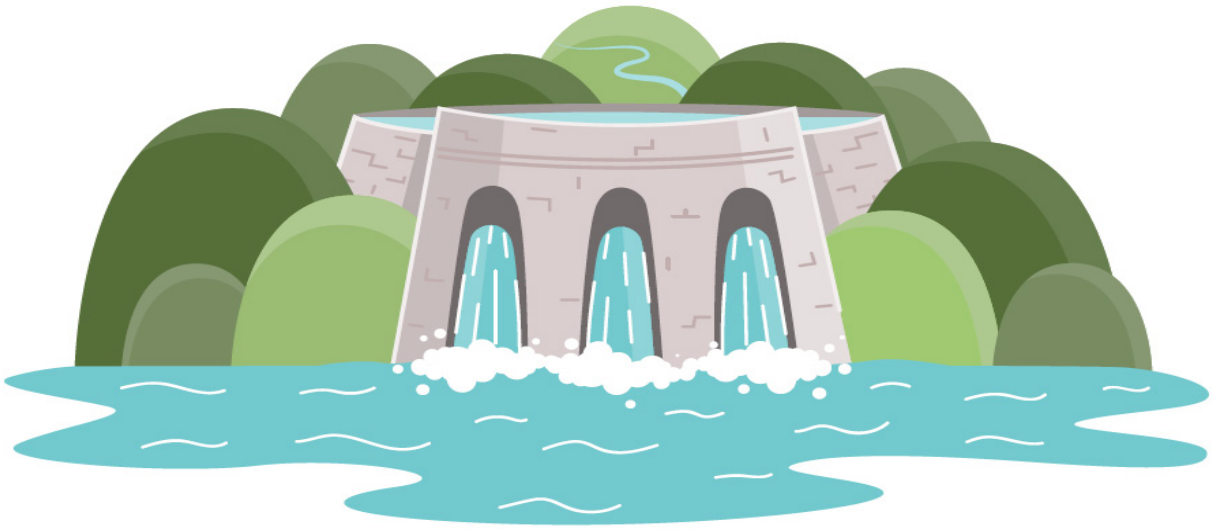
BBC TERRIFIC SCIENTIFIC

Teacher Resource



Water
Investigating the Mpemba effect.

Water

Terrific Scientific Campaign

Investigation: Water

Hello! Welcome to the Water Investigation from the Terrific Scientific campaign!

At BBC Terrific Scientific, we think it is vital to develop science learning in primary schools across the UK. By taking part in this activity, you will be developing your class's scientific thinking and investigative skills.

At Key Stage 2 (Second Level), **children need to:**

- **Develop** investigative skills.
- **Understand** when it is important to control variables.
- **Predict, observe and record** results.
- **Draw conclusions** (which may generate new questions).
- **Understand** the need to repeat activities.
- **Record** what they see and not what they want to see.

We have incorporated these principles into this exciting activity. We've made it suitable for primary classrooms by using readily available equipment and suggesting opportunities for support and differentiation.

The BBC deems this activity safe if following some basic precautions. It is your responsibility as a School to carry out your own risk assessment and we recommend you consider the risks and mitigations we have described in this activity pack, as well as any risks which may be relevant to your specific class environment.

As well as these key working scientifically principles, we have made sure there are links to the science curriculum for each nation, as well as cross curricular opportunities for further learning. We think these are just as important, as they help to explain the relevance of Science and how it links to the world around us.

On our website you will find a supporting 'How to' film which shows teachers and teaching assistants how to set up and carry out the experiment. You will also find additional resources including a step-by-step lesson presentation, including an introductory film which sets the investigation into context for your students.

We originally partnered with the University of Southampton for this investigation.

We hope this inspires you and your students to get scientific!

The Terrific Scientific Team.

Related links:

Find out more about Terrific Scientific and our other investigations on – bbc.co.uk/terrificscientific

Supported by: University of Southampton, Royal Society of Chemistry, Primary Science Quality Mark, Geological Society.

Contents

This pack will support you to investigate the Mpemba effect with your class, by gathering data to compare the freezing points of warm and cold water.

Learning intention

Children will investigate whether starting water temperature affects the time it takes for water to freeze.

Children will compare differences in freezing times of hot/warm water and cooled tap water to investigate what is commonly known as 'The Mpemba Effect'.

Children will discover and record the hardness of the water in their school.

Investigation:

We'd like you to investigate your tap water freezing times, by timing how long it takes cold water to freeze compared to hot water in your school's freezer.

The activity will:

- **Enthuse children in Science,** underlining the principle that Science is accessible to all.
- **Demonstrate** helps us to understand the world around us.
- **Gather** evidence through practical activities, observations and controlled investigations.
- Allow children to see that their results can directly **contribute** to further scientific study.
- **Develop** student's investigative skills, as well as building conceptual understanding.
- Help children to **understand** that all results are valid, even if unexpected.

What will the children learn? (England, Scotland, Wales and Northern Ireland)

England

Working scientifically

- Planning different types of scientific enquiries to answer questions, including recognising and controlling variables where necessary.
- Taking measurements, using a range of scientific equipment, with increasing accuracy and precision, taking repeat readings when appropriate.
- Recording data and results of increasing complexity using scientific diagrams and labels, classification keys, tables, scatter graphs, bar and line graphs.
- Using test results to make predictions to set up further comparative and fair tests.
- Reporting and presenting findings from enquiries, including conclusions, causal relationships and explanations of and degree of trust in results, in oral and written forms such as displays and other presentations.
- Identifying scientific evidence that has been used to support or refute ideas or arguments.

Chemistry

- Observe that some materials change state then they are heated or cooled, and measure or research the temperature at which this happens in degrees Celsius.

- Compare and group together everyday materials on the basis of their properties, including their hardness, solubility, transparency, conductivity (electrical and thermal), and response to magnets.

- Know that some materials will dissolve in liquid to form a solution.

water changing state, relating to everyday experiences.

Scotland

- Sciences; experiences and outcomes.
- Sciences; planet earth; processes of the planet; water changing state, relating to everyday experiences.
- Sciences; materials; chemical changes; the properties of water.
- Sciences; topical science (discussing Mpemba's experiment).
- Sciences; materials; properties and uses of substances; Exploring properties and changes in substances,

Wales

- Skills; Enquiry, planning, developing, reflecting.

Northern Ireland

- The world around us: Science and technology; change over time from key questions.
- How do things change?
- What kind of changes happen?
- Can we stop unwanted changes?

Investigating the Mpemba Effect

Introduction

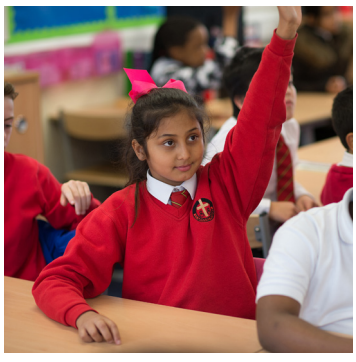
Some scientists have discovered that water doesn't always freeze how you would expect. Erasto Bartholomeo Mpemba was a young student of 11 or 12 years of age at school in Tanzania when he observed a phenomenon which today carries his name, all because he was in a rush to freeze hot cream. It had previously been observed by Francis Bacon, and even Aristotle, but the Mpemba Effect was first tested in detail in 1969 by Erasto Mpemba and Denis Osborne.

During our original investigation in February 2017 scientists at the University of Southampton were investigating the Mpemba Effect, to see if this discovery could be more widely applicable. To do so, they needed lots of people to repeat the same scientific investigation and we asked schools across the UK to send in their data. Although the study has now finished, you can still complete the investigation, conducting controlled comparative tests using your tap water

For more resources on Water and some ideas for additional lesson activities see our 'additional activities' section below.

Ask:

If your class wanted to make ice cubes or ice lollies quickly, would it be better to use cold water or warm water? Which would freeze faster?



Resources

- 1 Litre of tap water, cooled overnight in a fridge.
- Container to hold cold water.
- Plastic measuring cylinder.
- 1 Litre of heated tap water 50°C (See 'teacher notes' for safe heating and transporting).
- Safe, suitable insulating container to hold hot water.
- Plastic shot glasses (to be referred to as mini cups) – two per student OR minimum of 50 in total.
- Small, clear plastic trays (take away food type) – enough for all measuring cups to fit in freezer, plus some to examine the results.
- Freezer access with enough space for small trays.
- Large trays to contain spillages – one per group.
- Insulating box to bring samples to and from the freezer.
- Timer.
- Markers – one per group.
- Thermometer.
- Paper towels to clear any spillages.
- Water hardness strips (these are available online inexpensively, we recommend strips that have 5 possible results)
- Gloves.

Notes:

Extra items may be needed if extension investigations are undertaken while the water is freezing. See 'teacher notes' for suggested extension activities.

Please use recycled, compost-able or recyclable plastic wherever possible.

Expected duration

Approx. 2.5 hours. **NB:** There will be time between the set up and conclusion when you could carry out other activities. It is possible the activity could over run depending on the efficiency of your freezer and the activities you conduct in the classroom during freezing and after you have collected your results. Please allow enough time for preparation and rehearsal also.

Teacher preparation

We recommend:

To minimise the risk of water spillage each group can be given a tray on which to carry out the investigation and paper towels to clear up any spillages.

- We recommend you do a ‘dummy run’ yourself note down how long it takes before ice begins to form. If it begins to form before 80 minutes, note down this time, and adjust your student worksheets and plan to start timing the investigation in the classroom from this time onwards.

- Freezing time can be influenced by how often the freezer is opened, the type of freezer (chest or upright) etc. By having a ‘dummy run’, you will have a guide as to when you need to start taking more frequent readings when the water begins to freeze. Knowing this approximate time also allows you to plan other related activities which can be carried out while the water samples are in the freezer (See additional activities).

- For the ‘student worksheet’, plastic shot glasses have been referred to as ‘mini cups’, and should be referred to as such for the duration of the investigation.

- Prior to the lesson put the tap water (in a clean container) into a fridge to cool overnight. This is because a large temperature difference is required between cool and warm water. Leaving the tap water to cool overnight will be ideal, but a minimum of three hours is required.

Watch the film:

Our 'introduction film' will be really useful for introducing the investigation to your students. On our website you will find an online lesson presentation including this film, learning objectives and the steps of the investigation to share with your class.

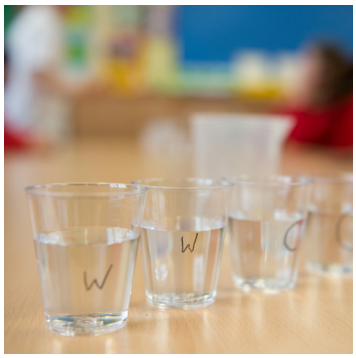
Notes:

New theories are constantly being explored to try to explain what has been observed.

- We recommend you heat the tap water to 50°C. In some schools, the staff room may have a wall heater. This can be used by adding cold tap water to lower the temperature. If a kettle is used, our advice is to rinse it out to flush loose scale and then boil tap water. Heat the water and test the temperature at intervals (you might want to pour a little into a warmed cup) until you reach 50°C. It should be poured into an insulated cup/flask with a lid for transporting to the classroom.

- Plan how you will introduce the investigation question. Talk about what happened when liquids freeze (a reversible change from liquid to solid) and how this change occurs when the temperature is reduced. Talk about how we recognise that freezing has taken place. Tell the children about the young Erasto Mpemba trying to make ice cream in a hurry and putting warm cream in the freezer. Ask the children what they thought happened. **How long do they think it took the warm cream to freeze compared to if he had frozen cream that was cold?** You can tell them that Mpemba noticed that the warm cream froze faster than he expected. He wondered if all warm liquids freeze faster than cold ones and went on to test this. **How do you think he did that? Do you think the same thing happens with water? How could you test it?**

- This is a great example of science being counter-intuitive and therefore a really good opportunity to talk about how science works - careful observation of phenomena (the warm cream froze faster) leads to questions (do warm liquids freeze faster than cold?) which are then tested against evidence (freezing times of different temperature liquids).



Ask:

Does warm water freeze faster than cold water?

What evidence could they to collect to answer it?

Is it a good plan?

Will the evidence collected answer the investigation question?

- Help children to plan an investigation to test Mpemba's findings. **Does warm water freeze faster than cold water? What evidence could they collect to answer it?** Students should be shown the equipment and told of the availability of a freezer. Talk about the importance of collecting accurate, valid and reliable data by: controlling the amount of water in the cups and putting the samples in the same freezer; and repeat testing (collecting several sets of results and working out the mean freezing time).

- Instructions for the investigation are provided to ensure that the results collected from across the country can be compared. Talk about these with the children. **Is it a good plan? Will the evidence collected answer the investigation question?**

- This is a comparative test, comparing two set of data: the time taken for water at two different starting temperatures to freeze. Children are investigating whether warm water freezes faster than cold water.

- As they are not collecting continuous data (water at a range of temperatures between cold and hot) they will NOT be able to draw a cause and effect conclusion i.e. the higher the temperature the less taken to freeze.

- Before starting, it may be useful to demonstrate how the students are expected to fill the mini cups by marking them at 25ml and carefully filling to this level.

Main Activity

1. The class should be split into small groups (e.g. groups of 3-5).

2. Each group should be given 3 clear plastic takeaway food trays, two plastic mini cups per child and a permanent marker pen.

3. Students should clearly mark their mini cups; one with ‘C’ (cold) and the other with ‘W’ (warm). They DO NOT need to mark their names/ groups. A line should be drawn on each mini cup at approximately 25ml.

- Prior to the lesson, it may be useful to measure 25ml using a measuring cylinder and pour this into a mini cup to see where it comes up to. A line should be drawn at this level, and this would then be the level children are advised to fill their cups up to.

4. Mini cups marked ‘W’ should then be given to staff in one of the clear plastic trays.

5. Staff should bring the cold and warm water to the class in suitable containers. The temperature of each should be taken by staff and noted down.

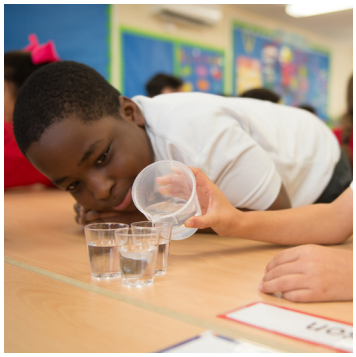
6. All groups should be given a beaker of cooled tap water. Children should take it in turns to each fill a mini cup to the level indicated. They are then to be placed into the second clear plastic tray.

- Prior to the investigation, children could practice filling cups so they learn to do this quickly and accurately. This is to ensure the water does not warm to room temperature during the activity.

7. Staff (plus students if possible) should collect all ‘C’ filled trays ready to go into the freezer.

Film:

Please make sure you have viewed the ‘How to’ film for this investigation available on our website: bbc.co.uk/programmes/p04fpy5l



Testing water hardness:

Water hardness testing strips are available to order online from many science and educational suppliers.

8. Staff should then measure warm water into ‘W’ mini cups and place in separate trays.

- It is important for the investigation that the water does not cool down, so this should be done at the last possible moment, after all the ‘C’ cups are collected.

9. Staff should take all samples and place them in the freezer. The starting time should be written down so time taken to freeze can be calculated later.

10. After **80 minutes** (or less, depending on your ‘dummy run’), staff should collect 4 mini cups from the freezer (2 ‘C’, 2 ‘W’) and bring these to the classroom in an insulated box.

11. Each group should be given a mini cup (if there are not enough, ask groups to join together). The contents of each cup should be poured into a plastic tray for the groups to look at. How much the water has frozen should be recorded in their results table.

- How much has frozen will range from none to completely. The method of measuring and recording should be decided by the students and teacher before the sample is frozen. Talk about how you will know that the water is completely frozen. We suggest you use a scale from 1-5 where 1 is liquid water and 5 is solid ice, although you could agree another method with your class.

Testing water hardness

While the water is freezing, the water hardness strips can be used to test the tap water. Results should be noted.

Find full instructions in the Water: Classroom presentation resource on our website.

Also see ‘additional activities’, where we also offer ideas of activities to do while you wait for the water to freeze.

Discussion:

You should discuss why it is important to collect multiple results for each temperature and to calculate the mean freezing time, as well as the importance of accurate measurement (of time, amount of water, and starting temperature) as well as making accurate comparisons of observations of freezing.

- The scale you choose is not key data, so we recommend you choose the most appropriate scale for your class. It can be used as an opportunity for learning about observation, measurement, estimating and recording. However, the key data which must be recorded unambiguously is the time at which the **water has frozen completely.**

- Mini cups and plastic trays should be recycled once the result has been recorded.

12. Every **10 minutes,** a member of staff should collect 4 further samples (2 'C', 2 'W') from the freezer for the groups to observe and record.

13. This process should be repeated until the remaining 'C' and 'W' samples are **completely frozen**. The time taken to reach this should be recorded as the end of the investigation.

14. As a class, groups should compare and discuss their results, and agree how to compile and analyse the results from the whole class.

15. The key pieces of data are **the time taken for each water sample (cold and warm) to become completely frozen and the hardness of the water.**

16. Remember that the children are comparing two data sets: warm and cold starting temperatures, and can **only conclude what the results show:** that warmed water freezes more quickly, more slowly or at the same time as chilled water. They cannot draw a conclusion that the higher the starting temperature the faster or slower water freezes.

Recording results

Children can record their own individual group results in the tables on worksheets. The majority class results need to be collated into a class results table which you can fill in with your class on a smart board, or flip chart. We have provided an example class results table you can use if you wish which can be customised for the number of groups in you class.

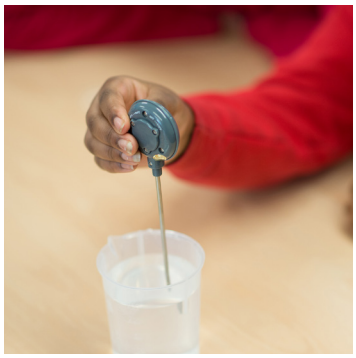
Remember:

The class results table must show the length of time taken for each sample to freeze, and the class means, plus the water hardness result.

Teacher notes

It is important to emphasise to the children that science is a process of gathering evidence to support or refute ideas about observed phenomena and sometimes these theories change and so the scientific thinking changes.

It is important to stress that whatever the results are, they need to be recorded and not dismissed. Young children may be expecting a certain result and may be disappointed if they complete the experiment and the results are different to those they predicted. They may feel like they haven't done it correctly and the results are wrong, but this is not the case.



The result will lead to interesting discussions and should be evaluated in terms of how well they answer the question. It may be that the experiment needs to be repeated with greater accuracy, but as Mpemba found out, it is also possible that strange results can lead to further investigations and new understanding.

NB: Boiling water does alter the hardness of the water. Water has temporary and permanent hardness, and boiling removes the temporary hardness, which is deposited as scale on the kettle. For this reason we suggest heating the water and testing with a thermometer at intervals until you reach 50°C. Using this method will mean that the cool and warm water have a similar hardness.

Additional activities

These activities could be undertaken during the investigation while the water samples are freezing, or as standalone activities on freezing, dissolving and changes of state.

Prior to this, you could print and cut out the Glossary for children to pair up the words and definitions.

The BBC deems the following activities suitable and safe for primary school children. It is your responsibility as a school to carry out your own risk assessment if you decide to carry out any of these extension activities, taking into account any risks, which may be relevant to your specific class environment.

Water Hardness:

While the water is freezing, children will measure the hardness of their tap water. This offers links to other big ideas such as dissolving and solutions.

Investigating dissolved minerals in water

An example which can be given of a solid dissolved in water is sugar.

- Students could stir increasing amounts of sugar in tap water, and as they stir it, it looks like it disappears.
- Explaining that it actually dissolves to form a solution is a good starting point.
- By adding increasing amounts of sugar, children can count the number of teaspoons of sugar it takes for a cup of water to be saturated. They will be able to see this happen as the sugar will still be present at the bottom of the cup.

Notes:

The Geological Society and The Royal Society of Chemistry have produced a series of additional resources around water and water hardness which you can find by following the link from our website bbc.co.uk/terrificscientific

- This can begin a discussion on other substances that can be dissolved in drinking water. As well as their tap water, they could investigate different drinks by reading the labels and seeing what else is dissolved in them.

- This is a good comparative investigation and can be linked to healthy living. You could encourage your class to draw bar charts of different dissolved contents e.g. the calcium content of different bottled drinks and compare them as a class.

Insulation and conduction

Talking to the students about the usefulness of insulation for this investigation and in real life can be tricky, but comparing the differences in materials may be a good way of showing this.

- Why do we not use the same jackets in winter as in summer? Are they keeping us warm or do they produce their own heat?

- Students can investigate the best material to keep water warm or water cool. Insulation is often only thought to keep things warm and not keep things cold, but there are many examples of insulation for cold, such as cool boxes for food.

- Children can predict which materials they think make the best and worst insulators and test their ideas.

- Different material containers could be used for warm and cool water and the temperature can be measured repeatedly to see which material is best to keep the temperature consistent.

Picking up ice with string

Challenge your class to pick up an ice cube from a full glass of water without getting their fingers wet and only using a piece of string provided.

- After a minute or two, demonstrate how to do this. Place an ice cube in a glass of water and wait for it to settle and float.
- Lay the string across the top of the ice cube and sprinkle some fine salt onto and around the string in contact with the ice cube and wait a few seconds.
- Carefully lift the string. If you cannot lift it, try adding more salt and trying again.
- This works because the salt drops the freezing point of the water. The ice melted slightly but refroze around the string.

Salting icy roads and pavements lowers the freezing point of water that forms ice, which leads to melting and prevents falling snow or rain from being able to freeze.

Discussion:

Ask children to think about what they have just observed and suggest why salt is added to their playground and roads in winter.

Do all liquids freeze the same?

Does olive oil have the same freezing point as water?

- Provide a range of liquids and ask the children to order them from the one they think has the lowest freezing point, to the one with the highest freezing point, and ask them to include salty water.
- Consider what could be affecting the freezing point.
- Provide the answers below and ask the class to work out the difference between freezing points. They can use their negative number lines to support them.

Liquid	Freezing point (°C)
Olive oil	-12°C
Water	0°C
Salt water	__°C (?)
Shampoo	-3°C
Sunflower oil	-17°C

Story-time

Mpemba story excerpt from his 1969 paper, "Cool?"

My name is Erasto B Mpemba, and I am going to tell you about my discovery, which was due to misusing a refrigerator. All of you know that it is advisable not to put hot things in a refrigerator, for you somehow shock it; and it will not last long.

In 1963, when I was in form 3 in Magamba Secondary School, Tanzania, I used to make ice-cream. The boys at the school do this by boiling milk, mixing it with sugar and putting it into the freezing chamber in the refrigerator, after it has first cooled nearly to room temperature. A lot of boys make it and there is a rush to get space in the refrigerator.

One day after buying milk from the local women, I started boiling it. Another boy, who had bought some milk for making ice-cream, ran to the refrigerator when he saw me boiling up milk and quickly mixed his milk with sugar and poured it into the ice-tray without boiling it; so that he may not miss his chance.

Knowing that if I waited for the boiled milk to cool before placing it in the refrigerator I would lose the last available ice-tray, I decided to risk ruin to the refrigerator on that day by putting hot milk into it. The other boy and I went back an hour and a half later and found that my tray of milk had frozen into ice-cream while his was still only a thick liquid, not yet frozen.

I asked my physics teacher why it happened like that, with the milk that was hot freezing first, and the answer he gave me was that "You were confused, that cannot happen". Then I believed his answer.

After learning about the story of Mpemba, there are ways in which it can be linked to English, Drama and even History by writing an account of Mpemba and his discovery.

- What surprises the children about Mpemba's discovery? As you explore this event further you could ask them, do you think the hot water freezing faster was what he expected? Why? Why not? Children could discuss this in pairs.

- Children could draw a story board, with speech bubbles to be filled in of what they imagine Mpemba told his friends and teacher about his findings with the hot cream.

- Alternatively, they could write a diary of Mpemba's day, including details of his environment, the reaction of the people around him and how he felt when his friends and teachers weren't convinced.

Discussion of results

Depending on your result, different conclusions can be formed by your class. Here, we provide possible talking points for you and your children to consider.

- Revisit the original question; has the investigation given you an answer?
- Did you find a difference in the freezing times?
- Did everyone in the class have the same results?
- If a difference was found, what do you think caused this? (Insulation, convection etc.)

- This may prove difficult, but students often come up with great and original ideas to reason their answers. It's good to list these suggestions and discuss their potential impacts on the Mpemba effect as a group, and there are many things that have been found to affect it.

- Students can compare their results with other schools on the Terrific Scientific Map and find out more about the Mpemba effect by visiting the Terrific Scientific website.

- Are the results valid? Did we control variables well? Amount of water, starting temperature by the time the sample went into the freezer, how long before removing from freezer and observing, freezer temperature (consistency between top and bottom, front and back, how often the door was open and for how long)
- Was our measurement accurate? How could it be improved?
- Should more results be taken to obtain a more significant mean result?

- Is a table the best way to show the results? Would drawing a graph be useful?

- Students can then put these ideas together and write a summary. This could start with **"I used to think that ... But now I know that ... Because..."**

Glossary

Mpemba Effect	A phenomenon where, in some circumstances, water that is initially hot freezes faster than water that is initially cold.
Hard Water	Water with a large amount of dissolved minerals.
Soft Water	Water with a low amount of dissolved minerals.
Freezing	The process when a liquid becomes a solid when temperature is lowered to a certain point.
Condensation	The process when a gas changes into a liquid when temperature is lowered to a certain point.
Evaporation	The process when a liquid changes into a gas below its boiling point.
Dissolve	The process when some solids mix with liquids to form a solution. The solid can no longer be seen but it has not disappeared.
Solution	A mixture formed of a liquid and dissolved solid.
Saturation	The point at which no more of a solid can dissolve in a liquid.
Insulation	The reduction of heat transfer between an object and its surroundings. Usually used to keep something warm or keep something cold.
Thermometer	A device for measuring temperature.
Comparative test	The accuracy of a measurement depends on the quality of the measuring apparatus and the skill of the scientists taking the measurement. In this investigation it will be difficult to measure the starting temperatures accurately, the temperature of the freezer and the exact freezing point.
Accurate	A 'best guess' of what might happen in an investigation based on the scientific knowledge you already have.
Reliable	Data is reliable if it can be replicated. In this case children across the country will be carrying out the same investigation. The reliability of the data form each class will be improved by each class taking repeated measurements.
Valid	Data is only valid if the measurements that have been made are affected by a single independent variable. In this case it will be difficult to control the starting temperatures and the temperature of the freezer. It will be possible to control the amount of water.

References

Science advancement happens by reading and understanding previous findings and adding to them.

Mpemba Story Excerpt

Erasto Mpemba and Denis Osborne, ‘Cool?’ Physics Education, 1969 (May, Vol 4) pp. 172-175 Accessed through the Royal Society of Chemistry: **http://www.rsc.org/learn-chemistry/resource/download/res00001018/cmp00001662/pdf**

Health and safety and control measures

Use of a thermometer

- To be used by staff, with (possibly) children reading the value.

Handling warm/hot water

- To minimise risk, only staff should have access. Staff should collect the hot water, transport it to the classroom, measure the temperature and pour it into marked mini cups. This should be done at the last possible minute to stop the water from cooling down, as this could affect the experimental outcome. We recommend you either heat tap water to 50°C, using the thermometer to measure the temperature or by using a wall water heater or kettle. If using a wall water heater or kettle, reduce the temperature of the hot water in the insulated cup/flask using cold water, using the thermometer to ensure that it does not drop below 50°C. We recommend having a fully stocked first aid kit available, which includes burn gel or a cold pack in case of accidental spillage.

Important!

Only staff should have access to hot water.

Remember:

Have a cold pack being readily available in case of accidental spillage.

Access to and using the freezer

- As access to a freezer may be in restricted areas for students such as a staff room or kitchen, we propose staff collect the samples each time, rather than the students.
- It may be that only kitchen staff may be allowed to place water samples in the freezer.
- Touching frozen items when collecting the frozen samples also poses a risk. Wearing gloves to collect the cold containers will minimise the chance of ‘cold burns’ as well as reducing the risk of introducing bacteria to items in a freezer.

Transporting samples to / from the freezer

- Using clear plastic ‘takeaway’ trays will catch any spillages.
- Ideally they should be carried in an insulated box to maintain the temperature.