Improving intermediate optics for greater conceptual understanding

Mark F. Masters, Ph.D.
and
Timothy T. Grove, Ph.D.

IPFW Department of Physics
Fort Wayne, IN 46805
What we want to accomplish

We want the students to develop greater independence in the laboratory.

We want the students to conceptually understand optics, to be able to think through optics problems, and to be able to solve problems in optics.
Two Pronged Solution

Use interactive engagement and tutorials in the classroom to help the students learn basic concepts.

Use skill building, discovery and concept based laboratories rather than explicit directive laboratories. At the end, the students must complete a longer term optics project using skills and concepts developed in the laboratory.
Topics and concepts for Class

**Geometric optics**
- Point and Extended sources
- Ray tracing
- Optical systems
- Aberrations

**Physical Optics**
- Wave nature of light
- Polarization: Physical representation and how polarizers work
- Interferometry
# Concepts addressed in Laboratory

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<th>Topic</th>
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<td>Point and extended sources</td>
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<td>What is an image</td>
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<td>Virtual and real images</td>
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<td>Image location. Virtual images really form behind a lens/mirror</td>
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<td>Does a real image require a screen?</td>
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<td>Point to point correspondence between image and object</td>
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<td>All rays do not pass through the focal points</td>
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<td>Why form images using curved mirrors?</td>
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<td>Polarization: What is linear, circular and elliptical polarization?</td>
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<td>Understanding, linear, ( \frac{1}{2} ) wave and ( \frac{1}{4} ) wave polarizers</td>
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Skills to be acquired in laboratory

- Handling/Cleaning Optics
- Use of lenses
- Imaging systems
- Use of mirrors for alignment
- Maintaining polarization through reflection
- Use of polarizers and waveplates
Example 1 From Class work

Students have a difficult time interpreting wave diagrams often believing that the amplitude corresponds to spatial extent.

They have to be guided to develop the interpretation of the diagrams.
Consider the sound wave shown below for a single instant in time in dry air at 20°C. The divisions are every 5 cm. The diagram below shows the number of particles at various discreet locations (the boxes) at some instant in time. Each dashed line indicates the position for that “box” of particles. Make a graph of the density of particles (# particles per volume) as a function of position based on this diagram. Describe the shape of the curve.

If this represents a wave, what type of wave (transverse or longitudinal) is shown in this situation?

This is a graph of the same wave taken a short time later. Determine the frequency, wavelength, speed of the wave and when this second image was captured relative to the first.
Make and attach an accurate graph of the position of an average particle near 15cm as a function of time.

Make and attach an accurate graph of the # particles/volume at 15cm as a function of time.

Are the particles moving from one end of the observed volume to the other?

On the grid on the below, draw the “wave” representation and the spatial representation for this wave with the doubled amplitude.

Does changing the amplitude affect the spatial extent – the size of the wave?
Example 2 from class work

Continuing in this mode, further questions can be asked to reinforce the concepts and start to relate waves and ray diagrams.

We develop quasi-quantitative ray diagrams to help understand the difference between irradiance and power.
Consider the following situation; light is traveling to the left in a monochromatic collimated beam.

Which observer (A-E) could see the light beam?

Now, suppose we doubled the intensity of the light beam. How would this change the diagram?

How would this change what the observers see?

Imagine that we were to represent this light beam as a wave:

Which observer can see the light beam?

How would you change your answer if you were to double the amplitude?

What would an observer see if they were at location 1? What about location 2?
Suppose you had two ray diagrams that looked like those shown in the figure below.

A

B

How would the power of the light represented by the two diagrams compare?

How would the intensity of the light represented by the two diagrams compare?

How does the intensity of the light vary with position along the beam of light?

Suppose you were to use the wave representation of this light. Sketch an appropriate wave for each on the grids below.
Who can see the light in these two situations?
Example 3 from class

What is the ray representation of this situation?
Example 3 continued
Example 4: Guided Derivation

Students must also learn and understand the mathematics of the physics.

Rather than lecture, tutorials are used to guide the students through derivations.

Assist students with derivation as students work and discuss as a class upon completion.

Derived results are then used in examples and homework.

Tutorials serve as notes for the students.
Reflection from curved surfaces.

Our goal is to determine the location of the image of a point source based upon the point source's distance from the mirror surface and the radius of curvature of the mirror.

Useful information: small angle approximation \( \tan \phi \approx \sin \phi \approx \phi, \cos \phi \approx 1 \)

Consider a point source located a distance “s” away from the surface of a convex spherical mirror of radius R. This is shown in the diagram above. Imagine a light ray that makes an angle \( \alpha \) from the horizontal axis and hits the mirror some height “h” above the horizontal axis.

How would you determine where the image of the point source is formed? What is the distance of that image from the surface of the mirror?

Is the image real or virtual?

Can you relate the angles \( \alpha, \alpha', \) and \( \theta \) together?

Can you relate the angles \( \alpha, \theta, \) and \( \phi \) together?
Using these two expressions relate $\alpha$, $\alpha'$, and $\phi$ together.

Relate the angles $\alpha$, $\alpha'$, and $\phi$ to $h$ through judicious use of the small angle approximation.

Using the relation you found between $\alpha$, $\alpha'$, and $\phi$ relate the object distance, $s$; the image distance, $s'$; and the radius of curvature, $R$.

Imagine that the source was moved very far away ($s$ becomes $\infty$). What does this determine?

You have worked out the equation for images under the paraxial approximation. What is the paraxial approximation?
Laboratory Problems

To develop independence in the laboratory the students need familiarity with the equipment.

The students need to understand basic principles of optics.

How can we accomplish our goals without the laboratories being cookbook?
Example from Laboratory

Why should you bother to use a concave mirror? Chromatic Aberration!
Polarization example from lab

How do you differentiate between circularly polarized light and “unpolarized” Light?

Diagram:
- Laser
- λ/4 plate
- Linear Polarizer in motorized mount
- Photometer detector
- Quartz - Halogen Lamp
- 50mm lens
- 632.8 nm filter
- λ/4 plate
- Linear Polarizer in hand-turned mount
- Photometer detector
Does it work?

In Class and Laboratory, because students do the work rather than being told, the class seems to progress more slowly than in straight lecture.

The students seem to understand optics better at the end of this process than if they were “shown” results.

In laboratory, the students do behave more independently.

If interested you can download the materials developed from http://users.ipfw.edu/masters

We are writing instructional materials as well.