Drawing Pictures As The Problem Solving Approach in a Physics Course

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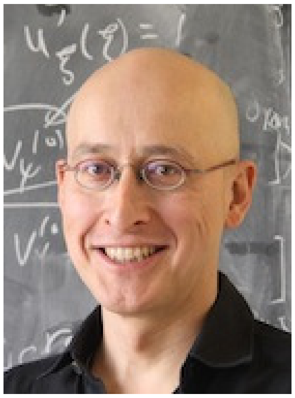


Background:

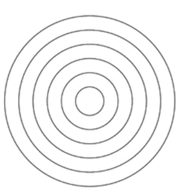
- Students want to solve physics problems by hunting for the "correct" formula and applying one of a series of memorized recipes.
- While formulas are easily memorized, they are difficult to interpret and understand even in the simplest of situations.
- The goal is to organize the solution seeking process so that students are compelled to first address the problem conceptually with a qualitative solution in mind.

The concept:

Young's double-slit interference experiment is the foundational paradigm for our teaching of the wave theory of light. Yet the majority of college level problems in this subject focus on finding the location of bright and dark fringes through the use of the formula $m\lambda = d \sin \theta$. This gives little understanding of the properties of wave. I emphasize the one and two dimensional pictures of wave interference to visualize constructive and destructive interference and present the students with problems whose solutions involves using these pictures to understand that the condition for bright bands is
Δr = integer λ instead of memorizing the $m\lambda = d \sin \theta$ formula.

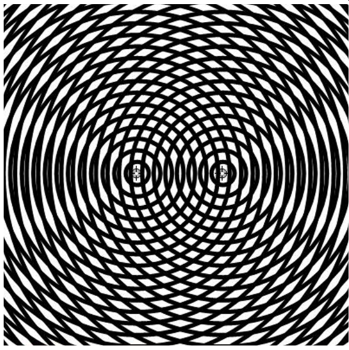
The application:

I work with two copies of this image of concentric circles:

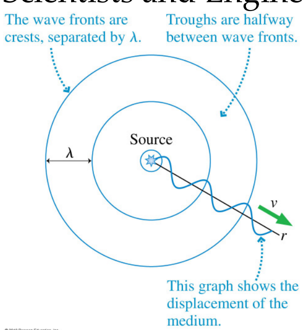


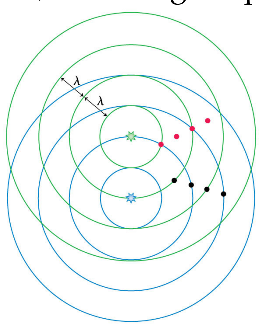
By overlaying the two images with their centres displaced by an integer or half integer number of wavelengths I have the students note the lines of constructive versus destructive interference and how their numbers change as the centres of

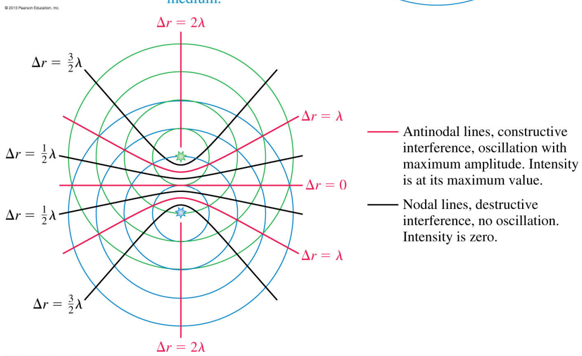
the circles are separated. As a reference of what they are too look for I refer them to this website:
http://demonstrations.wolfram.com/InterferencePatterns/
form which the following image is obtained:



I then show them this demonstration:
http://demonstrations.wolfram.com/WaveInterference/
In class I also present them with these pictures from Knight's book Physics for Scientists and Engineers, A Strategic Approach.







Problem 0

Using two sets of concentric circles drawn on the whiteboard, mark the points of constructive and destructive interference and connect the dots to get the antinodal and nodal lines.

After this exercise, my first goal is to have them solve the following conceptually difficult problem on their own where the wave sources can be either light or sound:

Problem 1

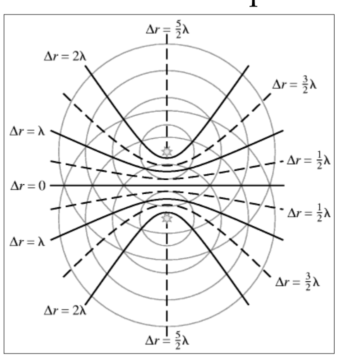
> You are standing at a point of destructive interference when both speakers are on. If you turn only one speaker on and keep the other off, you will hear it loud and clear. There is sound energy arriving to your ear moving your eardrum. However as soon as you turn on the second speaker you hear nothing. With both speakers on you are using twice as much electric energy to drive them, but NO energy is arriving to your ear! What happened? Is energy not conserved?

The next problem I give them is even harder:

Problem 2

> Two identical radio transmitters 25 m apart emitted identical radio waves with □ = 10 m. If a student walked around the antennas in a 500-m-diameter circle with a radio receiver, how many maxima would be detected?

The solution to this problem is this picture:



After the problem and picture is understood, I present them with the solution by formulas:

$0 \leq \Delta r \leq d$

$0 \leq m\lambda \leq d$

$0 \leq m \quad \leq d/\lambda$

$0 \leq m \quad \leq 25/10 = 2.5$, m=0,1,2. So there are 5 antinodal lines: -2,-1,0,1,2, and 2*5=10 loud spots.

At this point I increase the separation of the two transmitters so much that using a picture to solve the problem is infeasible. However the concepts are exactly the same:

Problem 3

Now separate the transmitters 200 times farther. Two identical radio transmitters ~~25 m~~ 5.0 km apart emitted identical radio waves with □ = 10 m. If a student walked around the antennas in a 500-km-diameter circle with a radio receiver, how many antinodal lines are there?

$0 \leq \Delta r \leq d$

$0 \leq m\lambda \leq d$

$0 \leq m \quad \leq d/\lambda$

$0 \leq m \quad \leq 5000/10 = 500$, m=0,1,2, …500. So there are 1001 antinodal lines -500, …,-2,-1,0,1,2,…500.

I then scale the problem down to go from radio wave wavelengths, which are macroscopic to the microscopic wavelengths of light where drawing a picture is also infeasible.

Problem 4

Now make it all 20 million times smaller. Two identical EM wave transmitters 5km/20million = 0.25mm apart emitted identical waves with □=10m/20million=500nm. If a student walked around the antennas in a 500-km-diameter circle, how many bright spots will she see?

About the instructor: After obtaining my doctorate in theoretical particle physics I was on the academic research path eventually landing in Montréal. Then the Zapatista uprising in Chiapas Mexico inspired me to move back to Mexico and work in a human right centre. Many years later I moved back to Montreal and I wanted to return to physics but in a more socially relevant way, and not just research, so that's why I looked for teaching jobs. Also, when you've been away from research for so long, you can't just go back to the a University position. All these reasons attracted me to teaching in CEGEP, and that's how I came to Marianopolis College, 18 years ago, where I teach physics and the liberal arts course on the history of science.