



Resource 1: Images of the lotus plant and how it is used in Hinduism

Print out the images without their captions so that the pupils will come with their own explanation of what these images are about and what are the links between them.



Lotus shaped garden at the Hindu temple Akshardham in Delhi, India

By Juthani1



Angkor Wat, Hindu temple in Cambodia *By Bjørn Christian Torrissen*



Hindu goddess
Lakshmi holding and
standing on a lotus



Lotus position, posture used for meditation in the Hindu Yoga



Durga Puja
By learning photography



*Nelumbo
nucifera*
flowers
By neofedex



Bud of
*Nelumbo
nucifera*
By Alvesgaspar



Resource 2: Materials for experiment workstations

Workstation 1

Research question: What happens if a drop of water falls on different leaves including a lotus leaf?

- 4-5 different types of leaves including lotus leaf (*Nelumbo nucifera*). If a lotus leaf is not available you can substitute it with nasturtium leaf (*Tropaeloum sp.*) or water lettuce (*Pistia sp.*)
- 2 pipettes
- 1 tray to put the leaves in and conduct the experiment
- bowl with water
- ruler
- 2 magnifying glasses

Workstation 2

Research question: What happens if drops of different liquids fall on the lotus leaf?

- 1-2 lotus leaves (*Nelumbo nucifera*). If a lotus leaf is not available you can substitute it with nasturtium leaf (*Tropaeloum sp.*) or water lettuce (*Pistia sp.*)
- 3-4 small pots with different liquids e.g. vinegar, soap liquid, honey, juice
- tray to put in the leaves and do the experiment
- 3 pipettes and 2 plastic spoons

Workstation 3

Note: this workstation includes two short experiments

[Experiment 3a resources](#)

Research question: What happens when a few drops of water fall on a lotus leaf that has ash on its surface?

ACTION POINTS:

- As part of the workstation resources print out the labels on **RootsRitualBGlabel1.pdf** (see image below for reference).
- Fold along line and place labels on the relevant workstation. **Workstation 3** should include two labels because it comprises two short experiments.

What happens if a drop of water falls on different leaves including a lotus leaf?

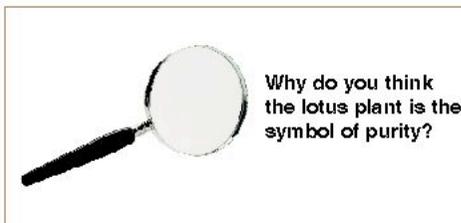
What happens if drops of different liquids fall on the lotus leaf?

What happens when a few drops of water fall on a lotus leaf that has ash on its surface?

How has the lotus plant inspired the glass manufacture to make a self-cleaning glass?

Can you find any similarities or differences between lotus leaves and other plants?

- Print the label on **RootsRitualBGlabel2** (see image below for reference) and place on each workstation so that the pupils will always remember the overall research question they have to answer in the end of the lesson





- 1-2 lotus leaves (*Nelumbo nucifera*). If a lotus leaf is not available you can substitute it with nasturtium leaf (*Tropaeloum sp.*) or water lettuce (*Pistia sp.*)
- small pot with ash (from fireplace or barbecue) or with dust
- plastic spoon
- magnifying glass
- tray to put in the leaves and do the experiment
- pipette
- bowl with water

Experiment 3b resources

Research question: How has the lotus plant inspired the glass manufacture to make a self-cleaning glass?

- piece of normal glass e.g. 10cmx20cm
- piece of self-cleaning glass e.g.10cmx20cm (you may find this by contacting glass making companies or retailers (e.g. <http://www.pilkingtonselfcleaningglass.co.uk/>)
- tray to put in the glass and do the experiment in

Workstation 4

Research question: Can you find any similarities or differences between the leaves of lotus plant and other plants?

- 4-5 different types of leaves including lotus leaf (*Nelumbo nucifera*). If lotus leaf is not available you can substitute it with nasturtium leaf (*Tropaeloum sp.*) or water lettuce (*Pistia sp.*)
- usb microscope, at least x400 magnification (you will find a list of affordable usb microscopes at: http://www.amazon.co.uk/s/?ie=UTF8&keywords=usb+microscope+x400&tag=googhydr-21&index=aps&hva did=7736463366&ref=pd_sl_7vxurveo9u_b)
- Laptop to connect the microscope



Resource 3: Experiment worksheets

Seeds of Unity 'Roots of ritual' worksheet

Find the research question that is displayed on each workstation and then record your experiment findings on the relevant section of this worksheet.

Research question: What happens if a drop of water falls on different leaves including a lotus leaf?

Use the tables opposite to record your observations.

- Surfaces that repel water are called hydrophobic (or water haters).
- Surfaces that hold on the water that falls onto them are called hydrophilic (or water lovers)

Research question: What happens if drops of different liquids fall on the lotus leaf?

- Try throwing drops of different liquids on the lotus leaf and write your observations. Are the liquids absorbed or stained?

Research question: What happens when a few drops of water fall on a lotus leaf that has ash on its surface?

- Put ash on the surface of the leaf and describe what happens when you pour water on it.

Research question: How has the lotus plant inspired the glass manufacture to make a self-cleaning glass?

- Use the pipette to pour water on both glass surfaces and write down your observations.

Table 1: Hydrophilic - Hydrophobic surfaces

Profile/shape of the drop				
Type of surface	Hydrophilic	Intermediate	Hydrophobic	Superhydrophobic

see: [RootsRitualBGtable1.pdf](#)

Table 2: Observations

Type of leaf (name or shape)	Shape of the drop and size Draw the profile of your drop (see Table 1) and measure the drops	Type of surface based on the level of hydrophilic /hydrophobic (see Table 1)	Do the water droplets roll or slide over the leaves?	Do the droplets wet the surfaces (is water left when pouring it?)

see: [RootsRitualBGtable2.pdf](#)



Research question: Can you find any similarities and differences between the lotus plant leaves and other leaves?

- Use the usb microscope to look at the surfaces of different leaves and compare them with each other. Can you see any structures on the leaves that are similar or very different?

Table 3: Observations

Leaves (write the name of your leaf and draw its shape)	Detail of the surface of the leaf

see: [RootsRitualBGtable3.pdf](#)



Resource 4: Explanations on the workstation experiments

Use the explanation on the experiments when all the groups will report on the findings. Encourage each group to speak about their last workstation experiment(s) and enhance their answer with the information provided below.

Research question: What happens if drops of different liquids fall on the lotus leaf?

- Surfaces that repel water are called hydrophobic (or water haters).
- Surfaces that hold on the water that falls onto them are called hydrophilic (or water lovers).
- In different leaf surfaces the water droplets may have different shapes, be absorbed or repelled, tend to move or slide differently depending on whether the surfaces are hydrophobic or hydrophilic.

Water wets most of the leaf surfaces except the lotus plant/nasturtium/water lettuce leaf. The water droplets slide over most of the leaf surfaces. However, when water droplets fall on the lotus/nasturtium/ water lettuce leaf roll like beads. If you measure the diameter of the drops or spots of water with the ruler the more hydrophobic the surface the smaller the diameter of the drop.

Ask the pupils: Would you expect a smooth or a rough plant surface to repel water and other liquids?

The behavior of water on a surface depends on a large extent on the roughness of the surface. People often think that the smoother a surface is the easier it is water to slide away from it. However, that is a misconception. When a surface of a leaf is rougher then the contact area between the leaf and the droplet is minimized and the drop rolls off very quickly as a result.

Research question: What happens if drops of different liquids fall on the lotus leaf?

When droplets of water fall on a lotus plant leaf they appear spherical like beads. When they fall on the leaf they roll off its surfaces and they don't wet



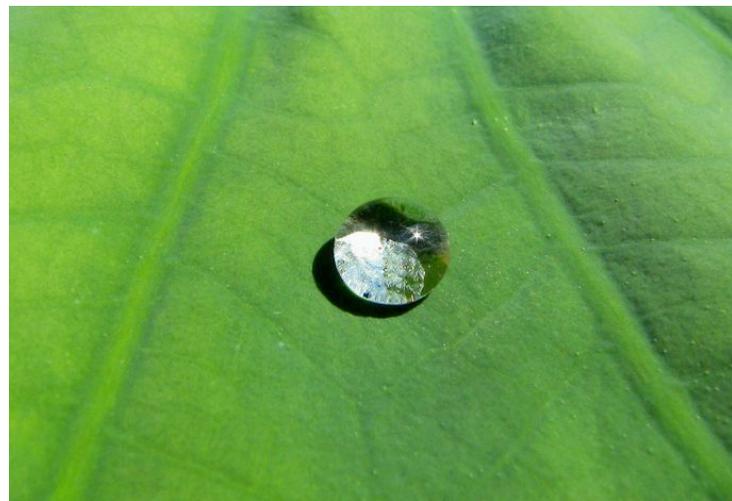
it at all. The lotus leaf repels the drops because it is superhydrophobic (**image of the lotus leaf**). The same phenomenon can be observed when drops of different liquids fall on the lotus leaf such as vinegar, liquid soap or even honey.

The leaves of the lotus plant have the distinct property of remaining particularly clean even if its natural habitat is muddy. Other leaves that share similar property are the nasturtium and the water lettuce.

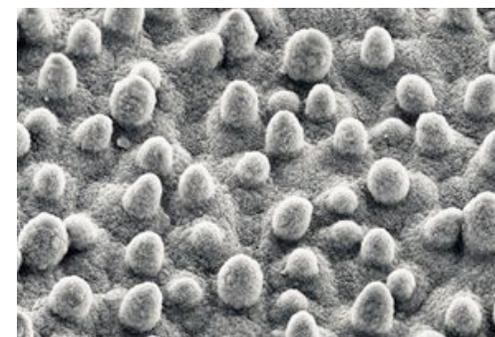
The superhydrophobic property that the lotus leaf demonstrates has been identified by the scientists as the lotus effect. The lotus effect which makes the leaf self-cleaning is caused by the special structure of the lotus leaf. In particular the leaf surface has a double structure. First of all the leaf epidermis (and its outermost layer called the cuticle) contains nanometer-sized bumps. These bumps are covered by waxes, which are hydrophobic and form the second layer of the double structure (**image Close up of the lotus leaf**). When water or other liquids fall on the lotus leaf because of the double structure the adhesion force between the drop and the surface is minimized and the liquid rolls away. Because of the bumps the drop often does not come in contact with the actual leaf surface.

If you rub the lotus leaf with your thumb (but not too hard) and you do the experiment again, you will observe that the leaf is no longer water repellent which means that if the leaf gets damaged then its superhydrophobic property is diminished. However, if the plant is living (if it is not cut off from its roots) then it can regenerate, the structure of its leaf surface is repaired and its' superhydrophobic property re-established.

German scientists from the Botanical Garden of the University of Bonn (one of which is the botanist Wilhelm Barthlott), examined the surface of Lotus leaves by using high resolution electron microscope recently. Barthlott and his colleagues have discovered the self-cleaning properties of biological surfaces such as the lotus plant and identified them as the lotus effect and have collaborated with the industry to develop self-cleaning surfaces.

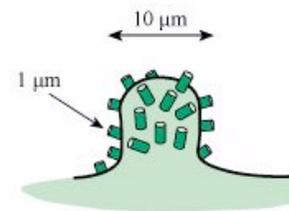


*Nelumbo
nucifera*
Hydrophobia
By Michael
Whitehead



Close-up of a lotus leaf. The roughness of the leaf surface results from the coexistence of micron-sized bumps and nanoscale hair-like structures.

By W. Barthlott





Research question: What happens when a few drops of water fall on a lotus leaf that has ash on its surface?

If you put ash or dust on a lotus leaf and add a few drops of water with a pipette on the surface and you tilt the leaf so that the drops can roll away the dirt is absorbed by the water and the drop leaves a clean track on the contaminated leaf.

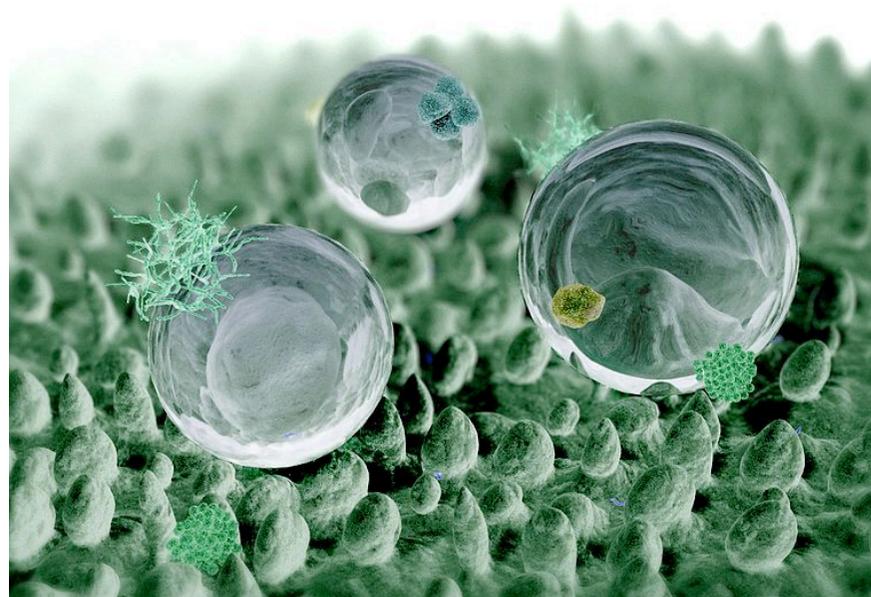
Ash/dust is hydrophilic so when they come in contact with water they get absorbed. Ash/dust adhesion (bonding force) to the leaf surface is lower than the adhesion to the water. As a result ash/dust is washed away from the leaf **(see image Water droplets on a lotus leaf carrying away dirt particles)**. This phenomenon is characteristic on lotus/nasturtium/water lettuce leaves because their surfaces have a particular microstructure (lotus effect) that makes them water repellent. Also, because the space between the bumps is too small for ash/dust particles to get in, the ash/dust always stays on top of the bumps. When a water droplet rolls of the leaf, it carries the ash/dust with it, and the leaf becomes clean.

Research question: How has the lotus plant inspired the glass manufacture to make a self-cleaning glass?

If you pour water on a normal glass surface and on a self-cleaning glass surface then you will observe that the self-cleaning glass feels dry when the water rolls off the surface while the normal glass remains wet. The glass industry based on the lotus effect has created a special coating for the glass to make its surface rougher and as a consequent water repellent (hydrophobic) and self-cleaning. You may ask the pupils: What other things from our every day life could be improved based on the lotus effect?

The lotus effect has inspired new innovative materials that are water-repellent, stainless and require less cleaning. Materials manufactured already include:

- paint for buildings - this paint is used to coat the surfaces of concrete buildings. Those surfaces are naturally harder to clean but with the paint it



Water droplets on a lotus leaf carrying away dirt particles

By William Thielicke



allows it to act as the lotus leaf

- textiles/clothes that are waterproof
- fabrics that get less stained and are easier to clean
- coating for the solar power panels to keep the solar cells clean and more effective

Research question: Can you find any similarities and differences between the lotus plant leaves and other leaves?

By looking through the microscope pupils will be able to see the structure of the plants' leaves. It is possible that they may be able to see the bumps on the lotus/nasturtium/water lettuce leaves but most of all they will be able to see the wax crystals that cover the bumps. Other plants leaves surface are also covered by waxes.

Ask the pupils: Why does the lotus leaf have this special structure?

Lotus effect is not a coincidental phenomenon. Some plants have evolved and developed that structure so that they can avoid contamination from inorganic materials (dust) which has a negative influence on the plant tissue (e.g. blocking of stomata, stronger heating under the sun). Lotus effect also prevents pathogenic organic contamination e.g. from bacteria or spores. The pathogens do not stay on the leaf surface as the spores are washed off with the rainfall. In case the spores are not washed off, they will not find enough water on the leaf surface in order to germinate so they will not be able to harm the plant.

References related to the 'Roots of ritual' lesson plan:

<http://www.lotus-effekt.de/en/funktion/index.php>

<http://nanoyou.eu/en/component/content/article/87-hands-on-activities/502-experiment-with-superhydrophobic-materials.html>

http://nanoyou.eu/attachments/135_NSB%20broschuere%20en%20web.pdf



Web links to download the pictures included in 'The roots of ritual' Botanic Garden lesson resources:

Lotus shaped garden at the hindu temple Akshardham in Delhi, India

http://upload.wikimedia.org/wikipedia/commons/a/a4/Akshardham_Lotus.jpg

Angkor Wat, Hindu temple in Cambodia

http://upload.wikimedia.org/wikipedia/commons/4/41/Angkor_Wat.jpg

Hindu goddess Lakshmi holding and standing on a lotus

http://en.wikipedia.org/wiki/File:Ravi_Varma-Lakshmi.jpg

Lotus position, posture used for meditation in the Hindu Yoga

http://en.wikipedia.org/wiki/File:Tanum%C3%A2nas%C3%AE_en_Meditacion_Loto_Padmasana.JPG

Durga puja

<http://www.flickr.com/photos/59670248@N05/6292065495/>

http://www.bgci.org/files/Worldwide/Education/Seeds_of_Unity/Roots%20of%20ritual%20Durga%20puja.jpg

Nelumbo nucifera

<http://www.flickr.com/photos/nanjenchan/4549264806/sizes/o/in/photo-stream/>

***Nelumbo nucifera* flowers**

<http://www.flickr.com/photos/neofedex/4527127883/sizes/l/in/photostream/>

Bud of *Nelumbo nucifera*

http://upload.wikimedia.org/wikipedia/commons/1/1d/Nelumbo_July_2011-3.jpg

***Nelumbo nucifera* Hydrophobia**

<http://www.flickr.com/photos/mwhitehead/2331388473/sizes/l/in/photo-stream/>

Close up of a lotus leaf

<http://physicsworld.com/cws/article/news/21927>

<http://www.lotus-effect.de/>

Water droplets on a lotus leaf carrying away dirt particles

<http://upload.wikimedia.org/wikipedia/commons/1/13/Lotus3.jpg>

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