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Demonstrations Illustrating the Difficulties Astronomers Face When Observing Astronomical Objects

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Abstract

This article describes a series of demonstrations used to illustrate the difficulties that astronomers face when they observe astronomical objects from Earth. The concepts covered include atmospheric distortion, atmospheric absorption, and the effect of the inverse square law on the intensity of light. These demonstrations were presented using predict-observe- explain tasks that promote active engagement and highlight misconceptions.

1. INTRODUCTION

The Australian state of New South Wales' Years 7–10 (students 13–16 years old) science syllabus requires students to "describe some of the difficulties in obtaining information about the universe" (Board of Studies 2003). The following demonstrations were devised to address this requirement and were introduced in an attempt to increase the number of hands-on activities in Year 10.

2. ATMOSPHERIC DISTORTION OF STARLIGHT

Starlight is refracted when it travels through air because of its changing speed caused by variations in temperature, pressure, and water vapor content. Turbulent motion within the Earth's atmosphere constantly mixes different air masses, which causes the refraction of starlight to vary over time. This leads to the familiar scintillation, or twinkle of stars, in the night sky. Astronomers use detectors to form images of objects over a period of time. The continual distortion of light entering the Earth's atmosphere within this time period blurs these images. A simple demonstration of this phenomenon involves observing a light globe through the turbulent air above the flame of a Bunsen burner (Figure 1). The image of the light source that one sees through the heated column of air appears to dance around. This is due to the varying refraction along the light path. This demonstration could be enhanced by creating a more pointlike light source. Making a video recording or taking a long-exposure photograph through the heat of the Bunsen burner could also demonstrate the blurring of images (Figure 2). The resulting image can then be compared with one taken without the Bunsen in the light path. This comparison clearly shows the loss of resolution in an image that is due to the distortion of the light path over time.

Figure 1. A light bulb appears to twinkle when observed at a distance through the turbulent air above a Bunsen burner flame.

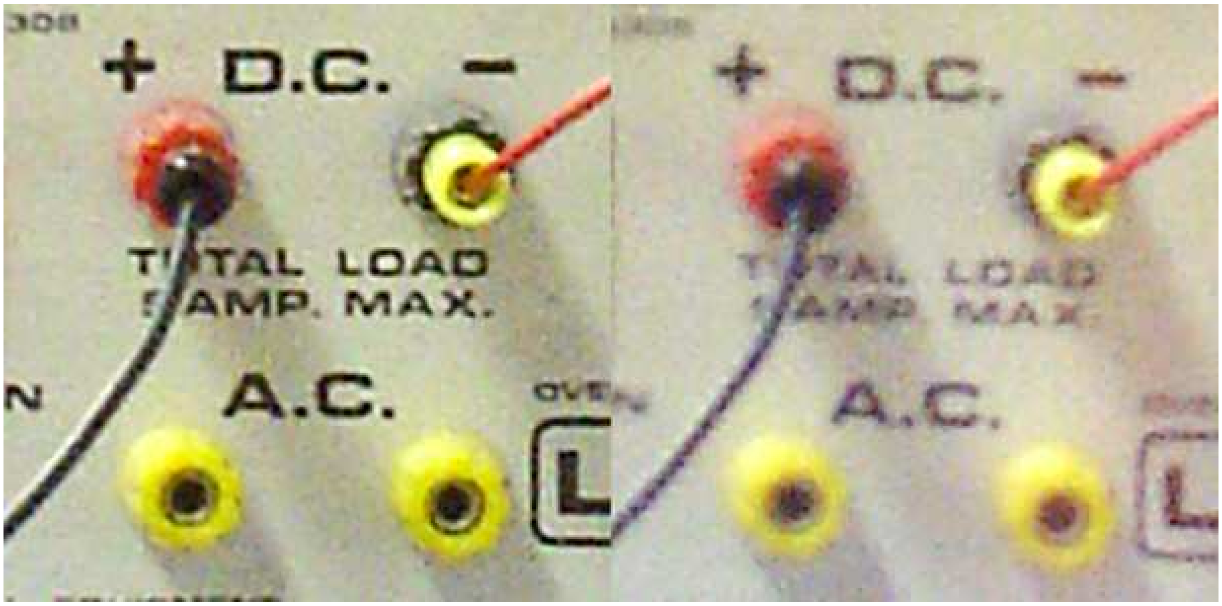

Figure 2. This image is the front of the transformer shown in Figure 1, which is above the Bunsen flame and below the light bulb. A comparison of the image when no flame is present (left) with the image taken through the heat from the flame (right), shows that the loss in resolution is clearly visible. These two images were taken using identical manual camera settings.

Care should be taken when performing this demonstration because the blue flame of a Bunsen burner can be difficult to see, and students may accidently burn themselves. For this demonstration, one needs to align the eye to see the light source through the rising hot air above the flame, as shown in Figure 1. It is important that students be made aware that the turbulent motion causing the twinkling of starlight does not only occur in one region of the Earth's atmosphere, as in this demonstration. Instead, it occurs throughout the full depth of the Earth's atmosphere.

A second demonstration involves shining a laser beam horizontally through cold water in a fish tank. The water in the fish tank represents the air in the Earth's atmosphere. The size of the laser beam is measured after it leaves the fish tank, when it falls on a flat surface. The next step requires the pouring of hot water into the path of the laser beam within the tank. This is followed by measuring the diameter of the laser beam again and comparing the two measurements. The increase in the diameter of the laser beam illustrates the loss of resolution in astronomical images that is due to atmospheric distortion. This loss in resolution leads to enlarged images of stars and the blurring of fine details in other objects. Astronomers go to great lengths to minimize this loss of resolution. Much of the progress in optical astronomy in recent years has been through efforts to reduce this loss in resolution during astronomical observations by using technologies such as adaptive optics.

Special care should be taken when using a laser in this demonstration to ensure that no stray laser light enters the eye because intense laser light may be harmful. It is wise to perform this demonstration at a height different from eye level and direct the beam away from students to minimize the risks. When using a laser in air or water, the introduction of chalk dust can be useful to allow the beam to be seen easily. This is especially useful with a red laser, which is normally hard to see in air, even in the dark.

A third demonstration involves placing an object, such as a spoon, in a clear glass full of water and observing it from above (left image in Figure 3). This is then compared with the view obtained while a hair dryer is used to blow air onto the surface of the water (right image in Figure 3). The image of the spoon is blurred significantly by the turbulent motion of the surface of the water. This illustrates the blurring effect, or loss of resolution, that is due to a turbulent atmosphere.

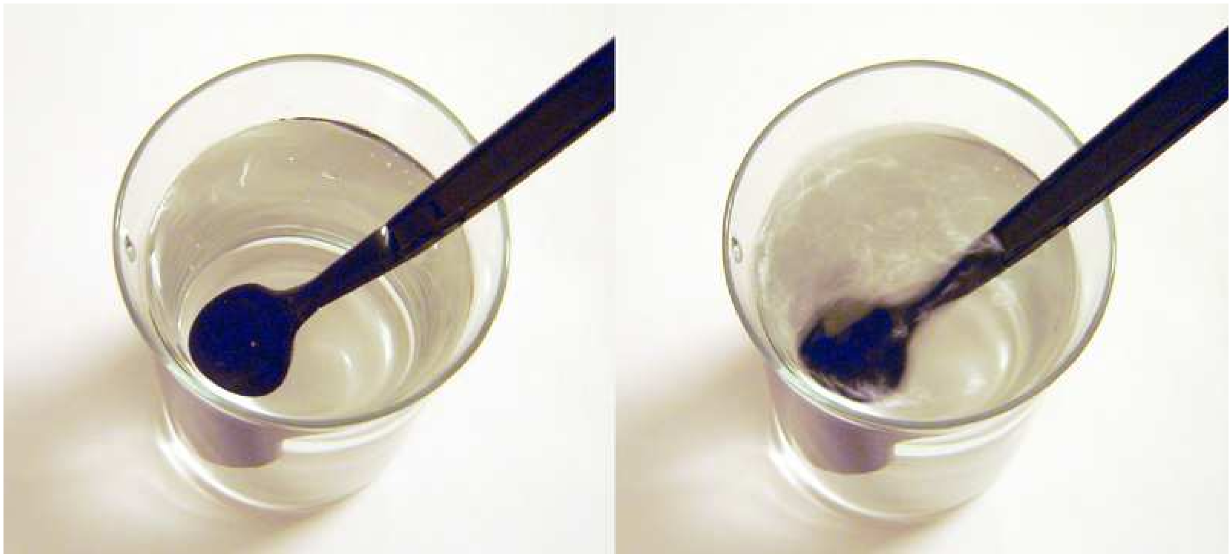

Figure 3. A spoon placed in a glass of water to demonstrate the loss of resolution due to atmospheric turbulence.

In this demonstration, the blurring effect originates from the motion of the surface of the water. This could lead to the misconception that atmospheric turbulence only occurs in a small layer of the atmosphere, thus creating an opportunity to discuss the limitations of models and correct any misconception.

The aforementioned demonstrations could be accompanied by a discussion of other familiar examples of light being refracted by turbulent motion. Common examples in air include the shimmering haze seen above a hot road, and a mirage above an expanse of flat ground on a hot day. A common example in water is the view seen when one is submerged in a swimming pool and looking upward. In these examples, objects appear blurred and their shapes distort because turbulent motion refracts light.

Students should be assessed on whether they understand the concept of atmospheric distortion and its effect on astronomical imaging. This can be done by asking them to draw a labeled diagram that shows the effect of the atmosphere on starlight. This assessment should include the requirement that students illustrate both the cause of atmospheric distortion of starlight and the effect as observed by astronomers. Any misconceptions that arise from these demonstrations should be highlighted in this process and corrected in any subsequent discussions or further activities.

3. ATMOSPHERIC ABSORPTION OF ELECTROMAGNETIC RADIATION

The absorption of electromagnetic radiation by gases in the Earth’s atmosphere does not allow large sections of the electromagnetic spectrum to reach the Earth’s surface. This limits the frequencies of electromagnetic radiation that astronomers can observe from Earth, and therefore what they can learn about astronomical objects. This drives astronomers to place their observatories on high mountains or above the Earth’s atmosphere at great cost in order to extend their observations into other parts of the electromagnetic spectrum.

A simple analogue to atmospheric absorption involves placing a vertical sheet of Perspex next to a Bunsen burner flame (Figure 4). Next, place your hands equidistant on opposite sides of the flame, with one hand shielded by the Perspex. You will easily feel that most of the infrared radiation has been absorbed by the Perspex. This is analogous to the atmospheric absorption of infrared. A quantitative investigation could also be conducted by measuring the temperature on either side of the flame using thermometers.

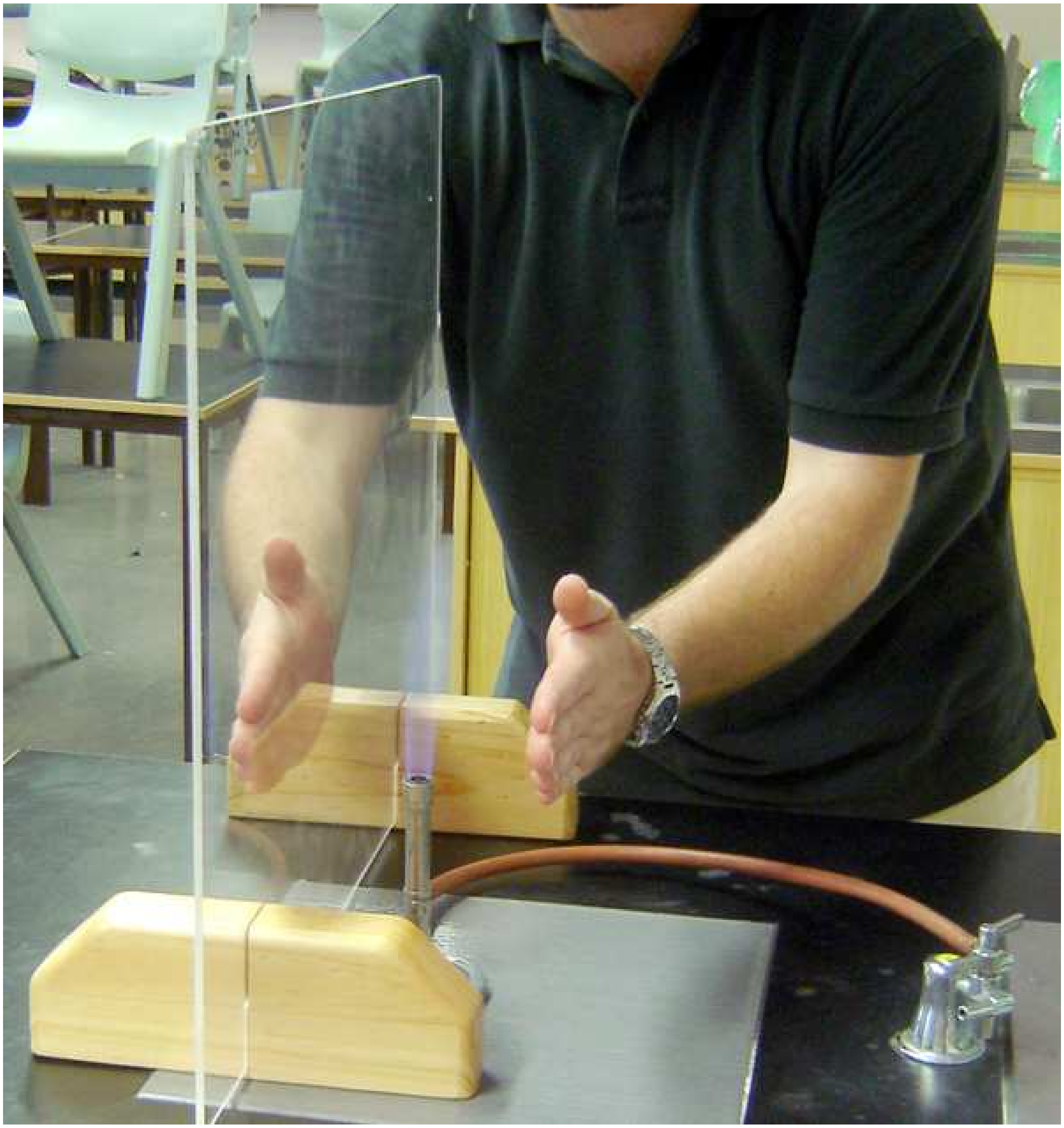

Figure 4. The demonstration illustrating absorption of infrared radiation by the Earth's atmosphere.

It is crucial to ensure that the Perspex does not heat up significantly during repeated demonstrations. If this occurs, the heat from the hot Perspex will give a false impression of the amount of infrared transmitted, compared with the unshielded side of the flame. As mentioned, the blue flame of a Bunsen burner can be difficult to see, so students should be cautious when placing their hands near the flame. This demonstration could also be performed using a bar heater instead of a Bunsen burner to alleviate the risk of being burned. A comparison could then be made of the heat received from the heater with and without the presence of the Perspex.

A possible misconception is that the atmospheric absorption of infrared radiation occurs in a small region, as in this demonstration's thin Perspex. It is important that students be made aware that atmospheric absorption occurs throughout the full depth of the Earth's atmosphere. It may be useful to mention that atmospheric absorption of infrared occurs because of the presence of greenhouse gases, such as water vapor and carbon dioxide. Students should be assessed as to whether they understand the concept of atmospheric absorption. This can be done by giving students data on the relative transmittance of the Earth's atmosphere across the electromagnetic spectrum, observed at sea level. Next, ask them to sketch graphs predicting the amount of incident radiation at different altitudes. Any inaccuracies in their responses could be addressed in a discussion to correct misconceptions, such as the one outlined.

4. THE INVERSE SQUARE LAW'S EFFECT ON INTENSITY

As the distance from a light source increases, the intensity of light that can be collected over the same area decreases proportionally to the distance squared. In other words, at any one time, the fixed amount of light from a source spreads over a larger volume of space as it moves away from the source. This means that a telescope collects less light the further it is from the source. The further an object (a star, for example) is from Earth, the fainter it appears, and the longer an astronomer must collect its light to study it. One way to counter this is to build a telescope with a larger collecting area to gather more light in the same amount of time. This illustrates the reason for the historical quest in astronomy for increasingly larger telescopes to study more distant, and therefore fainter, objects.

A good demonstration for the inverse square law involves measuring the voltage or current produced by a small solar cell (Figure 5). By varying the distance of the solar cell from a light source and measuring the voltage or current produced, a graph can be plotted and the trend observed. The voltage or current measured is analogous to the amount of light collected by the same telescope at different distances from a light source. This experiment could also be conducted using a light meter and data logger to gain a direct measurement of intensity.

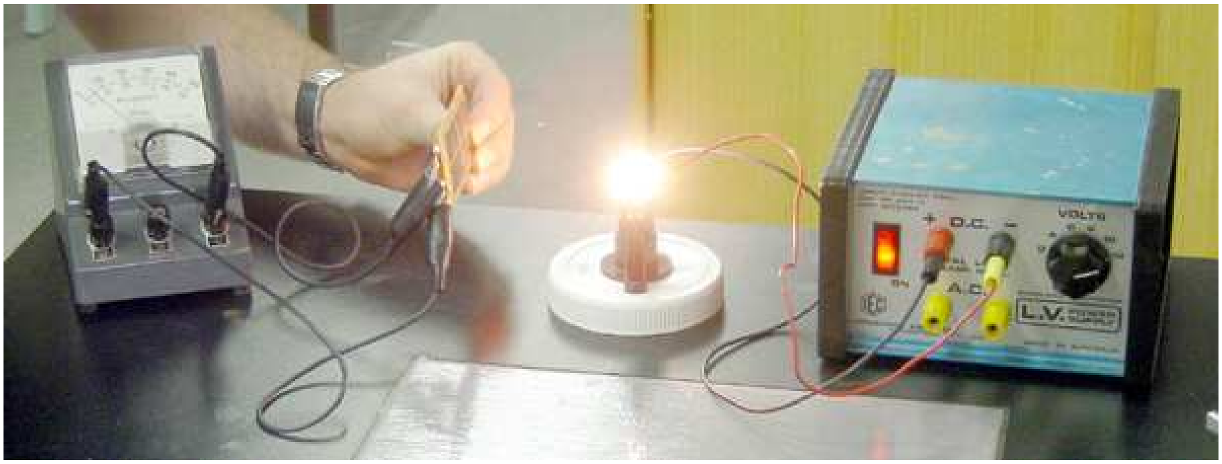

Figure 5. The apparatus used to simply demonstrate the effect of the inverse square law on light intensity at a distance. By moving the solar cell to the left in this image you can observe the rapid decline in current produced and therefore light collected.

A common difficulty with this demonstration is obtaining ammeters or voltmeters with the correct range of measurement. Commonly, a small solar cell may produce too much current for a microammeter and too little for a milliammeter. Damage to a microammeter may result if the ammeter reads off the scale for long periods. Selecting an appropriate voltage for the light globe or obscuring some of the surface area of the solar cell should provide an appropriate solution. A multimeter may also prove to be a good alternative, if available. Another common difficulty is the uncontrolled variable of changing background light levels within the classroom. This may be minimized if the room is darkened, but students' movements within the room can still cause changing background light levels if several experiments are being conducted. This can be a great opportunity to address the concept of an uncontrolled variable, and students can strive to minimize the effect during their experiment. Students often hold misconceptions regarding the inverse square law that are very resistant to change. Zeilik, Schau, and Mattern (1998) concluded that even after highly focused instruction, a large number of students still hold the misconception of an inverse relationship, rather than an inverse-square relationship, between the intensity of light and distance from the source. Students should be asked to compare their relationship to an inverse linear relationship graphically in order to make a clear distinction between the two.

5. IDEAS FOR INSTRUCTION

Within each of these demonstrations, students should be asked to use a predict-observe-explain task. In this process, students predict the outcome of the demonstration before it is performed. This is the first step in helping students confront any misconceptions that they may hold, and the task motivates them to find out what the answer is. Observation then gives them an opportunity to test their ideas with the demonstration, thus promoting students' active involvement in their learning. Following the demonstration, students have either proved to themselves that their ideas are correct, or they have created a conflict between their ideas and their observations. If a conflict exists, the students have a chance to challenge their current beliefs and revise their thinking. With the correct support, students can then modify their understanding to incorporate their observations and correct their misconceptions. Students should be asked to record their predictions, observations, and explanations during this process, and small-group discussion is especially important in the explanation stage.

Following each predict-observe-explain task, a class discussion should be held to ensure that all students have reached the same conclusions. At this point, an assessment of some form is essential to gauge postdemonstration understanding. The aforementioned ideas provide examples of possible postdemonstration assessments for each demonstration. Appropriate assessment is essential because the remaining misconceptions can be identified and addressed through further targeted investigation and discussion.

The structure of these demonstrations could be extended to include a component in which students would be asked to design the investigation for each situation, with the equipment provided. This could be done in groups and as a station-based practical experience, with students rotating through each activity. These strategies would further encourage students to be actively engaged in their learning and in constructing their own understanding of the concepts. Using a station-based lesson would also require less equipment.

6. CONCLUSION

Astronomers face many difficulties in increasing their knowledge of the Universe. A significant amount of effort is required for students to gain a reasonable understanding of these difficulties. The teacher faces an even greater challenge: addressing strongly held misconceptions. The predict-observe-explain model of instruction, which centers on active student involvement in the learning process, allows students to use demonstrations to achieve an understanding of these concepts within a reasonable amount of time.

Resources

Teaching resources for these demonstrations are available from the Teaching Science page of the author's Web site: http://www.jeffstanger.net.

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