IT for US

Information Technology for Understanding Science

Socrates Comenius programme

Action 2.1 - Training of School Education Staff

119001-CP-1-2004-1-PL-COMENIUS-C21

Education and Culture

Socrates

Thermal Energy and the Human Body

The human body uses energy continuously. The main source of energy is food containing carbohydrates which store chemical energy. Body systems convert carbohydrates into simpler substances which allow the energy to be stored and transported around the body to supply the needs of muscles and vital organs. As energy gets used, respiration occurs and heat is produced. During periods of intense physical activity, the rate of heat generation rises substantially, but the body always maintains a constant temperature through a variety of processes which balance heat generation with heat losses to the surroundings.

A. Introduction

The theme of this module is the thermal energy balance maintained by the human body. The principal source of energy to the body is food and a major output of energy is in the form of heat. The activities focus on the processes associated with the input and output of energy. There are four types of activities:

1. **Data logging:** Two laboratory experiments:
    - To investigate the energy value of food by measuring the heat produced when a potato chip is burnt.
    - To investigate the cooling effect of evaporation.
2. **Simulation**: Visual aids to assist an interpretation of the data-logging experiment on food and to explore the processes of heat transfer in the human body.
3. **Modelling**: A mathematical model to predict the changes of temperature in the data-logging experiment with a liquid evaporating.
4. **Video capture**: a video record of an experiment in which the heat generated by the human body is measured by placing the subject in an enclosed box and recording temperature changes.

1. Background theory

1. Energy input to the human body

The main source of energy to the human body is food. Energy stored in food is often regarded as chemical energy which resides in the chemical constituents of food. Typically, carbohydrates are considered to be the most useful substances containing this energy. The release of this energy requires reaction with oxygen through the process of ***aerobic respiration***. Expressed in its simplest form, respiration results in the following chemical change:

$$\text{carbohydrate} + \text{oxygen} \rightarrow \text{water} + \text{carbon dioxide}$$

Water vapour and carbon dioxide gas are constituents of exhaled air.

Superficially, respiration is a similar chemical process to ***combustion*** in that both are oxidation processes, the reactants and products are the same, and, in both cases, heat is produced. Respiration is sometimes regarded as a very slow form of combustion, but such a model breaks down when one considers the complex metabolic processes by which the constituents of food are broken down into a form to facilitate respiration. However, the similarity can be usefully exploited to determine a measure of the energy content of food. For practical purposes, the ***energy content*** of food and the ***heat of combustion*** (or enthalpy of combustion) can be regarded as equivalent. The latter can be measured in the laboratory using various types of calorimeter, designed to facilate the calculation of heat transfers from temperature changes.

In the human body, the liver is a major organ for metabolising food and, amongst other biological functions, is responsible for generating core heat in the body akin to a boiler in a central heating system. Muscles also generate heat when they are active. Thus most forms of physical exercise result in body heat.

2. Heat losses from the human body

By a complex regulation system, the internal temperature of the human body usually remains constant at 37°C. In comfortable climatic conditions, the external air temperature is usually less than this. The result of this temperature difference is that the body is constantly losing heat to the surroundings, mainly by ***convection***. The rate of loss of heat will depend upon the insulating properties of the clothes being worn, but in general Newton's Law of Cooling applies; that is, the rate of heat loss $\frac{\Delta H}{\Delta t}$ varies in proportion to the temperature difference between the surface of the body and its surroundings:

$$\frac{\Delta H}{\Delta t} = -K \cdot (T - T_s)$$

- where T and Ts are the temperatures of the body and surroundings respectively and K is a constant of proportionality.

The temperature of the skin is modified by the control of ***blood flow*** near the surface and by the process of ***sweating***. During conditions of cold external temperatures, the body restricts the blood flow through veins below the skin to conserve heat. During conditions of high external temperatures the body causes perspiration through pores in the skin. The evaporation of the sweat droplets involves the loss of latent heat and causes a cooling effect on the skin. The amount of heat lost is related to the mass (Δm) of sweat evaporated thus:

$$\Delta H = L \cdot \Delta m\,\Delta.$$

- where L is the amount of heat needed to evaporate 1 kg of water.

2. Pre-requisite knowledge required

- Food types (carbohydrate, protein, fat)
- Aerobic respiration
- Temperature measurement
- Celsius scale of temperature
- Effects of heating and cooling substances
- Heat transfer by convection
- A temperature difference causes the transfer of heat

3. Science concepts developed in the module

- Energy content of food
- Heat of combustion
- Latent heat of vaporisation
- The rate of cooling of a substance depends upon the temperature difference between the substance and its surroundings

4. Other useful information

- Further background theory about metabolism, body cooling and associated topics may be found at:

  http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

- A summary is attached as Appendix 1.

B. Didactical approach

1. Pedagogical context

Possible contexts in which the topic might be introduced:

- Comparing the energy values of a variety of different foods
- Consideration of the energy transfers when engaging in sporting activities
- Discussion of balanced diet and methods of dieting
- Consideration of sweating as a process which accelerates the loss of body heat.

CONSTRUCTING A TEACHING SEQUENCE:

Each of the contexts suggested above will involve different starting points for teacher exposition or class discussion, but it is strongly recommended that this leads promptly to one of the data-logging activities. Such practical activity is valuable for providing firsthand experience of the phenomenon which can be used to stimulate questions about the underlying scientific processes. The need for further investigation is a likely outcome and the simulation and modelling activities provide a useful means of extending investigation and deepening thinking. The simulation and modelling activities both demand quantitative description and analysis.

2. Common student difficulties

- Confusion between respiration and breathing
- Confusion between heat and temperature
- Understanding rate of change

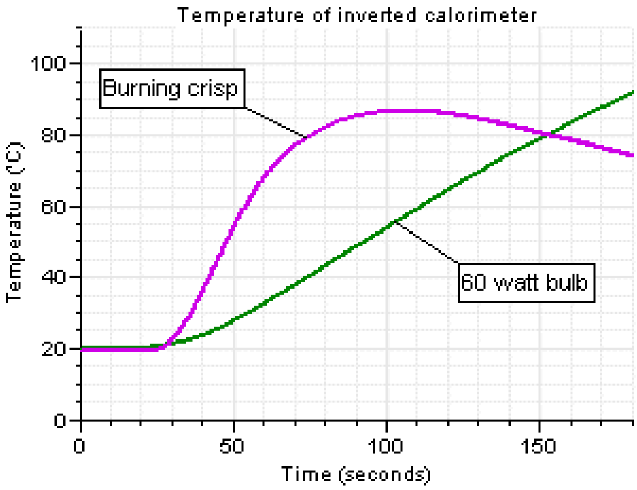
3. Evaluation of ICT

This section considers some of the practical arrangements for exploiting the use of ICT to best effect, and discusses the qualities of the ICT methods which make a special contribution to students' learning.

DATA-LOGGING

Both experiments use temperature probes which are generally very useful for conducting a large variety of simple experiments involving heating and cooling. Quite cheap probes can offer excellent sensitivity and accuracy well suited to real-time experiments.

Energy content of food:



In this example, the probe is secured in good thermal contact to the top of the calorimeter resting in an inverted position on a tripod. The principle is that when an item of food is ignited and burnt underneath the calorimeter, the rising hot gases heat up the calorimeter. The data-logging technique makes the graph of temperature against time visible immediately and when the burning is complete, the maximum temperature may be read from the graph accurately. Since we are interested in the total heat given out during burning, the calorimeter needs to be calibrated so that the temperature rise may be used for calculating the heat output. This is done by repeating the experiment using a standard mains electric spot lamp inside the calorimeter in the place of the burning food. The new graph of rise in temperature can be compared with the first graph and the time taken to reach the former maximum temperature may be measured. Multiplying this time by the wattage of the lamp gives the energy output of the food.

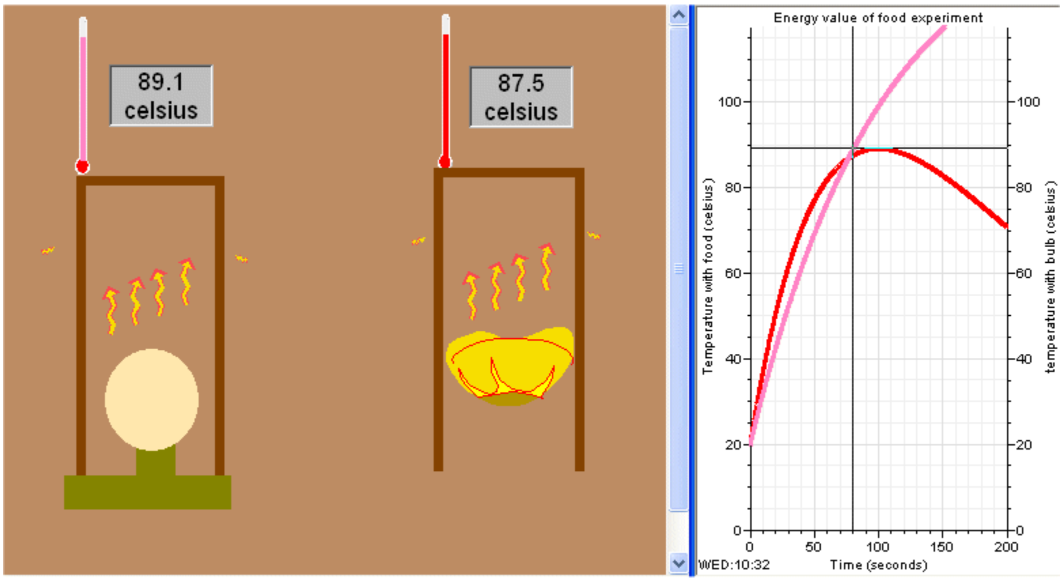
Evaporation of water:

In this example, the temperature probe is set up with a small strip of tissue paper rolled around its tip. After moistening the paper with several drops of water, the cooling effect due to evaporation becomes evident on the temperature versus time graph which develops while the experiment is in progress. The drop in temperature is quite small, but the software allows it to be magnified on the screen and easily measured.

SIMULATION

Energy value experiment:

This simulates the data-logging experiment of Activity 1a. Both parts of the experiment, the burning of the potato crisp and the calibration with the electric bulb, run simultaneously side by side with both sets of results displayed on the graph. The simulation may be used to prepare pupils thinking before performing the experiment, or it may be used for discussing the analysis of the results from the experiment. The cursor controls make it possible to take accurate readings from the graph.



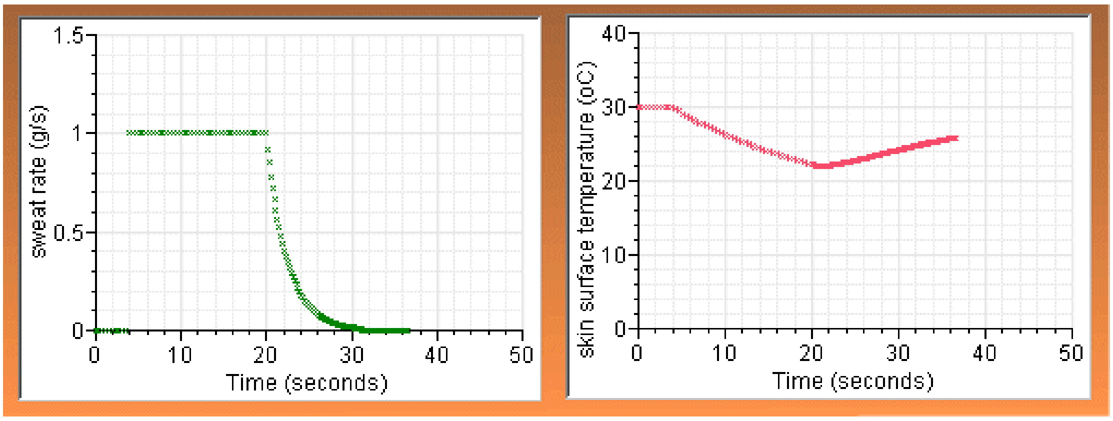
The remaining simulations facilitate a discussion of the main processes involved in heat transfer for the human body: the generation of heat in internal organs and through exercise, and heat losses through convection and evaporation. In the human body, the latter are automatically controlled by self regulating physiological mechanisms, but the simulations allow these to be controlled by the user so that the individual factors involved may be investigated.

Body convection:

This allows control of the two main variables determining the rate of convection, the ambient temperature of the surroundings and the skin surface temperature. It is soon apparent that the heat loss depends upon the difference between these two temperatures, moreover the relationship is found to be linear; that is, for every 1 degree increase, the rate of heat loss increases by the same amount. Thus the model for the simulation assumes Newton's Law of Cooling. Discussion can consider the conditions for this simple relationship: If, for example, convection is forced by movement, wind or a fan, then a different relationship applies. Here is an example of how simulations and models usually contain simplifying assumptions about variables and the relationships between them. The limitations of models need to be questioned and their data tested against real data from experiments.

Body evaporation:

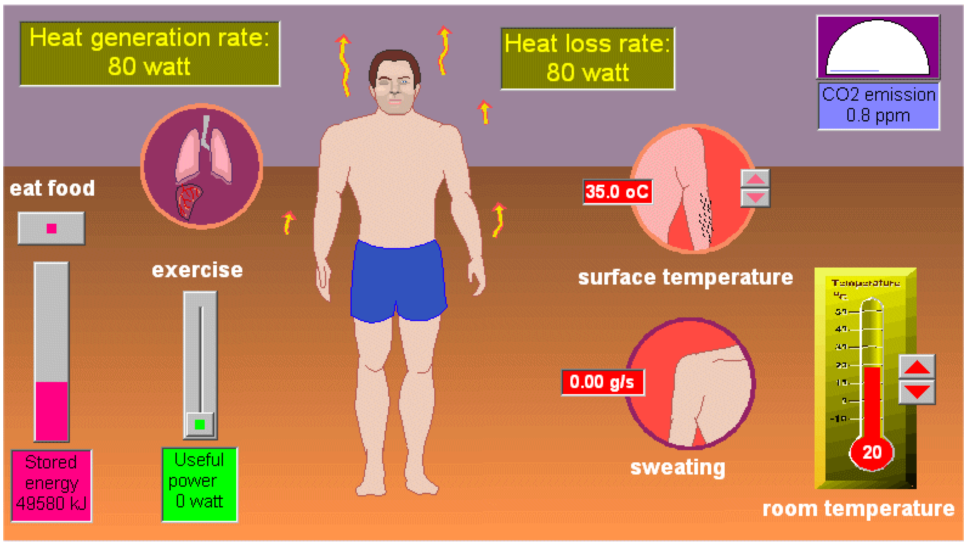
This simulation allows the user to control the rate of sweating at the surface of skin. The consequent cooling effect due to the evaporation of the sweat may be observed on the graph. This shows that the skin temperature decreases whilst the sweat rate is finite. The larger the sweat rate, the larger the rate of fall in temperature; however, the rate of fall is not constant because the model allows for the absorption of heat from the surroundings. A further investigation could find out the effect of the room temperature on the rate of change of skin temperature. Again, for the sake of simplicity, the scope of the simulation is limited. For example, the model takes no account of the effect of the relative humidity on the rate of evaporation.



Body energy balance:

This simulation calculates the combined heat losses due to evaporation and convection and allows them to be compared with the main sources of heat generation within the body. Its main teaching purpose is to prompt thinking about the sophistication of the self-regulatory processes which contribute to homeostasis, which results in a stable internal body temperature of 37 °C. The philosophy behind this simulation is for the user to attempt to control these processes in a way which imitates the perfect balance normally achieved by the body automatically. The difficulty of achieving this balance leads one to admire even more the sophistication of the natural control systems within the human body.

Food is the main source of supply of energy to the body and its slow metabolism in internal organs results in the generation of heat (mainly in the liver). The simulation demonstrates the slow release of heat from this process, normally about 80W. In contrast, muscular activity in exercise produces 'waste' heat much more quickly. Typically, muscles produce heat at three times the rate of useful mechanical power. For heat losses by convection and evaporation, the simulation incorporates ideas from the previous two simulations. Although this simulation gives the user independent control of skin surface temperature, in reality this is automatically controlled by systems within the body. Sweating is not normally triggered until skin reaches a temperature of 37 °C.



Modelling

The purpose of this activity is to use formulae to generate a set of data which approximates as closely as possible to the data captured in the data logging Activity 1b. The model performs a sequence of calculations, aimed at calculating small changes of *temperature* and *mass* of liquid during a short interval of *time*. Repetition of the calculations results in a set of data showing the temperature and mass of liquid varying with time. The model shows how the calculations are broken down into a few simple steps, each using a basic principle in physics.

The model assumes these physical concepts:

1. The rate of evaporation of the liquid contained in the tissue paper around the temperature probe varies in proportion to the mass of liquid remaining.
2. The rate of loss of heat due to evaporation varies in proportion to the rate of evaporation of the liquid and its latent heat of vaporisation.
3. The rate of heat gained from the surroundings varies in proportion to the difference in temperature between the liquid and its surroundings.
4. The temperature change depends upon the net heat transfer and the thermal capacity of the liquid and temperature probe.

The first concept is represented in the formula which calculates the change of mass of liquid Δm during a regular time interval Δt:

$$\Delta m = -V \cdot m \cdot \Delta t$$

- where m is the mass of liquid remaining, and
  V is a constant representing the volatility of the liquid

The second assumption is represented in the formula:

$$\Delta He = L \cdot \Delta m$$

- where ΔHe is the heat lost when mass Δm evaporates, and
  L is the latent heat of vaporisation of the liquid.

The third assumption is represented in the formula which calculates the change of temperature ΔT during a small time interval Δt:

$$\Delta T = K \cdot (T - T_s) \cdot \Delta t$$

- where Ts is the temperature of the surroundings, and
  K is a constant of proportionality

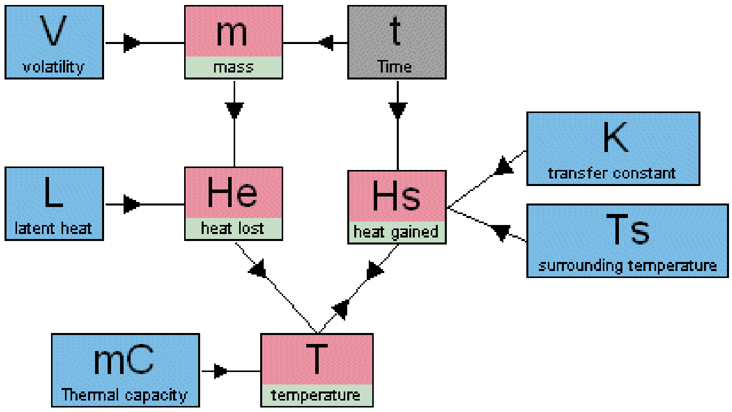
The resulting change of temperature ΔT is calculated by summing heat lost and heat gained:

$$\Delta T = \frac{(\Delta H_s + \Delta H_e)}{mC}$$

- where mC is the thermal capacity of the temperature probe.

Since the mass of liquid in the tissue paper is very much smaller than that of the temperature probe, its thermal capacity is ignored compared with that of the probe.

By studying the formulae and experimenting with different values for the constants, the physical assumptions implicit in the model may be evaluated.

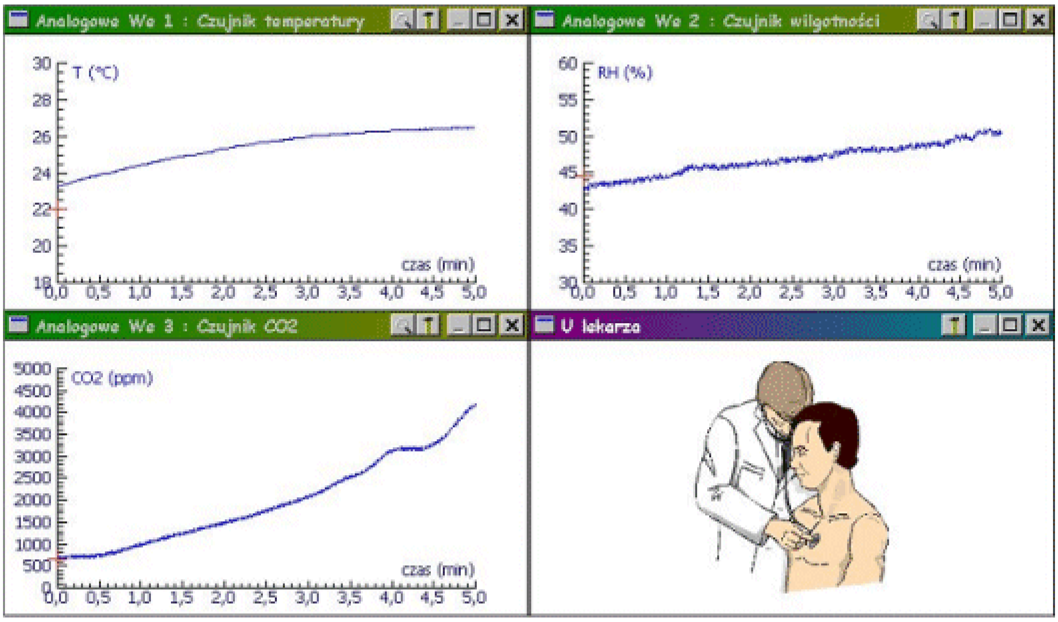


Each of the previous simulations contain similar models, and pupils may also investigate them to identify the variables involved, the relationships between them and the scientific principles represented by the formulae.

VIDEO CAPTURE

The video recording features a data-logging experiment designed to measure the rate of energy emission from the human body. The experiment was devised by Mats Areskoug, and his paper describing the theory and experiment is provided in Appendix 2. The experiment may be reproduced in the school laboratory, but in view of the unusual apparatus, the video recording conveniently allows the experiment to be studied and results analysed without the expense of too much time and money.

A thermally insulated box is prepared, containing sensors for temperature, humidity and CO2 concentration. A data-logger records readings from the sensors whilst a person spends a few minutes inside the box. The rise in temperature can be obtained from the graph and used to calculate the heat energy output from the person's body. The completion of the calculation requires a separate calibration experiment similar to that used in data-logging Activity 1b; a mains light bulb of known power output is placed inside the empty box and the rate of temperature rise again recorded using the data-logger. The method of calculating the equivalent heat output from the temperature rise is exactly the same as that used in simulation Activity 2a. This is an illustration of the complementary use of the different ICT tools: data-logging, simulation and video capture.



The measurements of CO_2 concentration and Relative humidity are useful as evidence supporting the chemical description of aerobic respiration in the body:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

Further, the increase in CO_2 concentration can be used to calculate the amount of glucose metabolised during the experiment. Since the Heat of Combustion (enthalpy) of glucose is known, the amount of heat generated by respiration may be calculated and compared with the result obtained from the rise of temperature. Calculations from sample data are included in Activity 4. A full explanation of the theory behind these may be found in the paper by Mats Areskoug 'The Power of the Human Body' provided in Appendix 2.

4. Teaching approaches

The four activities presented here offer distinctive but complementary insights into the science involved in this topic. For the activities to be effective for teaching and learning, it is helpful for teachers to consider two types of skills in using the software tools:

- ***Operational skills*** which concern the manipulation of the computer hardware and knowledge of the features in the software.
- ***Procedural skills*** which concern the manner in which the software tools are employed in the lesson context for the purpose of achieving learning benefits. A dominant aspect of these skills is the development of an inquiring approach to the analysis and interpretation of data and to making links with previous knowledge.

Such skills are important for the preparation of pupils for the activities, and the activity sheets below each contain indications of the skills needed for the particular activity.

For the teacher, there are further *pedagogical skills* which contribute to the effectiveness of the activities:

1. Clarity of learning objectives for each activity.
2. Understanding of the special value of the ICT method and exploiting its full potential in purposeful ways.
3. To manage the activity in a way which promotes 'appropriate' rather than 'indiscriminate' use of ICT.
4. To integrate the learning from each activity to develop pupils' understanding of the topic.

The development of the last of these is a particular aim of the IT for US Project, and the activities presented below have been specially selected to illustrate how integration might be achieved. Comparisons of the observations and results of each activity form a central role in this integration process. For example:

- Compare the two sets of data collected in the first data-logging experiment; the data obtained with the electric lamp is used to calibrate the data from burning the potato crisp;
- Use the results from the two data logging experiments (1. burning, 2. evaporation) to contribute to a discussion about human respiration and the energy balance maintained by the human body;
- Use the simulations to amplify the discussion of respiration and energy;
- Compare data from the model with experimental data;
- Compare the data from the video-recorded experiment, data-logging experiments and the models.

In these, the graph is a key tool in facilitating comparisons and interpretations and skills with graphs generally provide a common thread in exploiting IT for US activities.

Teachers will usually have their preferred sequence of teaching themes involving, demonstrations, explanations, class experiments, but the table below suggests a suitable sequence exemplifying a logical development of concepts. The right hand column shows how the activities in this module may be chosen to enhance the teaching sequence.

Teaching sequence	IT for US Activities
Oxidation liberates energy in a fuel *Experiments with burning fuels to find energy content Food is fuel to the human body • Experiment burning an item of food in a quasi calorimetric bomb	D-Logging: 1a. Energy content of food Simulation: 2a. Energy content of food
Heat energy emitted from a human body comes from 'burning' food in the process of 'Aerobic respiration' • Experiment to measure heat emitted from human body in insulated box Calculations of energy balance (optional)	Video: 4. Energy emission from human D-Logging: Experiment featured in video
Heat energy is lost when a liquid evaporates • Experiment to measure the temperature of an evaporating liquid	D-Logging: 1b. Evaporation of a liquid Model: 3. Evaporation of a liquid
Thermal energy changes in the human body	Simulation: 2b. Body evaporation Body convection, Body energy balance

The non-computer experiments (*) are not described here, since their details are well established in conventional teaching schemes and text books.

The management of the classroom setting also has an important influence on the successful integration of activities. When access to computer equipment is scarce it is likely that the teacher will wish to present the activity as a demonstration in a didactic manner. In this mode, the teacher can give strong guidance to pupils' thinking about the comparisons between the activities. Alternatively, pupils could perform the activities in small groups of three or four pupils, each group engaged on a different activity. Integration might be achieved by each group making a presentation of their results to the whole class. In chairing these presentations the teacher can prompt discussion of the significant findings of each group.

It is worth considering that all the activities may be used in a variety of learning contexts; it is not necessary to consider their mode of use exclusively as a first experience of the topic. For example, the simulations could be used to prepare thinking about the video-recorded experiment. Similarly, the evaporation model could be used either before the data-logging experiment to prepare thinking about the experiment, or it could be used as a means of extending the investigation, or as a revision exercise, or for distance learning. Although the activities have been designed to provide complementary experiences, it is not essential to use all of them; two, three or four activities might be chosen according to how well they suit the needs of teachers and pupils in a particular context. In varying conditions between schools and within schools at different times of the year or different stages in the curriculum, needs and appropriateness are likely to change; for example, data-logging equipment might not be available at the time of need, an individual pupil might need a revision or extension activity, an enrichment activity might be required to occupy some spare time, a quick activity might be needed if time is scarce. The overlapping features, such as graphical presentation, between the activities allows them to be used to a certain extent as alternatives, but their distinctive features also allow them to be used as complements to each other. The table below summarises the distinctive potential learning benefits of each. It is a useful guide to the special value of each ICT activity.

Activity	Potential learning benefits, 'ICT value'
Data-logging 1. Burning 2. Evaporation	Whole process of heating or cooling may be observed without interruption. Graph of temperature changes is displayed during experiment Results may be related to visual observations (e.g. the times for the beginning and end of burning) Graph analysis tools facilitate detailed investigation of data.
Simulation	Animated graphics provide a visual stimulus for thinking about the roles of evaporation and convection in maintaining temperature balance in the body. The complexity of controlling several processes associated with heat generation and loss within the human body may be appreciated. The simulation of the burning crisp may be used to brief students for performing the data-logging experiment.
Modelling	The model demonstrates how the relevant physical principles can be expressed in simple stages using mathematical formulae. The model calculates temperature data which can be compared with data obtained from the real experiment (data-logging) on evaporation. The effect of altering parameters such as surrounding temperature, mass of substance, thermal capacity and latent heat capacity may be investigated.
Video capture	The video sequence records an experiment which may be difficult or inconvenient to set up in a lesson. The method of calibrating the results is similar to that used in the first data-logging experiment.

5. Resources for Student Activities

Using Insight software

Activity	Software program	Files available
1. Data-logging	Datalogging Insight	Set-up files: 'Energy value set up' and 'Evaporation set up'. Open these files to configure the program ready for the experiments. Data files: 'Energy value data' and 'Evaporation data' *These files contain sample sets of data.*
2. Simulation	Simulation Insight	'Energy value expt' 'Body convection' 'Body evaporation' 'Body energy balance'
3. Modelling	Simulation Insight	'Evaporation model'
4. Video	Media player Datalogging Insight	'Body heat expt' 'Human body data'

Equipment and materials for Activity 1 (Data-logging)

- Computer
- Software – *See table above*
- Interface (data-logger)
- Temperature sensor
- Copper calorimeter
- Tripod and heat resistant mat
- Packet of potato crisps
- Tongs
- 100W bulb in holder
- Matches, Adhesive tape, Pipette, Filter paper

C. Student Activities

ACTIVITY 1A. EXPERIMENT TO MEASURE THE ENERGY CONTENT OF FOOD

Learning Objectives:

1. To measure the rise in temperature of a copper calorimeter when an item of food is burnt inside it.
2. To calibrate the calorimeter for heat transfer using a standard electric bulb.
3. To calculate the amount of heat given out by the item of food when burnt.

APPLIED ICT TECHNOLOGY: DATA LOGGING

STUDENT LEVEL: AGE 14-17

RECOMMENDED SETTINGS: STUDENT ACTIVITY IF ENOUGH EQUIPMENT IS AVAILABLE, OTHERWISE TEACHER DEMONSTRATION

Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Starting and finishing real-time logging
- Using the cursor tools for obtaining measurements from the graph

Procedural Skills:

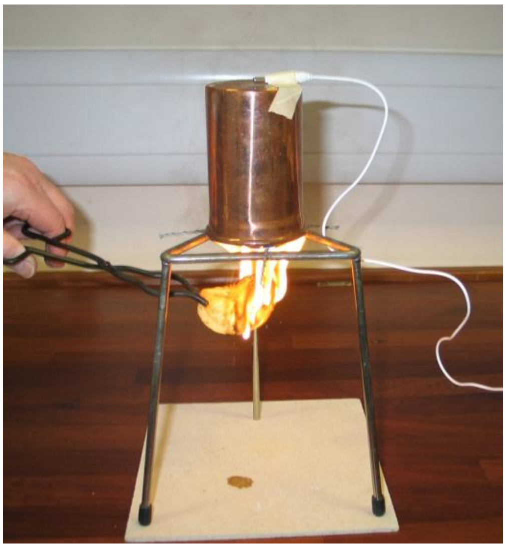
- Evaluating measurement quality
- Analysing data using graph
- Reading values/slopes

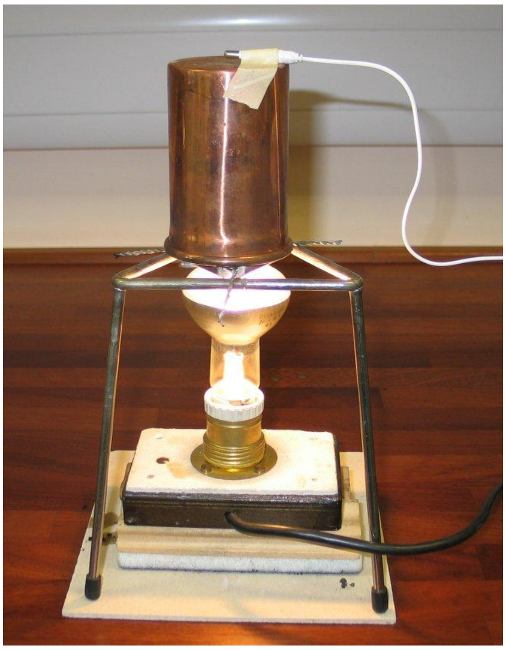
Materials:

- Interface (data-logger)
- Temperature sensor
- Copper calorimeter on a tripod on a heat resistant mat
- Handling tongs
- Food item (potato crisp)
- 100W bulb in holder (reflector type)
- Matches
- Adhesive tape

Activity method:

1. Place the calorimeter in an inverted position on the tripod.
2. Use adhesive tape to secure the temperature probe on the top of the calorimeter, ensuring that it makes good thermal contact.
3. Set the data logging software to record temperature for about 2 minutes. Start recording.
4. Grip the potato crisp in the tongs and carefully light it with a match. Immediately hold the burning crisp under the calorimeter.
5. Observe the Temperature vs Time graph.
6. Allow the calorimeter to cool down to room temperature, and then repeat the experiment with a mains bulb in place of the burning crisp. Switch off the lamp when the temperature reaches the maximum temperature of the first experiment.
7. Overlay the new Temperature vs Time graph on the previous graph.





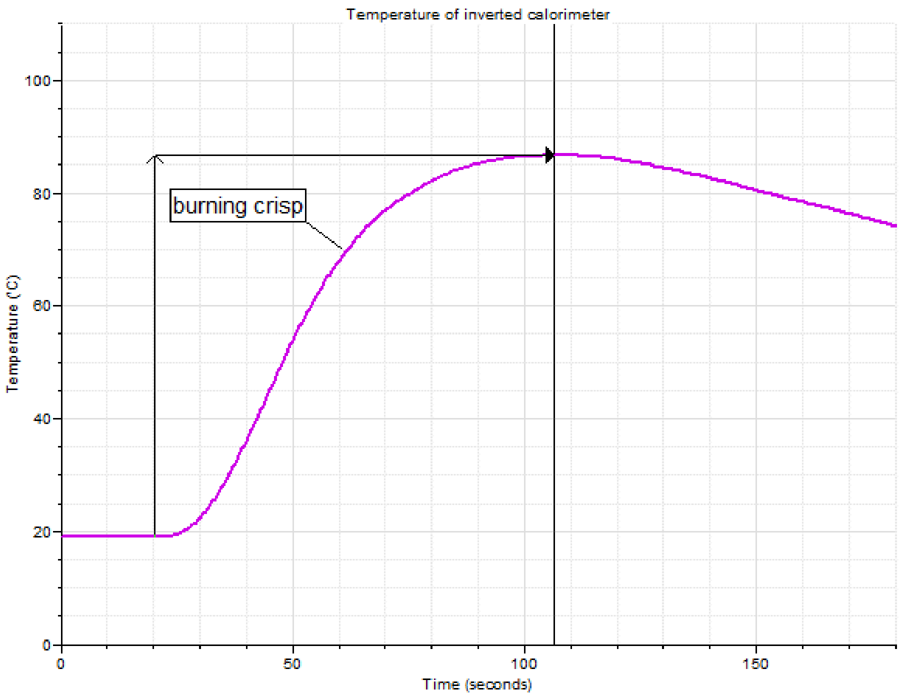
Analysing activities:

1. *Sweeping cursors*
   After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect.
2. *Add captions to graph*
   Annotate each graph to indicate the experiment which produced the line: the food experiment or the bulb experiment.

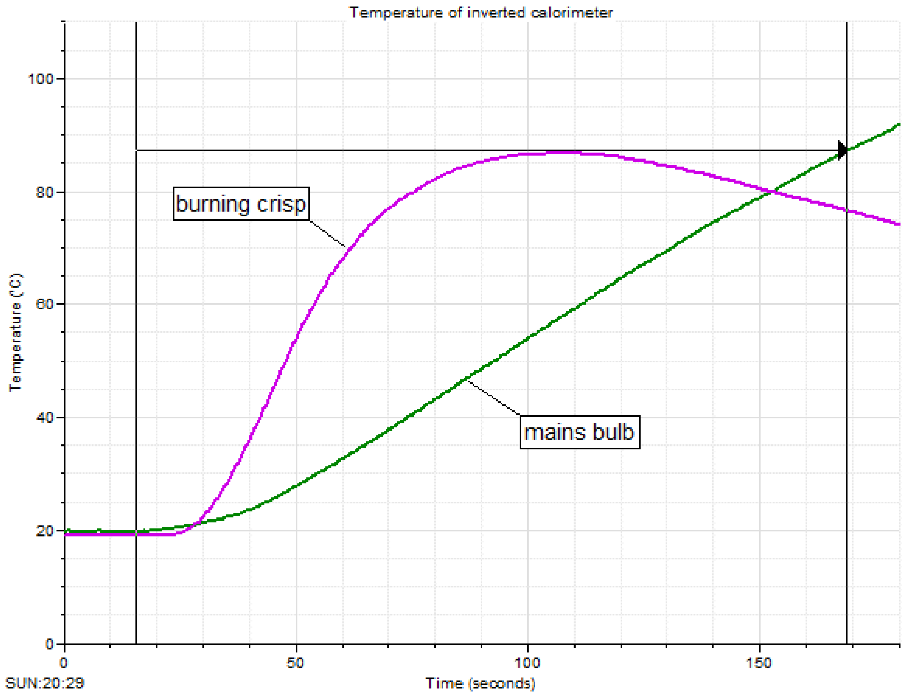
3. *Take readings from the graph*
Record the highest temperature reached in the potato crisp experiment. Use the *Interval* graphing tool to measure how many seconds it took the for the mains bulb to reach the same temperature.
Calculate the energy supplied using $\Delta H = 100 \times \text{interval}$.

4. *Time measurements*
Find the time period for which the potato crisp was burning.

5. *Measure rate of change*
Use the *Rate* and *Gradient* graphing tools to measure and compare the rates of warming up in each experiment. Could these values be used to calculate the energy in the food?



Burning crisp: Reading highest temperature and time for burning



Mains bulb: Time to reach highest temperature with crisp

Further work:

- Repeat the experiment with other fast food products and compare the results with the values of energy content displayed on the packets.
- Obtain the data for the energy content of a range of breakfast cereals by recording the values displayed on the side of the packet. Make a list of the results and sort them in order from high to low energy content.
- Perform an experiment to measure the heat output from the human body. See Activity 4 for details.

ACTIVITY 1B. EXPERIMENT TO MEASURE THE EFFECT OF A LIQUID EVAPORATING

Learning Objectives:

1. To measure the fall in temperature of a liquid when it evaporates.
2. To understand the factors which influence the cooling effect of evaporation.

APPLIED ICT TECHNOLOGY: DATA LOGGING

STUDENT LEVEL: AGE 14-17

RECOMMENDED SETTINGS: STUDENT ACTIVITY IF ENOUGH EQUIPMENT IS AVAILABLE, OTHERWISE TEACHER DEMONSTRATION

Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Starting and finishing real-time logging
- Using the cursor tools for obtaining measurements from the graph

Procedural Skills:

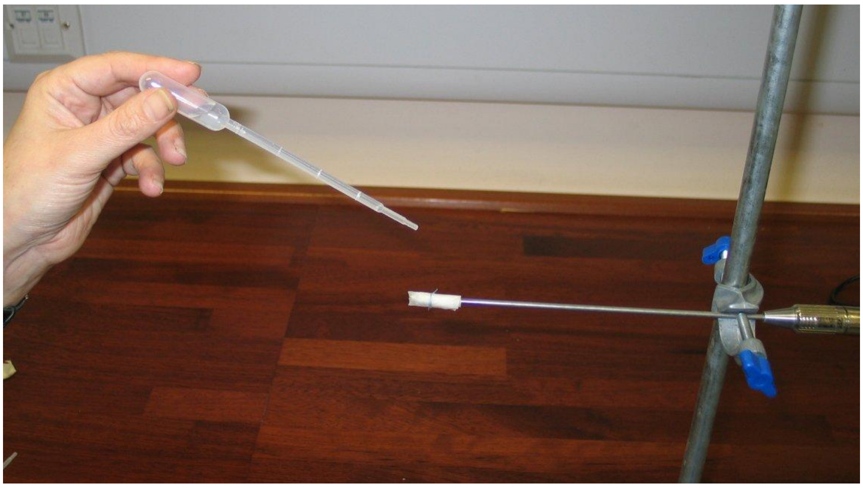
- Evaluating measurement quality
- Analysing data using graph
- Reading values/slopes

Materials:

- Interface (data-logger)
- Temperature sensor
- Tissue paper
- Pipette

Activity method:

1. Assemble the temperature probe in the stand with a piece of tissue paper wrapped around its tip.
2. Fill a pipette with water.
3. Set the data logger to record temperature for 15 minutes.
4. Use the pipette to soak the tissue paper with water.
5. Observe the Temperature vs Time graph.



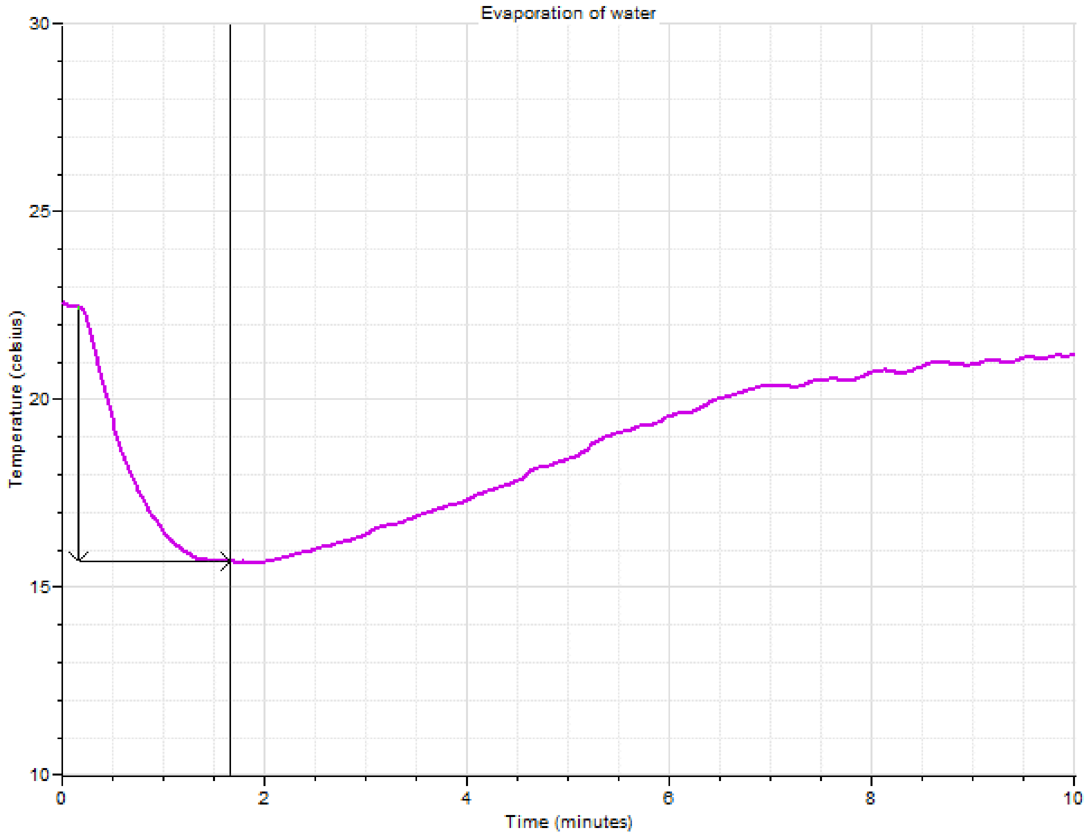
Analysing activities:

1. *Magnify the graph*
   Use the Zoom or scaling tool to increase the vertical scale so as to magnify the change of temperature.

2. *Sweeping cursors*
   After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect.

3. *Take readings from the graph*
   Record the lowest temperature reached in the experiment.
   Use the *Change* graphing tool to measure the maximum fall in temperature.

4. *Time measurements*
   Use the *Interval* graphing tool to measure how many seconds it took the for the lowest temperature to be reached.



Taking readings of *Change* and *Interval*.

ACTIVITY 2A. UNDERSTANDING THE 'ENERGY CONTENT OF FOOD' EXPERIMENT

Learning Objectives:

1. To understand the energy transfers which cause changes of temperature of the calorimeter in the data-logging experiment 1a.
2. To understand the use of the mains bulb as a means of calibrating temperature changes of the calorimeter to determine heat transfer.

APPLIED ICT TECHNOLOGY: SIMULATION

STUDENT LEVEL: AGE 14-17

RECOMMENDED SETTINGS: STUDENT ACTIVITY OR TEACHER-LED CLASS DISCUSSION

Operational Skills:

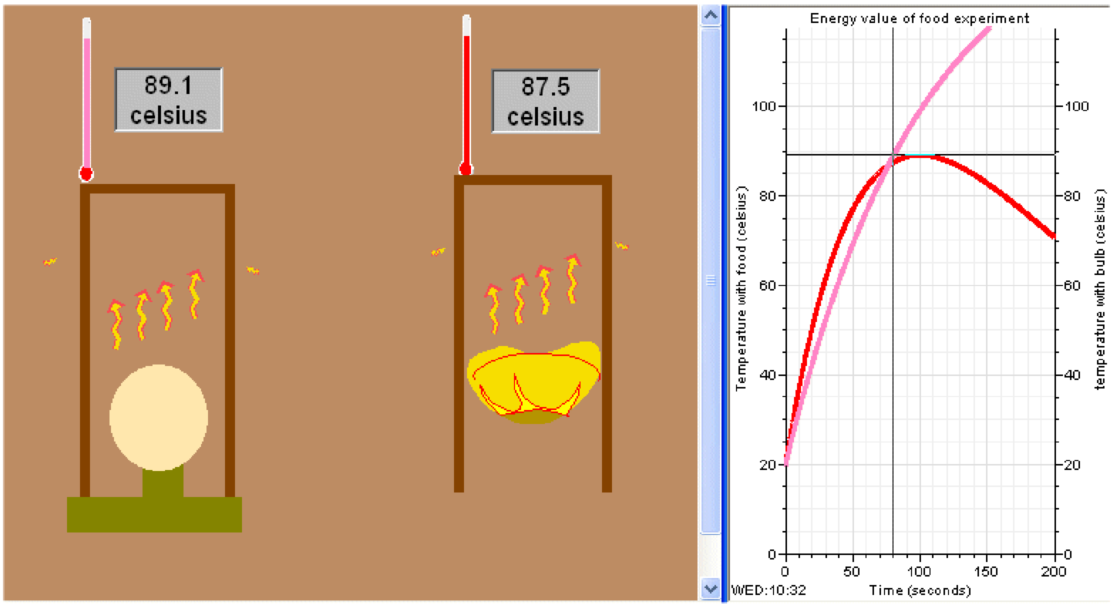
- Using the software controls for running the simulation
- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

Activity method:

1. Open the *Insight* file 'Energy value expt'.
2. Look carefully at the simulation window and notice that it shows two experiments which will run at the same time. The experiment on the left shows a mains bulb heating up the inside of the calorimeter. The experiment on the right shows an item of food being burnt inside the calorimeter.
3. Look at the graph and notice that this shows temperature of the calorimeter against time. By comparing the two graphs, it is possible to calculate the amount of heat produced by the burning crisp.



Analysing activities:

1. *Sweeping cursors*
After running the model and observing the heating and cooling, replay the changes using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect. Observe that the temperature begins to fall when the crisp has finished burning.

2. *Add captions to graph*
Annotate the point on the graph to show where the crisp stopped burning.

3. *Take readings from the graph*
Make a note of the *maximum temperature* reached when the crisp burns. Find the *time* taken for the bulb to reach the same temperature. Calculate the amount of heat given out by the bulb during this time using:
Heat (in joules) = **power** (in watts) x **time** (in seconds)
This is the same as the amount of heat produced when the crisp has completely burnt.

ACTIVITY 2B. INVESTIGATING ENERGY CHANGES IN THE HUMAN BODY

Learning Objectives:

1. To understand the factors which affect the loss of heat energy by the convection of air around the body.
2. To understand how sweating and evaporation allow the human body to lose heat.
3. To understand how food and exercise create heat energy in the body and how this needs to balance the body's losses of heat through convection and evaporation.

APPLIED ICT TECHNOLOGY: SIMULATION

STUDENT LEVEL: AGE 14-17

RECOMMENDED SETTINGS: STUDENT ACTIVITY OR TEACHER-LED CLASS DISCUSSION

Operational Skills:

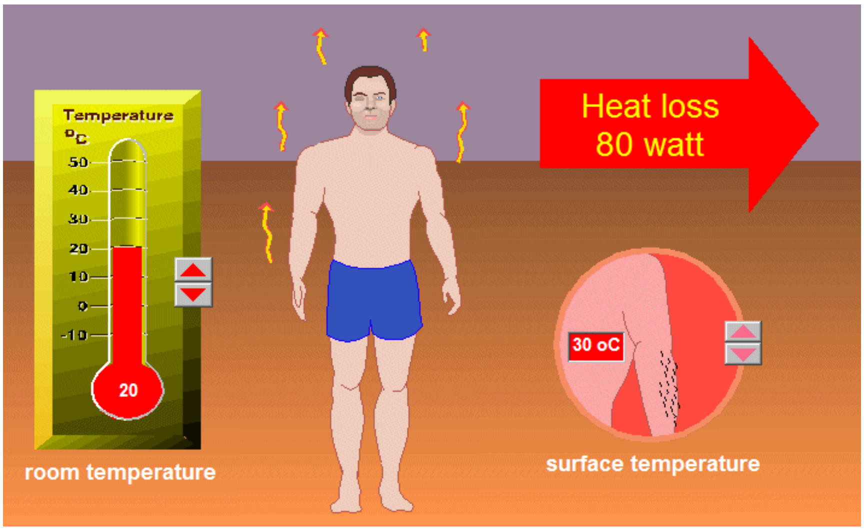
- Using the software controls for running the simulation
- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

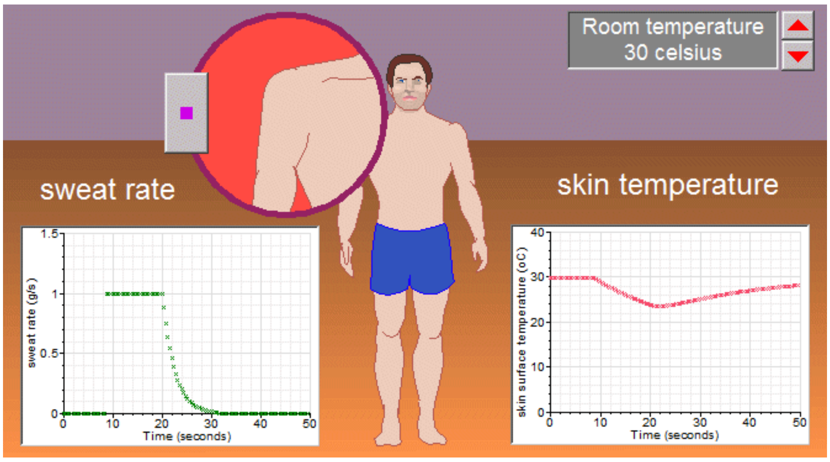
Investigating convection:

1. Open the *Insight* file 'Body convection'.
2. Adjust the value of room temperature and notice its effect on the rate of loss of heat. (If the heat loss shows as negative, this corresponds to the body gaining heat from the surroundings.)
3. Adjust the value of room temperature and notice its effect on the rate of loss of heat against time.
4. Adjust the value of skin surface temperature and notice its effect on the rate of loss of heat against time.
5. Make a simple rule which predicts the rate of loss of heat to the surroundings.
6. How would the rate of heat loss be affected by the wearing of clothes? Explain.



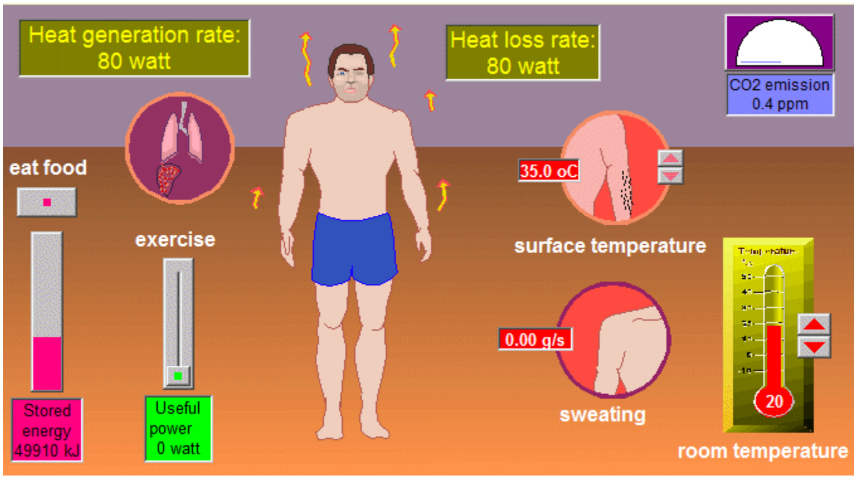
Investigating evaporation:

1. Open the *Insight* file 'Body evaporation'.
2. Click and hold on the sweat rate button to cause sweating to start. Notice the effect on the skin surface temperature whilst sweating occurs.
3. Think about why the sweat rate reduces when you release the button.
4. What causes the skin temperature to rise when sweating ceases?



Investigating heat changes in the human body:

1. Open the file 'Body energy balance'.
2. The simulation shows three processes which generate heat in the body: heart and lungs function, food metabolism and performing exercise.
3. Press the 'eat food' button for a few seconds and notice the effect on the energy stored. Describe the process in the body which generates heat from stored energy.
4. Set the 'exercise' on for a few seconds and notice the effect on the heat generated. Describe the process in the body which generates heat during exercise.
5. Adjust the value of room temperature and note its effect on the rate of heat loss. At what value of room temperature does the heat loss reduce to zero?
6. Adjust the value of skin surface temperature and note its effect on the rate of heat loss. How does the body control the skin surface temperature?
7. At what value of skin surface temperature does sweating begin? Notice the effect of sweating on the rate of heat loss.
8. Choose a value of room temperature. Then adjust the controls for food, exercise and skin temperature so that the rate of heat generated balances the rate of heat loss. The human body performs this process automatically. Can you control the functions as well as your body does?



ACTIVITY 3. INVESTIGATING MODELS OF ENERGY CHANGES IN THE HUMAN BODY

Learning Objectives:

1. To understand that the rate of cooling during evaporation depends upon the mass of water present, its volatility and latent heat.
2. To understand that when the temperature of a body is lower than the temperature of its surroundings, the body receives heat from the surroundings.

APPLIED ICT TECHNOLOGY: MODELLING

STUDENT LEVEL: AGE 14-17

RECOMMENDED SETTINGS: STUDENT ACTIVITY OR TEACHER-LED CLASS DISCUSSION

Operational Skills:

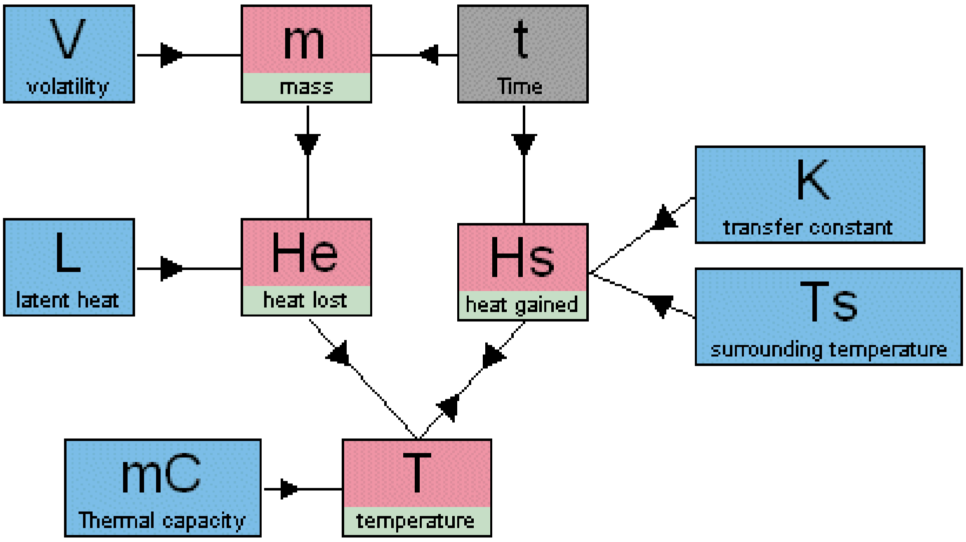
- Using the software controls for running the simulation
- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Describe observations and link these with theoretical explanation

Evaporation (using Simulation Insight)

1. Open the *Insight* file 'Evaporation model'.
2. Click on the START button to run the simulation.
3. Observe the shape of the Temperature vs Time graph and try to explain it.
4. If water were more volatile, the constant 'V' would be larger. Stop the model, make V = 0.2 and run the model again. How does the graph differ from before.



Body energy models (using Simulation Insight)

1. Open each of the previous simulation files, show the model window and find out how the models work:

   'Energy value expt'

   'Body convection'

   'Body evaporation'

   'Body heat balance'

ACTIVITY 4. ANALYSIS OF A VIDEO RECORDING OF AN EXPERIMENT TO MEASURE THE RATE OF ENERGY EMISSION FROM THE HUMAN BODY

Learning Objectives:

1. To measure the rate of heat emitted by the human body.

Operational Skills:

- Using the cursor tools for obtaining readings from the graph

Procedural Skills:

- Relate the graphs to the theory of respiration

APPLIED ICT TECHNOLOGY: VIDEO CAPTURE

STUDENT LEVEL: AGE 15-17

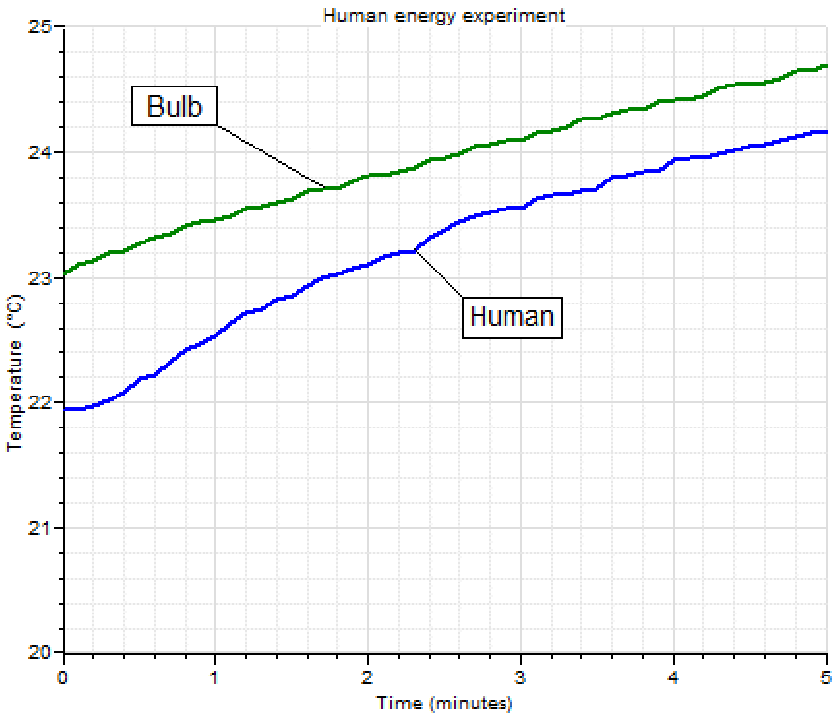
RECOMMENDED SETTINGS: STUDENT ACTIVITY OR TEACHER-LED CLASS DISCUSSION

Activities:

The video shows an experiment in which a person sits inside a thermally insulated box for a few minutes. During that time a data-logger records measurements of temperature, humidity and carbon dioxide concentration inside the box. Afterwards a similar experiment is conducted, but with an electric bulb instead of a person inside the box. By comparing the temperature increases in each experiment, the rate of heat emitted by the person may be calculated.

Analysing activities:

1. Open the *Insight* or *Coach 6* file 'Human body data'.



2. *Take readings from the temperature graphs*

- Make a note of the *temperature* reached after 5 minutes when the person is in the box.
- Note the *time* taken to reach the same temperature with the electric bulb in the box.
- Calculate the amount of heat given out by the bulb during this time using:

  Heat (in joules) = **power** (in watts) x **time** (in seconds)

  This is the same as the amount of heat emitted by the person during 5 minutes.
- Calculate rate of heat emission using:
  Rate of emission (in watts) = **Heat** (in joules) / **time** (300 seconds)

Sample data from video

Volume of chamber: 1 m^3
Duration of experiment: 5 minutes
Increase in CO_2 concentration: 2259 ppm
Increase in temperature: 2.2 degrees Celsius
Increase in Relative humidity: 6.7 %
Time for 100 W bulb to increase chamber temperature by 2.2 deg C = 418 s (6.97 minutes)

Calculation of rate of heat emission

Heat emitted by 100W bulb in 418 seconds = 100 * 418 = 41800 J
Rate of heat emission by human body over 300 seconds = 41800 / 300 = 139 W

3. *Take readings from the humidity and CO_2 graphs*

Take readings of the *increase* in relative humidity and the *increase* in CO_2 concentration during the 5 minute period of the experiment. Discuss the reasons for these increases in relation to the process of aerobic respiration in the human body.

These readings may also be used to calculate the amount of glucose metabolised during the experiment and the consequent rate of heat generation in the human body. Using the sample data from the video, the following calculations may be made.

Emitted CO_2 in mol:

1 ppm (part per million) corresponds to 1 cm^3 in 1 m^3. Since the volume of the box in the experiment is 1 m^3, the increase in CO_2 corresponds to a volume ΔV= 2259 cm^3 = 2.259 litre.

At 273 K (0°C) at 1 atm pressure, 1 mole of gas has a volume 22.4 litre (V_0).

It follows, at 298 K (25°C) at 1 atm pressure, 1 mole of gas has a volume given by

$$V_t = V_0 \frac{T}{T_0} = 22{,}4 \frac{298}{273} = 24{,}45$$

Thus 1 litre contains 1 / (24.45) mol

Hence, 2.259 litre contains 2.259 / 24.45 = 0.092 mol of CO_2

Combustion of glucose:

For the oxidation of glucose, $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ one mole of glucose being burned yields 6 moles of CO_2. Therefore 0.092 mol of CO_2 emitted in the experiment originates from 0.015 mol of glucose being burned.

The Heat of Combustion (enthalpy) of glucose is 2812 kJ/mol

The yielded heat is therefore ΔH_b=0.015 * 2812 = 42.2 kJ.

Power of combustion is P= 42200 J /300 s = 141 W

Energy for water vaporisation:

Relative Humidity change ΔRH = 6.7%

Saturated vapour pressure of water at 278 K is 3167 Pa

Thus, change of water vapour pressure Δp = 6.7% * 3167 Pa = 212 Pa

Number of moles emitted:

$$\Delta n_{H2O} = \frac{\Delta pV}{RT} = \frac{212Pa \times 1m^3}{8.31J/mol/K \times 298K} = 0.0856mol$$

The Latent heat of Vaporisation of water is 44 kJ/mol

Thus, heat required is ΔH_w= 0.0856 mol * 44 kJ/mol = 3.766 kJ

Hence, power required for water evaporation = 3766 / 300 = 12.5 W

Comparison of calculated results

According to the measurements of CO_2 emission, the metabolism of glucose in the human body generated 141 W. The emission of water vapour required 12.5 W, leaving 128.5 W to be emitted as heat. Within experimental error this compares well with the calibration value of 139 W obtained with measurements with the bulb.

A full discussion of the background theory to the experiment and explanation of the calculations may be found in the paper by Mats Areskoug 'The Power of the Human Body' provided in Appendix 2.

4. *Compare the results with a simulation*
Open the simulation 'Body energy balance' (with Simulation Insight) and compare the data with the results of the experiment with the box.