*Physics > Big idea PMA: Matter > Topic PMA3: Energy of moving particles*

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| **Key concept (age 14-16)** |
| **PMA3.2: Specific heat capacity** |

**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 developing an understanding of the physical meaning of specific heat capacity, in order to prepare students for solving problems involving specific heat capacity.

The conceptual progression starts by checking understanding of the distinction between temperature and energy in a thermal store. It then supports the development of understanding the physical meaning of specific heat capacity in order to enable calculations to be completed accurately and with insight and understanding.

**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 different materials**

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| **Learning focus** | Specific heat capacity is the amount of energy added to the thermal store of a material in order to increase the temperature of 1kg of that material by 1oC. | | | | |
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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** | | | | |
| Distinguish between energy in the thermal store of an object and the object’s temperature.  **P** | Describe what a material’s specific heat capacity indicates about the amount of energy transferred as it changes temperature.  **P** | Explain why a material’s specific heat capacity affects the rate at which its temperature will change as its thermal store gains or loses energy. | Predict how one quantity in the equation ΔE = mcΔΘ is affected by changes to other quantities. | Make calculations using the equation ΔE = mcΔΘ. |
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| **Diagnostic questions** | Hot water | Metal and ice | Hot drinks | Side-by-side | Rearranging specific heat capacity |
| Energy in a thermal store |
| Fresh bread | Bed warmers |
| Temperature change |
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| **Response**  **activities** |  | Calorimeters | Hot water bottle |  |  |

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| Key: | | | | | | |
| **P** | Prior understanding from earlier stages of learning | |  | |  | |
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| **Hot water** | | **Fresh bread** | | **Metal and ice** | | **Hot drinks** | | **Bed warmers** |
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| Two-tier multiple choice | | Confidence grid | | Simple multiple choice | | Simple multiple choice | | Confidence grid |
| **Side-by-side** | | **Energy in a thermal store** | | **Temperature change** | | **Rearranging SHC** | | **Calorimeters** |
|  | |  | |  | |  | |  |
| Two-tier multiple choice | | Simple multiple choice | | Simple multiple choice | | Simple multiple choice | | Predict, explain; observe, explain  (PEOE) |

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| **Hot water bottle** |
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| Focused cloze |

**What’s the science story?**

Heating a system will change the energy stored within the system and raise its temperature or produce changes of state.

Specific heat capacity of a material is the amount of energy required to raise the temperature of one kilogram of the material by 1oC (or one Kelvin).

The amount of energy required to increase the temperature of a material is calculated by multiplying the mass of the material by both its specific heat capacity and the increase in its temperature.

**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 to check that students do not have any persistent blocks on their learning. Time spent consolidating the scientific understanding of earlier concepts before moving forward can accelerate progression later.

**Key concept: PMA1.4 Thermal store of energy**

Learning focus: each different material will have more energy in its thermal store if either its temperature or mass is increased.

This key concept:

* Develops understanding of energy in a thermal store.
* Distinguishes between energy (in a thermal store) and temperature.
* Introduces the equation ΔE = mcΔΘ to calculate the quantity of energy needed to increase the temperature of a material.

**What does the research say?**

Some misunderstandings about thermal ideas are both common and persistent (Erickson and Tiberghien, 1985; Driver et al., 1994), so it makes sense to check students understanding at each stage of their learning to make sure you are building on a good understanding of the key concepts before progressing with new ones. For example, a significant minority of students continue to confuse the concepts of temperature and energy throughout their secondary science education (Driver et al., 1994; Chu et al., 2012; Adadan and Yavuzkaya, 2018).

Most students correctly understand that raising the temperature of a particular object also increases the energy in its thermal store. However, fewer than half (n=342) of 11- to 15-year-olds in a study by Gonen and Kocakaya (2010) understood that, when they are at the same temperature, a larger mass of a material contains more energy in its thermal store than a smaller mass of the same material. It is common for students to think that an object at a higher temperature has more energy in its thermal store than an object at a lower temperature, even when the hotter object has a much smaller mass.

By age 13-14 Adadan and Yavuzkay (2018) found that about 50% of Turkish students (n=305) showed a clear scientific understanding of thermal concepts, increasing to 65% of those age 15-16 (n=213). However, they also found that 10-20% of 13- to 14-year-olds continued to regard heat as a material substance that could flow and that the numbers of those with this misunderstanding did not change much with age. In a separate study of 16- to 19-year old Korean students (n=515), Chu et al. (2012) found similar levels of understanding of thermal concepts. They also found that whilst many students could apply a scientific understanding well to situations they had studied, a large minority of students still had some difficulty applying the same concepts to everyday situations. Adadan and Yavuzkay’s study (2018) actually found that as students got older and their understanding of thermal concepts improved, the way in which they applied their scientific understanding to new situations became increasingly inconsistent.

Vosniadou (2013) suggests that students may not apply their scientific understanding to new situations for one of two reasons. Their understanding may have become fragmented as they learnt new scientific concepts without fully integrating them into a consistent internal framework. This disconnect means that students to not notice a problem in applying scientific understanding to some situations and non-scientific understanding to others. Alternatively students may have integrated new scientific understanding into an existing (not entirely scientific) framework to form a more advanced misunderstanding - a synthetic understanding caused by attempting to square scientific with non-scientific understanding. Giving students opportunities to discuss everyday applications of thermal concepts in small groups is one way to support them in moving towards a more consistent scientific framework, through the social construction of scientific understanding through focused dialogue.

In addition to mass and temperature, the other factor that affects the amount of energy in the thermal store of a material is the specific heat capacity of the material. This is a measure of the amount of energy needed to raise one kilogramme of a material by one degree C. All sort of factors affect what the specific heat capacity of a particular material is. Never-the-less, specific heat capacity is a value that can be calculated from just a few measurements and then used to predict how a material will respond to heating or cooling.

Herrington (2011) suggests the traditional method of teaching specific heat capacity, which involves learning the related definitions and equations and using equations to determine the specific heat capacity in a laboratory setting contributes to confusion about specific heat capacity. Although students are often able to calculate values with the equation, they often do not often understand what specific heat capacity tells us about a material. Instead it can be more effective to introduce students to the concept of heat capacity and to guide them to make connections to their own personal experiences before introducing definitions and equations.

One way to think about specific heat capacity is as a measure of how hard it is to change the temperature of a material. For two objects of the same mass, the one with the bigger specific heat capacity will be harder to warm up as it requires more energy to increase its temperature by 1oC. The same object will also be more resistant to cooling down, as it needs to transfer more energy to its surroundings in order to reduce its temperature by 1oC. Adadan and Yavuzkaya (2018) found that 35% of 13- to 16-year-olds (n=518) had the misunderstanding that objects that warm up readily retain their temperature better than objects that are harder to heat up.

In this progression toolkit an understanding of the physical meaning of specific heat capacity is developed before introducing its formal definition and the mathematical equation from which it can be calculated. This allows explicit links to be made between students’ physical understanding and the mathematical operations, and this helps students to understand the equation in terms of its implications in the real world (Redish and Kuo, 2015).

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.

**Guidance notes**

This key concept may be followed with an investigation to measure the specific heat capacity of a solid or a liquid.

A detailed investigation to measure specific heat capacity involving the calculation of energy input using the equation E = IVt is often competed by students during later studies in physics, at age 16-19. This method involves measurements of current, voltage and time, in addition to mass, and temperature change. At age 14-16 the measurement of energy can instead be made more directly. If an electrical heater is used it can be plugged into a Joule meter to measure the energy it supplies during the investigation. Alternatively the instruction for the practical could require students to turn an electrical heater on for a specified amount of time with the quantity of energy the heater transfers in that time being told to them.

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