if it feels cold it will cool, and if it feels warm it will warm. (Erickson and Tiberghien, 1985)

Students are typically very good at identifying materials that are good thermal conductors or insulators, and recognise in particular that metals are good conductors. However, this does not mean that students have a clear understanding of conduction and insulation. It is fairly common for students to describe good conductors as materials that heat or cool quickly (Erickson and Tiberghien, 1985). This is subtly different to understanding that energy is quickly transferred through a good conductor by heating. For example, heating the end of a glass rod (insulator) with a Bunsen burner will quickly increase the temperature of the end of the rod, but the rod will not transfer energy along its length at all quickly.

Textbooks often explain thermal conduction in terms of increased vibration of the particles in a hot region of an object causing their neighbours to vibrate more rigorously, and so on through the material of the object. This explanation does not, however, account for why metals are good conductors whereas non-metals (usually) are not. In fact this model only explains the very slow conduction through insulators (and *one* of the modes of conduction through a conductor). To avoid confusion it is important to explain, at this stage, the more rapid conduction in metals in terms of the movement of free electrons. (Millar, 2011)

In a study Chu et al. (2012) found that more than a quarter of 14- to 16-year olds (n=344) thought that materials like wool have the ability to warm things up. Measuring the time for an ice-cube to melt when it is wrapped in wool compared to another ice-cube wrapped in aluminium foil challenges this misunderstanding. An account of why the ice-cube wrapped in foil melts first needs to be explained in terms of how a good conducting material transfers energy by heating more quickly than an insulator. The scientific approach is to consider the system, to identify where the temperature is higher and to consider how the energy can be transferred by heating to where the temperature is smaller. (Erickson and Tiberghien, 1985)

The progression toolkit for *thermal conduction* begins by identifying objects that are good conductors or insulators in order to develop students’ understanding of conduction as the flow of energy by heating, from where the temperature is higher to where it is lower. A commonly used thermal conduction practical has been modified to emphasise this idea. Students are given the opportunity to reflect on a model of thermal conduction to explain conduction in solids generally and metals in particular. They are challenged to apply their understanding of this to several new situations.

**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: *PMA1.3 Thermal energy store* describes how this energy is transferred into or out of a thermal energy store by heating.

A poor conductor such as glass is often described as an insulator. Glass is a poor insulator, and it is true that poor insulators are also poor conductors. In this key concept poor conductors such as glass have been described as insulators to match the terminology used in most courses at this level. Super-conductors and perfect insulators are at opposite ends of a continuum, which is not clearly defined in the middle.

The energy stores and pathways approach is described more fully in ‘BEST Approaches: Teaching energy’ (Fairhurst, 2018).

**References**

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., 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>.

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