Discovering Some of Your "Yardsticks" Are Actually "Meter-sticks"

Suggested Grade Level(s): 9-12
Estimated class time: one class period

Summary

This lesson uses a simple discrepant event to demonstrate the underlying cause for early miscalculation of the size of the Milky Way galaxy. Students are directed to observe two light sources that a famous astronomer (in this case their teacher) has told them are equally bright. The students will easily observe the lights are not equally bright; they will then examine the type of problems that would arise if they believed both lights were equally bright and they used the brightness of the lights to judge how far away they are. This mirrors the problem that was created when Harlow Shapely standardized the Cepheid period-luminosity relationship without recognizing there were two types of Cepheid variable stars with intrinsic differences in absolute magnitude.

Objectives

- Students will understand how advances and improvements in our ability to accurately observe celestial objects directly impacts our ability to accurately measure distance in space and hence the size of the galaxy (universe).
- Students will predict the type of errors that would result if a measuring tool is inaccurate.
- Students will correlate a model of a problem to the actual problem encountered by astronomers in the first half of the 20^{th} century.

National Science Standards

- NS.9-12.1 SCIENCE AS INQUIRY
  As a result of activities in grades 9-12, all students should develop
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- NS.9-12.4 EARTH AND SPACE SCIENCE
  As a result of their activities in grades 9-12, all students should develop understanding of
  - Origin and evolution of the earth system
  - Origin and evolution of the universe
- NS.9-12.5 SCIENCE AND TECHNOLOGY
  As a result of activities in grades 9-12, all students should develop
  - Understandings about science and technology
- NS.9-12.7 HISTORY AND NATURE OF SCIENCE
  As a result of activities in grades 9-12, all students should develop understanding of
  - Science as a human endeavor
  - Nature of scientific knowledge
  - Historical perspectives

Knowledge Prerequisite

This lesson is targeted toward advanced middle school students or high school students who are familiar with the following topics:

- the reduction of light over distance
- absolute magnitude and apparent magnitude of celestial objects
- the behavior of Cepheid variable stars and the knowledge that the length of their period indicates their true brightness

Teacher Background/Notes

- The success of this lesson is strongly influenced by the teacher's ability to engage all students in the dialogue. Encourage as much participation as possible while monitoring time.
- The lesson can be accomplished within a standard 45 minute period when students are held to strict time limits for each part of the lesson. If necessary, the Evaluation portion may be assigned as homework and the activity completed outside of class.
- This lesson also serves as a basis for an extension to an activity in the 1929 edition of the *Cosmic Times* (Determining Size and Age of the Universe)
- It is important to direct the students to not look directly at the bulbs when making their observations. They should try to keep the bulb out of their direct field of view. It is likely they will tend to do this anyway to avoid the discomfort of the glare.
- The bulbs should be the same physical size and have identical finishes. The only difference should be the wattage.
- A form for students to use when recording predictions, observations, conclusions, etc. is provided.

Materials

- 2 ceramic lamp bases
- 1 soft-white light bulb, 25 watt
- 1 soft-white light bulb, 60 watt

Procedure

I. Engagement

Announce to the students

- There are two light sources positioned on [lab] tables in the room.
- The lights are positioned in such a way that both lights will be equidistant from every student.
- Ask the students to write a prediction about what they will observe when the room lights are dimmed and the two light sources are turned on.

- If students need clarification, guide them to understand that they could describe the color of the light, its intensity, and/or the extent to which it illuminates the room, or any warmth sensed from the bulbs.
- Hopefully, at least one student will ask if both lights are the same power or wattage. If they do not, raise this point for them and respond by stressing the bulbs are the same …of course we know they are not … but neither did Harlow Shapely when he treated Type I and Type II Cepheids as equivalent objects.

When all students have written their personal predictions

- Canvass the class and consolidate the predictions on the board.
- Develop the point that the lights should be equally bright, in addition to other valid predictions.

II. Exploration

- Dim the room lights and turn on the two bulbs.
- Give students approximately one minute to record their observations.
- Remind the students to not look directly at the bulbs for any length of time. There is enough difference in brightness that they should easily make this distinction.

  It is very likely that students will quickly point out that the lights cannot possibly be the same wattage as one clearly appears brighter than the other. Continue to stress that *to the best of your knowledge, both bulbs are the same.*

- Next, have them write a brief statement as to whether or not their predictions were supported by observations.

III. Explanation

- Ask students what the primary discrepancy was between prediction and observation. This should be the unexpected difference in brightness.
- Ask what information they believe to be erroneous. This would be the information regarding the wattage of the two bulbs.
- Present the following scenario:
  - Here in the room we can easily see the bulbs are equidistant, and one is clearly brighter than the other. This immediately leads us to question the accuracy of the statement that *both bulbs are the same.*
  - Imagine the bulbs are so far away that we simply cannot judge if the bulbs are positioned at different distances, however we can still observe differences in brightness

- Ask students what conclusion they would reach if they observed both bulbs, believed they were identical, and yet one appeared brighter than the other.
- Field student responses and emphasize the conclusion that we would believe the brighter bulb is closer / dimmer bulb is farther, when in fact they might be equidistant.

IV. Extension

- Ask students what problems might arise if astronomers believed all Cepheid variable stars had identical period luminosity relationships, when in fact they do not. Clarify this question with an example such as:
    - Suppose you were observing a Cepheid variable star with a period of 4 days and used that information to calculate its absolute magnitude at –4.1.
    - You could then compare its absolute magnitude to its apparent magnitude to calculate its distance.
    - Unknown to you, this type of Cepheid isn't the same as the Cepheids used to establish the original period-luminosity relationship. *This 4 day Cepheid had an absolute magnitude of only –3.5.*
    - In what way would your distance calculation be incorrect?
- Ask students to write a statement regarding the types of errors that might have resulted in the early part of the 20th century when astronomers believed all Cepheid variable stars had same period-luminosity relationship when they used them to measure the dimensions of the Milky Way Galaxy. If the class will benefit from small group discussion of this topic then encourage such activity.

V. Evaluation

Have students read the *'Yardsticks' in Neighbor Galaxy Double Universe's Size* article and respond to the following points in writing.

- Explain the relationship between the light bulbs used in the classroom demonstration and the Type I and Type II Cepheids discussed in the article.
- Even though you were told the bulbs were equally bright, you could easily see they were not. What events or technology allowed Walter Baade to "see" Cepheids with identical periods were not all equally bright?

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I. PREDICTION

II. OBSERVATIONS

III. SUPPORT / CONTRADICT STATEMENT

IV. ERROR DISCUSSION

V. 'YARDSTICKS' ARTICLE

- Explain the relationship between the light bulbs used in the classroom demonstration and the Type I and Type II Cepheids discussed in the article.

- Even though you were told the bulbs were equally bright, you could easily see they were not. What events or technology allowed Walter Baade to "see" Cepheids with identical periods were not all equally bright?