In this section of Resonance, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. “Classroom” is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

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A Public Experiment in the History of Science
Naked Eye Visibility of the Transit of Venus

Participate in an internet-based project to measure the Astronomical Unit in three steps, called the Vamana Project. (For details see www.vamana.net). 250 schools and 2000 students around the country are already participating. You may join too by doing the experiment described below and sending your results in the appended Reporting Form.

As per historical records Jeremiah Horrocks was the first human to witness the Transit of Venus on Sunday Dec 4, 1639. He had mastery over Keplerian Astronomy. In addition, he was a keen observer of the sky. The records state that he was poor but he seems to have bought himself the new invention of those times, a telescope.

Kepler had predicted for the first time, that a Transit of Venus will take place in 1631. No one in Europe saw it because the Sun was below the horizon in Europe during the transit. Horrocks made his own calculation and found that the transit of Venus occurred in pairs separated by an interval of eight years. Thus he was ready in 1639 to verify his own calculations that predicted a transit for Dec 4, 1639. He set up his telescope on that day to see the Sun’s image in projection right from the morning. He had drawn a circle with degree markings into which the projected
image of the Sun would fit and on which he would mark the position of Venus.

He started his vigil the day before fully conscious that calculations could be in error by as much as a day. No Venus! The next day, Dec 4, 1639 was a Sunday. The sky was intermittently cloudy. But Lady Luck was on his side. He turned his telescope towards the Sun while Venus as a dark spot was still on the solar disc! He made three observations of its position before the Sun dipped below the horizon of Liverpool. Horrocks had entered the pages of history. He became the first human to see Venus as a black dot on the disc of the Sun. Since that time ONLY two pairs of transits of Venus have taken place and we are readying for the next pair to occur on June 8, 2004 and June 6, 2012. Horrocks observed the transit by projecting the Sun’s image formed by a telescope on a screen and observing it. This is the best way to view the transit even today. Project the image of the Sun through a telescope on a screen and view it.

The question we wish to pose is ‘Could Horrocks have seen the transit of Venus on that Sunday afternoon with naked eye, without the help of a telescope’?

Conditions for Naked Eye Visibility of Venus in Transit

The first point to notice is that this is a bright field observation i.e., the object to be detected is dark in an overwhelmingly bright background. There are two aspects of the functioning of a human eye that are of importance in examining this problem:

i) The smallest angle or limit angle that a dark object must subtend at the eye to be detected by it.

ii) The correct range in contrast between the object and the background that will enable the eye to detect the object. If the background is such that the object merges with it, the eye can no longer see it. This is what happens in a dark field observation of stars in a night sky. The light pollution in the cities makes faint stars invisible and you are only able to see the brighter ones.
The usually accepted limiting angular dimension of an object detected by the eye in a bright field observation (called Visual acuity) is about one arc minute at about 2000 lux of luminance (1 lux = 1.46 milliwatts/sq. metre). This angle decreases with decrease in luminance, up to about 0.25 minute of arc at a luminance 100 lux. Lower light levels do not decrease this angle any further.

The angular size of Venus on the day of the transit is 57.8 arc seconds, just a few arc seconds smaller than 1 arc minute. The angular size varies slightly about this value, from transit to transit, depending the distance between Venus and the earth. The luminance of direct sunlight is over a million lux! So, for the high luminance associated with the direct sunlight, Venus would be simply swamped by the glare. A person may be able to see Venus as a tiny black dot on the solar disc, if and only if, the glare from the Sun is cut down SAFELY. Fully tested and approved filters manufactured for SAFE viewing allow only 1 part in 100,000 of the incident sunlight in the ultraviolet, visible and infrared regions. While these filters will cut out sunlight to about 10 lux, the already black Venus just gets only a little bit darker! So the contrast is still adequate and such filters can indeed help the public to view the transit of Venus safely.

The transit of Venus on June 8, 2004 gives us an opportunity to test if indeed it may have been possible to view the transit of Venus without using a telescope and glare-busting filters. The most probable method that could have been used to do so, would be to view the Sun in pinhole projection.

**Pin Hole Projection**

Pin hole projection of the Sun has been made popular by many groups around the world especially when there is a solar eclipse. The basic version uses only a hole, but in better versions, the hole is placed over a mirror to produce a brighter, directed image of the Sun.

I am proposing an experiment using pin hole projection that can
be tried by a very large number of people in their own homes to TEST if this method could indeed have been used to view Venus in transit by our ancestors. In joining this endeavour we can all participate in a great Public Experiment in the history of science.

A typical pin hole projector with or without a mirror is still too crude for making a serious observation. Given below are the instructions for constructing a cardboard altazimuth mount for the pinhole pasted on a mirror. This will bring the image of the Sun inside a suitably darkened room, from where it can be monitored over the entire transit.

**Materials Needed:** Small mirror: 1 cm × 1 cm (preferably front-silvered, but a handbag mirror without finger prints is also acceptable); flat card board 3 to 5 mm thick: 25 cm × 5 cm; the Pattern (Figure 1) in this write-up; a paper punch; white card: 1 cm × 1 cm; thermocol: 5 cm × 5 cm.

**What to do:**

1. Paste the pattern on cardboard and cut it at the outline (Figure 1).
2. Make a shallow slit along the dotted lines with a blade. Do not cut through. Fold as shown.
3. Paste the mirror at the centre of A. Tape a 1 cm by 1 cm white card/paper with a 5 mm hole (a hole made by a typical paper punch) in the centre on the mirror.
4. Insert drawing pin/common pin through E and the face of the thermocol. Check if the top part rotates smoothly.
5. Cut out the sleeve S. Fold and glue to the viewer as shown.
6. Insert C into the sleeve. Pull C back and forth to see if you can smoothly change the slant of the mirror.

Your Venus viewer is now ready for testing. Place the viewer on a window ledge. Use a stool of the height of the window if your window has no ledge. Adjust the slant mirror to reflect the sunlight horizontally. Now rotate the viewer about the drawing pin to send the light inside the room. You can view the image of the Sun on the opposite wall. This wall must be at least 2 m from the
1. Cut the pattern and paste on cardboard.

2. Cut out sleeve S.

Figure 1. Pattern for making ALTAZIMUTH mount.
viewer, so that a 2 cm image of the Sun is formed. (Figure 2).

Larger the distance of the projection wall, larger the size but fainter the image. 2 to 3 m may be the optimum distance.

**The Experiment:** Set up the experiment a day or two before the transit date at about 11.00 a.m. IST.

1. Paste a SMOOTH WHITE paper on the wall. As the image will keep shifting a large white chart paper will be needed.

2. COMPLETELY DARKEN THE ROOM except for the beam of light. These two instructions are very important, as Venus will be a black dot less than 1 mm in size if the solar disc is 2 cm.

Near the date of the transit, the Sun will take a southerly course for all observers north of Ujjain. Observers in these latitudes should select a south-facing window to project the Sun. Those living south of Ujjain should choose a north-facing window. The altitude of the Sun during the transit will always be higher than 50°. (Consult a map of India to know your location with respect to Ujjain).

3. Adjust the slant of the mirror to reflect the sunlight horizontally. Then swivel the mirror to direct it inside the room. Change the slant and the rotation angle whenever the image moves out of view.

4. Measure the size of the projected solar image and cut a card circle of that size.

5. Leave the set-up undisturbed if possible. Otherwise mark location of the viewer and its slant so that you can repeat the set-up quickly on June 8, 2004.

**On June 8, 2004 between 11.30 a.m. and 5.00 p.m IST.**

1. Adjust the image of the Sun to fall on the paper fixed to the wall. Check that the size is the same as your cardboard circle cut out the previous day.
2. Every half an hour, draw the position of the Sun on the paper with the help of the disc. Mark the position of any dark spot within this circle. Note the time of observation next to the circle.

The slant and swivel of the mount will have to be adjusted if the image drifts out of your paper. If such an adjustment has been made, note it on the paper. Report your results as in the format given below.

**REPORTING FORM**

Name ___________________________ Location ___________________________

1. Did you see a tiny black dot on the solar disc on June 8? Yes/No
2. If yes,
   a. Its size was (select one) half/one fourth/one tenth/one twentieth/one fiftieth of the solar disc.
   b. It was seen between ___________ time and ___________ time in IST.
3. Did you see more than one black spot? Yes/No. If yes, how many? ( )
4. Submit the paper fixed to the wall with your observations. If you saw more than one black spot draw both in each diagram. You can draw as many diagrams of the Sun at different times with the dark spots as is convenient, but a minimum of three is necessary – at around 12 noon, 1.30 p.m. and 3.00 p.m. – for the report to be accepted for analysis.

Please submit the result even if you saw NO BLACK SPOT. A negative result is also important. All those who submit reports will be acknowledged.

12 noon 1.30 p.m. 3 p.m.

**Weather During Observation:** Clear/partially cloudy/windy

*Figure 2* Pattern for making ALTAZIMUTH mount is in the following page.

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Your results should reach us latest by June 15, 2004.