

Evaporative cooling

Secondary: (ages 11 – 14)

Science (chemistry)

In this 10-lesson unit students investigate the driving question, ‘When I am sitting by the pool, why do I feel colder when I am wet than when I am dry? Students investigate intermolecular forces between molecules and energy transfer during phase changes of matter. Students start by experiencing the phenomenon of evaporation and cooling of different liquids. Later activities include experiments to measure temperature and mass changes when liquids evaporate, and using several computer-based simulations to explore energy transfer, forces, and interactions between molecules in different phases. Throughout, students continuously build, use, evaluate, and revise their own computational and hand-drawn models to answer the driving question.

NB: This unit includes an annex with adaptations for [remote learning](#)

Time allocation 10 lesson periods

Subject content Plan and conduct investigation of electrical forces between particles. Develop and use models to illustrate how kinetic energy is transferred between molecules during phase change

Creative and critical thinking This unit has a **creativity** and **critical thinking** focus:

- Generate ideas about patterns in data
- Propose how to model a scientific problem
- Justify outcome of models and acknowledge bias and uncertainty
- Engage in inquiry, review and appraise alternatives, compare perspectives, and reflect on chosen solutions

Other skills Communication; collaboration

Key words evaporation; cooling; kinetic energy; phase change; modelling

Products and processes to assess

The unit provides opportunities for students to develop their modelling and scientific explanation skills by engaging them in sharing ideas, performing investigations, constructing and revising models, collecting data, and using models to explain phenomena. Students develop a model that explains how kinetic energy is transferred between molecules during phase change. Models should include representations of the spacing, motion, kinetic energy, and potential energy of the molecules in this system. Ideally, they provide several possible explanations for the phenomena, while considering the limitations, plausibility, and usefulness of each explanation. During the work process, students demonstrate high engagement, ask new questions, raise several hypotheses, and discuss possible outcomes. They actively test both the internal and external consistency of information, consider alternative perspectives, and provide relevant and useful feedback on other models.

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Teaching and Learning plan

This plan suggests potential steps for implementing the activity. Teachers can introduce as many modifications as they see fit to adapt the activity to their teaching context.

Step	Duration	Teacher and student roles	Subject content	Creativity and critical thinking
1	Lesson period 1	Students are introduced to the Driving Question of why having wet skin makes you feel cooler. Students experience the anchoring phenomenon in which they feel cooler when their hands are wet in a bowl with water. Students construct their initial model of the phenomenon in pairs. The purpose of this for students is to access their prior knowledge about this phenomenon. The purpose for the teacher is for formative assessment to inform planning for lesson 2. Students explain their model to another pair in turns so that they can share ideas and begin working toward some consensus in understanding.	Constructing a model to identify a pattern between the structure of particles and their behaviour (evaporation and temperature).	Making connections between experiences of being cold whilst wet and scientific concepts Stretching and playing with unusual/new ideas to explain phenomenon
2	Lesson period 2	Students go to two stations that are designed to explore the effect of heat transfer into a system as it changes both the temperature and state of matter (i.e., water). They conduct an experiment to collect data about changes in water in various states as it is heated up and evaporates. They then analyze and interpret the data to explain the temperature changes they observe.	Using data to make connections between the identity of the change in phase and the temperature that occurs as a liquid evaporates.	Generating ideas about patterns in their data
3	Lesson period 3	Students review the patterns of data from lesson 2 and learn how to use a bar chart model to represent energy transfer during evaporative process. In this lesson, students develop a bar chart model to explain the effect of heat transfer into a system as it changes both the temperature and the state of water.	Using patterns in data from the experiment to develop a model that describes cause and effect relationships between energy and temperature changes, and between energy and phase changes. Using the bar chart models they generated to make predictions, and	Proposing how to model a scientific problem

			using these predictions to evaluate their model, by comparing the predictions with their empirical data.	
4	Lesson period 4	Students experience two group activities to explore the particulate nature of water when it is heated. Students construct and use a paper-pencil model to provide particle level explanations for why the temperature rises when heat is added to water in the liquid phase. Students learn that thermal energy can be absorbed or released during temperature changes.	Using evidence from investigations to draw paper-pencil models to show the relationships between kinetic energy, energy transfer, and the movement of water molecules.	Exploring, seeking and generating ideas to produce a model
5	Lesson period 5	Students experience four lab activities (observing the temperature of ice, ice/water, boiling water, and water vapor over boiling water). Students will use this data to develop particle-level models that explain why the temperature does not change during phase changes. Students learn that thermal energy can be absorbed or released during phase changes. Students develop a model to show how a system gains or loses thermal energy.	Interpreting observations collected from an exothermic process to describe the various energy changes that occur during different phase changes using particulate level diagrams, ASU energy bars, and system representations.	Exploring, seeking and generating ideas to produce a model.
6	Lesson period 6	Students reflect on their drawn models. Students review the learning from lessons 2-5 and incorporate ideas from the lesson into their initial model in lesson 1. Students share their models to receive feedback.	Revising their model that represents the spacing, motion, kinetic energy, and potential energy of the molecules in this system. There should be some representation of skin molecules, liquid water molecules, and water vapour molecules.	Reflecting on the chosen scientific approach relative to possible alternatives Justifying the relationships and outcome of their models. Reviewing alternative theories and opinions

				and comparing/finding perspectives on the problem
7	Lesson period 7	Students experience the phenomenon of liquids having different evaporation rates. After this, students perform an experiment to collect data about the evaporation rate of these three liquids. This activity provides evidence that evaporation involves 1) a temperature change and 2) a loss of liquid mass in an open system. Students go to two stations that are designed to test the rate of evaporation of acetone, water, and ethanol.	Using data to making connections between the evaporation rates of different substances, and the temperature changes that occur during evaporation.	Generating ideas about patterns in their data
8	Lesson period 8	Students review the patterns of data in Lesson 7 and construct and use models to explain how the strength of the intermolecular forces in a substance affect the state of matter of a substance at a certain temperature.	Using models to identify the relationship between the strength of IMF and the state of matter at a given temperature. Using models to make observations and construct explanations about how kinetic energy is transferred among molecules. Collecting data from Lesson 7 to describe the pattern between temperature and the kinetic energy of molecules.	
9	Lesson period 9	Students compare the viscosity of water, ethanol, and acetone by observing how each chemical spread on different surfaces (on pennies). Students construct explanations for how differences in the strength of attractive forces between particles can account for different macroscopic properties.	Explaining (using differences in IMF) why more drops of water stay on a penny as compared to acetone.	Appreciating the novelty of solution, explanation, and/or possible consequences
10	Lesson period 10	Students present their final models and explanations to the whole class and may take a unit test. They can then perform a final assessment of the unit to reflect on what has been learned	Constructing explanations of the process of evaporative	Acknowledging any bias, uncertainty, or limitations.

cooling, connecting the
energy changes to Producing and
changes in the structure articulating a new model
of matter in the system.

Resources and examples for inspiration

Web and print

- The Concord Consortium's Building Models STEM Resource Finder
https://learn.concord.org/eresources/1481.run_resource.html
- States of Matter PhET simulation (<https://phet.colorado.edu/en/simulation/states-of-matter>)
- Energy forms and changes PhET simulation
(<https://phet.colorado.edu/en/simulation/legacy/energy-forms-and-changes>)
- Curriculum website (Unit 1: Evaporative Cooling):
(<https://sites.google.com/a/msu.edu/pire-cese/file-cabinet/chemistry-resources/unit-1-evaporation>)
Contact for requesting access permission: Sarah Maestrales (maestral@msu.edu)

Other

- Computers for modelling activities

Opportunities to adapt, extend, and enrich

- This unit is the first in a sequence of four high school chemistry units. The other units focus on the periodic table, combustion reaction and conservation of atom and matter.

Creativity and critical thinking rubric for science

- Mapping of the different steps of the lesson plan against the OECD rubric to identify the creative and/or critical thinking skills the different parts of the lesson aim to develop

	CREATIVITY Coming up with new ideas and solutions	Steps	CRITICAL THINKING Questioning and evaluating ideas and solutions	Steps
INQUIRING	Make connections to other scientific concepts or conceptual ideas in other disciplines	1,10	Identify and question assumptions and generally accepted ideas of a scientific explanation or approach to a problem	1, 9,10
IMAGINING	Generate and play with unusual and radical ideas when approaching or solving a scientific problem	1-9	Consider several perspectives on a scientific problem	6,10
DOING	Pose and propose how to solve a scientific problem in a personally novel way	3,4,5, 8	Explain both strengths and limitations of a scientific solution based on logical and possibly other criteria (practical, ethical, etc.)	6,9,10
REFLECTING	Reflect on steps taken to pose and solve a scientific problem	6, 9,10	Reflect on the chosen scientific approach or solution relative to possible alternatives	6,9,10

Annex 1: Remote learning adaptations

This plan suggests potential steps for implementing the activity in remote modes of delivery. Teachers can introduce modifications as they see fit to adapt the activity to their teaching context.

Step	Duration	Teacher and student roles	Subject content	Creativity and critical thinking	Adaptions and considerations for online modes of delivery
1	Lesson period 1	Students are introduced to the Driving Question of why having wet skin makes you feel cooler. Students experience the anchoring phenomenon in which they feel cooler when their hands are wet in a bowl with water. Students construct their initial model of the phenomenon in pairs. The purpose of this for students is to access their prior knowledge about this phenomenon. The purpose for the teacher is for formative assessment to inform planning for lesson 2. Students explain their model to another pair in turns so that they can share ideas and begin working toward some consensus in understanding.	Constructing a model to identify a pattern between the structure of particles and their behaviour (evaporation and temperature).	<p>Making connections between experiences of being cold whilst wet and scientific concepts</p> <p>Stretching and playing with unusual/new ideas to explain phenomenon</p>	<p>(This unit involves online student group work. Developing and agreeing with students to a code of conduct for group work may avoid unproductive behaviour during unsupervised work).</p> <p>Introduction can take place in a live video conferencing call. Small groups may be more manageable than pairs to make it easier for the teacher to join each group call/break-out room.</p> <p>Students can try the cooling effect of water at home. A collaborative online document can be used to create models.</p> <p>Students can then be broken into new groups to share and get feedback before reporting back to their original group (N.B. This will require the teacher to construct two sets of groups in advance and use the breakout rooms feature or independent group calls).</p>
2	Lesson period 2	Students go to two stations that are designed to explore the effect of heat transfer into a system as it changes both the temperature and state of matter (i.e.,	Using data to make connections between the identity of the change in phase and the temperature	Generating ideas about patterns in their data	This is difficult in an online environment unless an appropriate virtual lab is available. Alternatively, students may watch a video of the test (performed by the teacher or available online)

		water). They conduct an experiment to collect data about changes in water in various states as it is heated up and evaporates. They then analyze and interpret the data to explain the temperature changes they observe.	that occurs as a liquid evaporates.		and observe and answer questions over video conferencing software. Students then graph this information in between live sessions and a video conferencing call can be held to pose questions and prompt students to notice patterns.
3	Lesson period 3	Students review the patterns of data from lesson 2 and learn how to use a bar chart model to represent energy transfer during evaporative process. In this lesson, students develop a bar chart model to explain the effect of heat transfer into a system as it changes both the temperature and the state of water.	Using patterns in data from the experiment to develop a model that describes cause and effect relationships between energy and temperature changes, and between energy and phase changes. Using the bar chart models they generated to make predictions, and using these predictions to evaluate their model, by comparing the predictions with their empirical data.	Proposing how to model a scientific problem	The instruction of creating bar chart models can be easily found online. The teacher can prepare a video showing students how to use the model and then arrange video calls to check progress – or this can be done during a live whole-class video conferencing session and the teacher can visit small breakout rooms.
4	Lesson period 4	Students experience two group activities to explore the particulate nature of water when it is heated. Students construct and use a paper-pencil model to provide particle level explanations for why the temperature rises when heat is added to water in the liquid phase. Students learn that thermal energy can be absorbed or released during temperature changes.	Using evidence from investigations to draw paper-pencil models to show the relationships between kinetic energy, energy transfer, and the movement of water molecules.	Exploring, seeking and generating ideas to produce a model	Teacher can provide a video on this and students can work on their models individually or in group calls/breakout rooms. Links to the calls can be circulated in advance and the teacher can join each call briefly to check progress and give feedback. Teacher can ask students work on drawing a paper-pencil model individually or in group calls/breakout rooms. A free version online draw tool can be used for students to draw models.

5	Lesson period 5	Students experience four lab activities (observing the temperature of ice, ice/water, boiling water, and water vapor over boiling water). Students will use this data to develop particle-level models that explain why the temperature does not change during phase changes. Students learn that thermal energy can be absorbed or released during phase changes. Students develop a model to show how a system gains or loses thermal energy.	Interpreting observations collected from an exothermic process to describe the various energy changes that occur during different phase changes using particulate level diagrams, ASU energy bars, and system representations.	Exploring, seeking and generating ideas to produce a model.	As above.
6	Lesson period 6	Students reflect on their drawn models. Students review the learning from lessons 2-5 and incorporate ideas from the lesson into their initial model in lesson 1. Students share their models to receive feedback.	Revising their model that represents the spacing, motion, kinetic energy, and potential energy of the molecules in this system. There should be some representation of skin molecules, liquid water molecules, and water vapour molecules.	Reflecting on the chosen scientific approach relative to possible alternatives Justifying the relationships and outcome of their models. Reviewing alternative theories and opinions and comparing/finding perspectives on the problem	Students share their models either in a group call where they are asked to share and present their screen or by providing links to online documents to be reviewed by other students asynchronously. A group of students can be asked to review each link and annotate the document with questions about the model so that the student/s who created the model receive feedback. The teacher will guide and moderate this process to ensure feedback is appropriate and constructive.
7	Lesson period 7	Students experience the phenomenon of liquids having different evaporation rates. After this, students perform an experiment to collect data about the evaporation rate of these three liquids. This activity provides evidence that evaporation involves 1) a temperature change and 2) a loss of liquid mass in an	Using data to making connections between the evaporation rates of different substances, and the temperature changes that occur during evaporation.	Generating ideas about patterns in their data	This is difficult in an online environment unless an appropriate virtual lab is available. The liquids may have to be changed accordingly. Alternatively, students may watch a video of the test (performed by the teacher or available online) and observe and answer questions over video conferencing software. Students then graph this information in between live sessions

		open system. Students go to two stations that are designed to test the rate of evaporation of acetone, water, and ethanol.			and a video conferencing call can be held to pose questions and prompt students to notice patterns.
8	Lesson period 8	Students review the patterns of data in Lesson 7 and construct and use models to explain how the strength of the intermolecular forces in a substance affect the state of matter of a substance at a certain temperature.	Using models to identify the relationship between the strength of IMF and the state of matter at a given temperature. Using models to make observations and construct explanations about how kinetic energy is transferred among molecules. Collecting data from Lesson 7 to describe the pattern between temperature and the kinetic energy of molecules.		Teacher can ask students work on drawing a paper-pencil model individually or in group calls/breakout rooms. A free version online draw tool can be used for students to draw models. The teacher may need to check that all students are able to use the online draw tool.
9	Lesson period 9	Students compare the viscosity of water, ethanol, and acetone by observing how each chemical spread on different surfaces (on pennies). Students construct explanations for how differences in the strength of attractive forces between particles can account for different macroscopic properties.	Explaining (using differences in IMF) why more drops of water stay on a penny as compared to acetone.	Appreciating the novelty of solution, explanation, and/or possible consequences	The teacher can provide a video showing how the chemical spreads on different surfaces and ask students to respond to some questions about this to guide them in a process of noticing and exploring the differences.
10	Lesson period 10	Students present their final models and explanations to the whole class and may take a unit test. They can then perform a final assessment of the unit to reflect on what has been learned	Constructing explanations of the process of evaporative cooling, connecting the energy changes to changes in the structure of matter in the system.	Acknowledging any bias, uncertainty, or limitations.	Student presentations can be pre-recorded and a link provided (students may have to share access not just to the link to the PowerPoint but also to any audio or video clips that they have created and embedded). Alternatively, presentations can take place in a live video conferencing call.

Producing and
articulating a new
model

The final test and assessment can also take place in the call or it can be a take-home assessment with responses submitted to the teacher at a defined time and format.