

EXAMINING THE EFFECTIVENESS OF INTERACTIVITY IN  
A 3-DIMENSIONAL WEB-BASED TUTORIAL ON  
INTERFERENCE PHENOMENON

By

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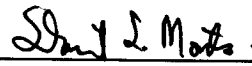
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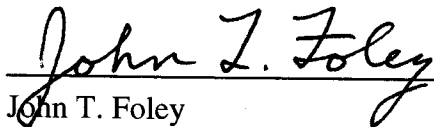
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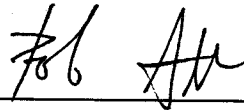
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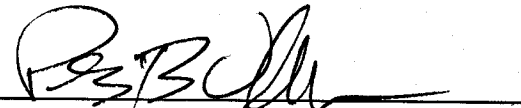
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In recent years there has been an increased interest on the role of web-based simulations in student learning. I have conducted a preliminary study on the effectiveness of interactivity in 3-Dimensional simulations to help students learn the interference phenomenon. The study was based on a Pretest-Posttest design with the experimental and control groups completing different but equivalent web-based tutorials. The experimental tutorial was based on the use of highly interactive 3-dimensional simulations developed by the WebTOP project. The only difference between the control tutorial and the experimental tutorial is that the control tutorial used static images instead of simulations. The content of both tutorials addressed the common misconceptions students usually have about waves and interference as identified in previous physics education research.

The results suggest that student learning from both tutorials was significant with no significant difference in learning between the two groups. The study also identified several factors that might have affected the results and that should be the subject of further study.

## DEDICATION

I would like to dedicate this thesis to my husband Qiu Pangsha, my parents Li WanXing and Huang HuiJuan, and to my sister Li QiaoHong.

## ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation to my advisor Dr. Taha Mzoughi, his guidance and help far exceeded one could expect from an advisor.

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# CHAPTER I

## INTRODUCTION

### *1.1 Prior Research on Simulations*

It is well known that students usually have problems visualizing physics phenomena in the real world from the symbols and algebraic equations used to describe physics. This difficulty in visualizing phenomena hinders student learning of physics in general [1] and optics in particular. It may be caused by two possible reasons. The first reason is related to the physics content itself. Scientists observed the real world phenomena and found out the underlying rules, then put these rules into abstract mathematical expressions that can be used to describe the phenomena efficiently [1]. When time comes for students to learn these physics phenomena they are presented with the material in the form of elaborate mathematical descriptions. Students usually have difficulties relating the mathematical formalism to the actual physical phenomenon even when the formalism is accompanied with extensive text explanations and in-class demonstrations. The second reason is the preconceptions or misconceptions that students build from their own common-day observations [2]. This is especially true in optics where some of the phenomena are based on properties and behaviors that are not visible with the naked eye. Student's common-day observations in this case are limited to

geometrical optics. For example, the general impression about the behavior of light when it passes through narrow slits is that it travels in a straight line and just keeps going in that manner until it hits a target. When studying Young's double-slit interference experiment, students often fail to consider whether the geometrical or physical optics model is valid. Even after instruction about the topic, a large portion of students use a hybrid model with elements of both the ray and wave models to describe the observed pattern [3]. With all of these factors, should we be surprised when some students fail to understand physics phenomena? What we need to do to clear up student preconceptions or misconceptions and help them construct the correct relevant concepts is to enable them to rebuild the physics phenomena from the abstract equations, and to replay them just like they are in the real world.

Computer-based simulations provide an environment within which visualizations of complex or dynamic behaviors are allowed. Sometimes, for those systems that are too huge (a planetary system), too small (molecules), too dangerous (a nuclear reactor), or too expensive (a wind tunnel), simulations may be the only practical method for rebuilding and replaying them [4]. Along with the booming of the personal computer and the Internet, interactive, animated real time simulations that once were available only for the military and scientific communities have become accessible for more and more people. Many applications have been developed, and hundreds of physics simulations have been written and made available on the World Wide Web. But is it enough to just expose students to a visual display of the phenomenon? Allowing students to surf the web and view the visual display is, no doubt, more interesting than just reading a textbook

explanation or listening to a lecture, but the level of learning is questionable. Simply allowing students to play with animated, interactive simulations without any guidance and exercises may result in students using the simulations only for entertainment purposes such as watching movies or playing video games. The key to building a better learning environment is to provide a higher level of engagement that is designed to support the learning process [5]. Furthermore, the learning environment should provide guidance and support to students. Visual displays and simulations can help enhance the learning environment but must be integrated with other interactive features such as questions and feedback [4]. These learning environments, including the guidance, simulations, visualizations, questions, and instructions are often packaged as web-based tutorials.

In web-based tutorials, there are usually at least two types of interactivity, the manipulation of the simulation variables and the feedback feature. Generally speaking, an interactive simulation includes an animation scene and some related parameters with which students can change the situation and thus control the animation of the scene. After going through a series of parameter modifications and evaluations, students can get a better idea on how the different factors or parameters in the system (simulation) affect the physical characteristics and behavior of the system. Interactive simulations “provide an exploratory environment”, which allows students to form hypotheses and test them, and to ask what if and why questions [4]. Resources on the Internet includes many examples of interactive simulations of waves and the interference phenomenon. For example, the award-winning website “Physics 2000” developed by the physics department of

University of Colorado at Boulder, includes simulations and discussion of the Interference phenomenon listed under the subtopics “The Atomic Lab” [6]. The “Physics 2000” site uses java applets together with question-answer style text to explain physics phenomena. Another example is the ExploreScience.com website authored by Raman Pfaff [7]. This website contains a large number of simulations, with content in physics, math, and life sciences including simulations on waves and on the interference phenomenon. In addition to the work done in developing these simulation modules, several studies have been done to investigate the effectiveness of interactive, dynamic simulations on student learning. Some results showed that the visualizations and simulations were useful in enhancing the student’s conceptual understanding of the topics. [8,9,10]. There are also studies that suggest that the use of simulations does not result in an improvement in student performance [11].

Another form of interactivity in tutorials is the feedback feature. Unlike feedback from an instructor or tutor, feedback from computer-based tutorials is tireless, unbiased, accurate, nonjudgmental, and can even, theoretically, be adapted to the learning styles and needs of each individual student [12]. Feedback from instructors may be affected by many factors, such as the mood of the instructor, the time that they give the feedback, and the instructor’s style in explain answers. For instance, students are likely to receive inadequate feedback if any when they seek it from an instructor who is in a hurry, an unprepared person such as a teaching assistant, or if they seek it late at night. Recent research has grouped feedback into eight levels: no-feedback, knowledge-of-response, answer-until-correct, knowledge-of-correct-response, topic-contingent, response-

contingent, bug-related, and attribute-isolation [12]. It indicated that there is no clear-cut “best” type of feedback in computer-based instruction that is appropriate for all learners and learning outcomes. The authors of the research suggest that designers and developers of computer-based tutorials need to identify the type of feedback that is most effective for their specific educational settings [12].

### ***1.2 Prior Research on Waves and Interference***

To understand the interference phenomenon, students must first have a correct understanding of the concepts of waves, wave properties, wave propagation and wave superposition. Once students learn these basic concepts, the interference phenomenon becomes easier to understand.

When studying waves and interference phenomenon traditionally, students listen to the lecture, read the textbook, observe wave propagation and interference phenomena in lab, and solve homework problems. In this learning cycle, the experience in lab is, without doubt, an important part. The lab experiments demonstrate wave propagation and the interference phenomenon in front of the students’ own eyes, transforming the abstract formula into something they can visualize.

In physics lab, several kinds of waves are studied including mechanical waves, oscillations in electrical circuits, and sound waves. For example, in the “Wave Motion on a String” experiment in the department of physics and Astronomy at Mississippi State University, students connect a mechanical vibrator to a string that is run over a pulley some distance away, where weights are used to set the tension in the string. When the

vibrator is oscillating, students observe the motion, the amplitude, and the superposition of waves.

On the other hand, an interference lab usually utilizes a laser beam (as the light source), various slit masks, and an observation screen on which an interference pattern is observed. For example, in the interference experiment at the department of physics and Astronomy at Mississippi State University, students set up a NeHe Laser on one end of an optical rail, a camera connected to a computer on the other end of the rail, and a holder with slits between the laser and the camera. When studying the effects of slit width and slit separation in double slit interference, students change the mask and adjust camera alignment until they have a ‘good’ pattern on the computer, which gets the pattern from the camera. During this process, students need to slide the slits slowly back and fourth patiently and carefully to get the interference pattern. Through this process, students can learn the way that physicists do physics. However, the process is time consuming, the patterns obtained are not very clear, and often they do not get results at all.

As mentioned above, experiments are very beneficial for studying waves and interference phenomenon. However, physics labs have limited time, experiments on each topic are normally only held once each semester, and they generally need to be finished within two hours. How can we make it easier for students to observe the phenomenon at any time, at their own pace and without going to a certain location where related equipment is set up? Our web-based tutorial works as an alternative way to solve these problems.

### 1.2.1 Misconceptions about Waves

Studies about students understanding of waves yield the following: [13]

1. Students consider waves as objects
  - When asked how to make a wave move more slowly when one end of a taut string is flicked by a demonstrator while the other end is attached to a distant wall, roughly 90% of students focused on the motion of the hand in creating the wave instead of the medium properties. They made implicit analogy between wave pulse and an object like a ball.
  - When asked about what happens if two waves travel toward and pass through each other, most students thought the two waves would collide like balls.
2. They don't Understand the superposition principle
  - Some students consider the amplitude of the waves smaller when it travels on a taut string due to friction and energy loss.
3. They don't understand the mathematical formalism used to describe waves
  - Students have difficulty relating the behavior of the waves to the different parameters used in describing the wave. They have difficulty dissociating the time from the position and identifying the amplitude.

### 1.2.2 Misconceptions about Interference

Based on the long term investigation by the Physics Education Group at the University of Washington on student understanding of geometrical and physical optics, students have the following misconceptions about interference [3,14]:

1. Difficulty of relating interference to differences in path length.

When provided with the setup in Figure 1.1, and told that the two small objects  $S_1$  and  $S_2$ , oscillate in unison and asked to determine both the phase difference ( $\Delta\phi$ ) at points A, B, and C and if each point corresponds to maximum constructive or complete destructive interference.

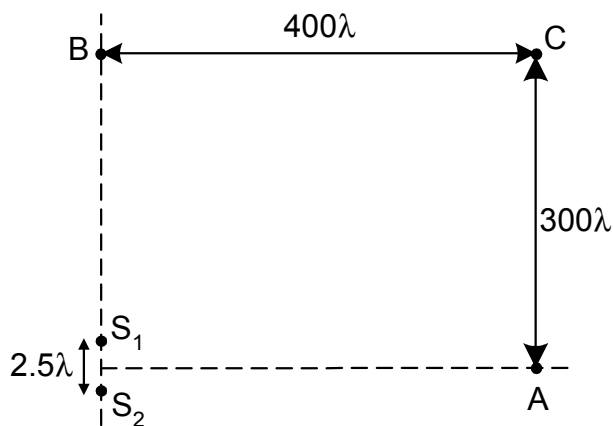


Figure 1.1 Path Difference Pretest

Only about 35% of the students have given correct responses for both points A and B. Only 5% have given the right answer for point C, with another 5% indicating awareness that the difference in distance to the two sources is critical.

2. Failure to relate a sufficiently narrow slit to a point source.

When provided with the a photograph of a double-slit interference pattern in Figure 1.2, and told to sketch what would appear on the screen if the left slit were covered. To give a correct response, the students must recognize that the minima are due to destructive interference of the light from the two slits and that each slit can be treated as a point source. Thus after the left slit is covered, the screen would be (essentially) uniformly bright.

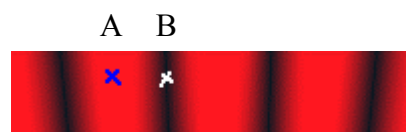


Figure 1.2 Interference Pattern

A correct response has been given by 20%-40% of the students, depending on whether it was asked near the beginning or near the end of lecture instruction on interference. Both before and after instruction, most of the remaining students have predicted that part or all of the basic pattern would remain. Only 55% of the graduate students who were tested in the subject have recognized that the screen would be bright.

3. Failure to distinguish between geometrical and physical optics.

When tested with the question described above, students often use geometrical concepts or hybrid of geometrical optics and physical physics to solve interference problems. For instance, some students believe when one slit is covered, only half of the original interference pattern appears (e.g., the maxima on

one side vanish). About 45% of students used a hybrid model with elements of both the ray and wave model.

4. Difficulty in relating an interference pattern to features of the equipment setup. Several parameters in the optical system (including the wavelength of the light, the distance between adjacent slits, and the number of slits), may change the interference pattern. When given two interference patterns, with the maxima and minima farther apart than in one pattern, students are asked by what means this can happen. Only 25% of students recognized that decreasing the slit separation could lead the increase in separation of the maxima.
5. Difficulty in applying superposition to the interference of more than two waves. When provided with the a photograph of a double-slit interference pattern in Figure 1.2, and told the two-slit mask is replaced by a three-slit mask with the same separation between adjacent slits. They are asked if point A still has zero intensity, and if the location of point B still has the maximum constructive interference. Only about 10% of the students have given the correct response for both points A and B.

## CHAPTER II

### EXPERIMENTAL DESIGN

To study the effectiveness of interactivity in learning the interference phenomenon, we developed two web-based tutorials. Both tutorials have the same design, cover the same topics, and have the same structure; the only difference is the interactive feature. The interactivity in one tutorial, let's call it the experimental tutorial, is extensive and is based on the Virtual Reality Modeling Language (VRML). The interactivity in the other tutorial, let's call it the control tutorial, is limited to web-based navigation and immediate feedback. In the following sections, we will discuss the topics in the structure of the tutorials.

#### ***2.1 Topics in the Tutorials***

As mentioned in Chapter 1, the topic that was chosen is interference because of its suitability to the simulations we had available and because of prior research done on the subject. Both tutorials were designed to help students to learn the interference phenomenon by waves in a ripple tank and by light waves. The topics focus on five documented misconceptions students have in their understanding of waves and

interference phenomenon [3,13,14]. The following is a list detailing the way the tutorial is designed to address these misconceptions:

- To help students understand the concepts of path difference and superposition of waves, the two basic concepts needed to understand interference phenomenon, the tutorials include a set of quantitative and qualitative questions about both topics, followed by a detailed overview of wave properties.
- By using both the waves module and the n-slit module of WebTOP, the tutorials are intended to help students identify the similarities and differences between light waves and waves in general. In particular, it is expected that students will understand that the narrow slits in the n-slit module serve as point sources.
- The visualization in the tutorials are intended to help students realize that geometrical optics cannot be used to predict the behavior of light when passing through very narrow slits.
- The tutorials are designed to enable students to understand the role and the effect of each of the equipment setup features on the interference pattern. Each individual factor that may have an effect on the interference pattern including the amplitude of wave, wavelength, the distance between adjacent sources, is studied separately in the tutorials.
- The effects of changing the number of slits without changing the separation between adjacent slits are discussed for both the n-slit module and the waves module.

The structure of the tutorials is shown in Table 2.1:

Table 2.1 Tutorial Structure

Section Number	Contents
Section 1 Ripple tank:	Basic Properties of waves  Wave properties, Superposition of waves Path difference.
Section 2 Ripple tank:	Interference pattern by two sources:  Effects of amplitude, wavelength, distance between sources, and phase difference. Quantitative questions on locations of maxima and minima.
Section 3 n-slit:	Interference pattern in n-slit module:  The effects of wavelength, distance between slits, and number of slits. Qualitative and quantitative questions on locations of major maxima and secondary maxima.
Section 4 Ripple tank:	Interference pattern by three sources:  Qualitative questions on locations of major maxima Quantitative question on locations of secondary maxima.

## 2.2 *Experimental Tutorial*

The highly interactive tutorial used in the experiment is based on The Optics Project (WebTOP), a 3D interactive graphic system with content in Optics developed by Foley et al. [15]

### 2.2.1 WebTOP

WebTOP has modules pertaining to eight different subject areas: Waves, Geometrical Optics, Reflection/Refraction, Polarization, Interference, Diffraction, Scattering, and Lasers. The main page of WebTOP is shown in Figure 2.1. Each module has an interactive "scene", a section about the theory behind the phenomenon, a section about how to operate the simulation, an examples section in the form of stored sessions, and a number of suggested exercises.

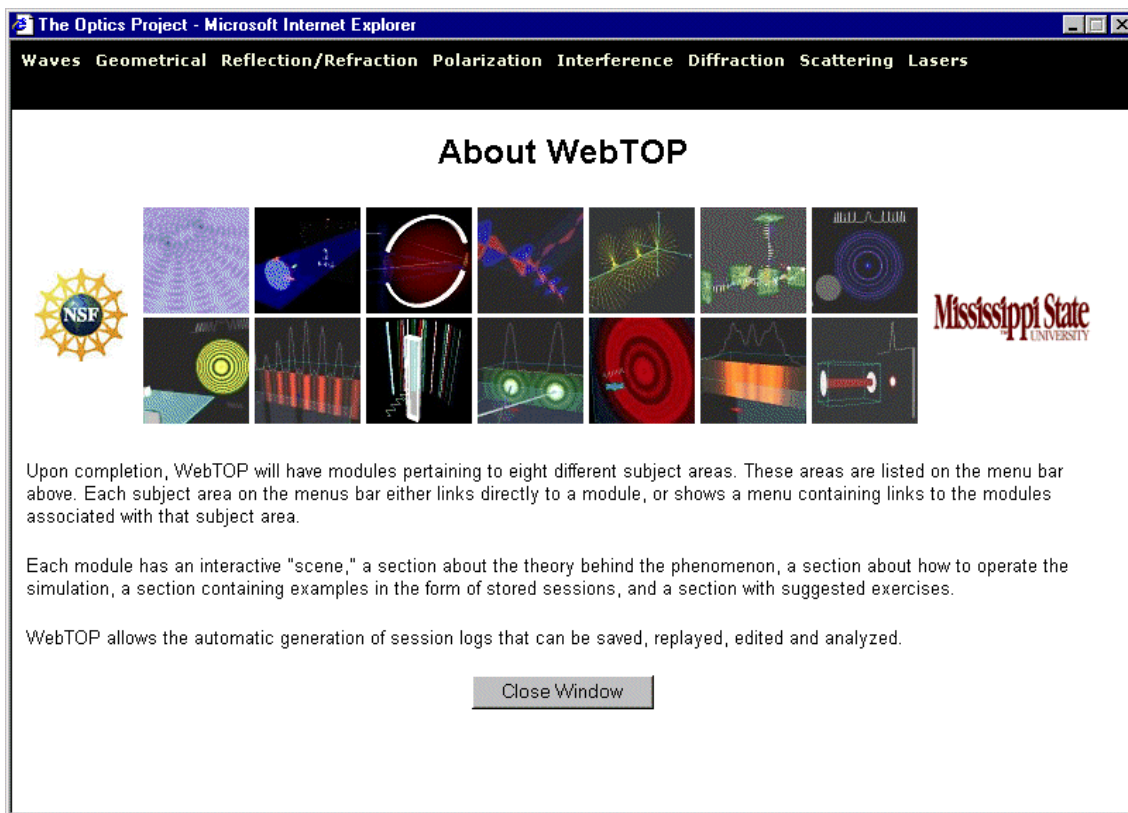


Figure 2.1 WebTOP Main Page Providing Links to Each of the Available Modules

Our experimental tutorial is based on two of the WebTOP modules, the Waves module (ripple tank) and the Fraunhofer N-slit module. In the following sections, I will describe the operation of each of the modules and the way they are implemented in the tutorial.

### 2.2.1.1 *Waves Module*

The waves (ripple tank) module simulation window is shown in Figure 2.2. [16] It is made up of four components: the Scene, the Navigation Icons, the Console, and the Recording Panel.

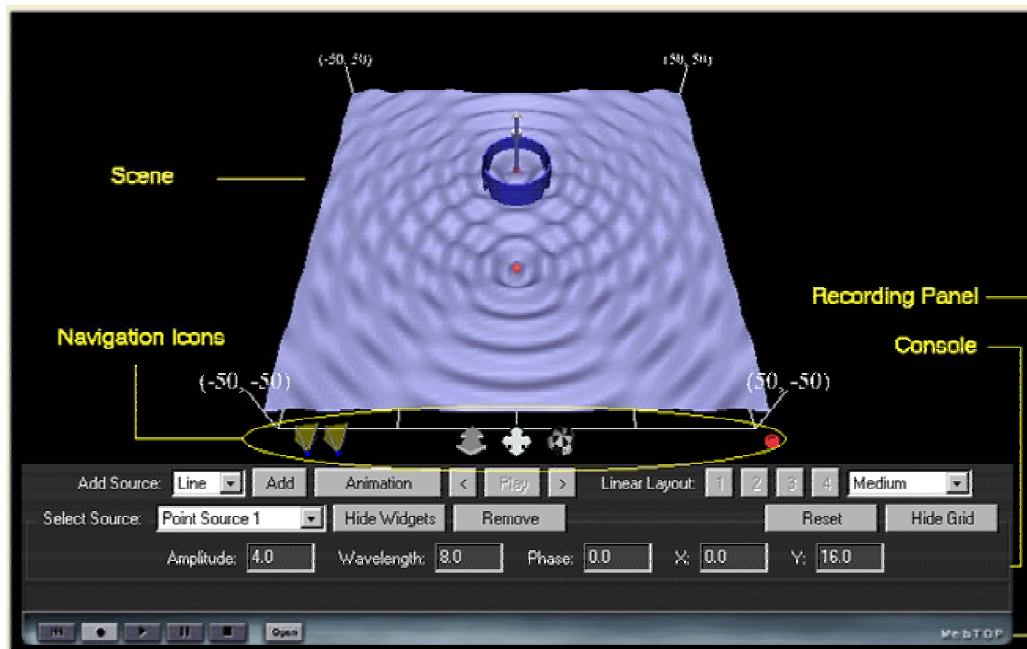


Figure 2.2 Waves Module Simulation Window

Figure 2.3 shows a view of the control panel with controls used to manipulate the parameters in the Waves module. Students can add or remove sources, set source

parameters, and manipulate the scene. To add a source, they can select either Line or Point from the Add Source pull down window, and then click on the Add button. In this experiment, we use only point sources. To change the parameters of a particular source, such as the coordinates of the source, the amplitude, wavelength, and phase of the generated wave, students can select the source from Select Source pull down menu, and then type the values in the appropriate keyboard entry boxes. To control what is shown on the scene by pressing the Hide Widgets button, students can elect to hide the source, show it as a point source marker, or as a marker along with widgets. They can also select to show or hide the grid under the scene and enable or disable the animation of the resulting interference pattern.

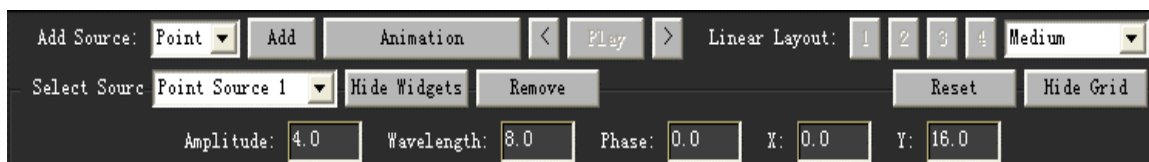


Figure 2.3 A Snapshot of the Waves Module Control Panel

Besides the keyboard entry boxes, pull down menus and buttons are available on the Console to allow students to control the source parameters directly by manipulating the corresponding widgets. Widgets are geometrical shapes that are attached to the scene and that can be manipulated by using the mouse. Each widget can be used to control a physical parameter of the simulation. Widgets used for the Wave model are shown in Figure 2.4. To change the position of a wave source, students can select the position widget of the source, the thin long cylinder as shown in figure 2.4, then drag the cursor to

the intended coordinate. In order to observe the effect of changing wavelength on interference pattern, students can select the wavelength widget of target source, drag cursor outward to increase wavelength, or toward the center of source to decrease it. To change the amplitude, students can select the amplitude widget on the target source and drag the cursor up to increase the amplitude or down to decrease it. The way to change phase is similar to that of amplitude, students can select the phase widget on the target source and drag the cursor up and down to increase or decrease the phase, and the allowable phase values are from 0 to 180°.

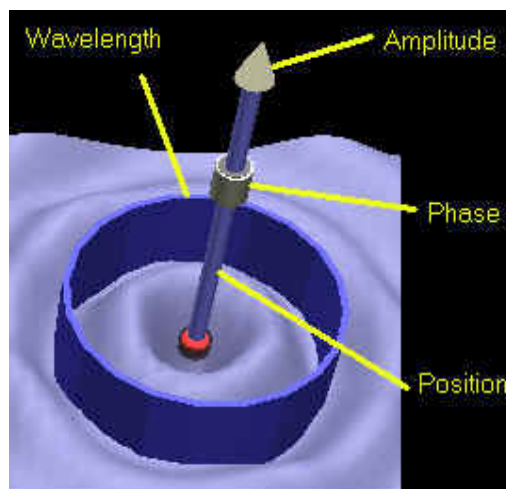


Figure 2.4 Widgets of the Wave Model

When observing the propagation of waves or the interference pattern in the ripple tank, we can use the Navigation Controls as shown in Figure 2.5 to have a better view of the scene. Students can zoom in and out with the Zoom icon, move the scene up and down, left and right with the Pan button, and rotate the scene with the Rotate icon. This brings the real 3D world to the students by allowing them to view the scene from any angle, any view point, and at any detail they desire.





Viewpoint	Zoom	Pan	Rotate
			

Figure 2.5 Navigation Icons

### 2.2.1.2 *N-Slit Module*

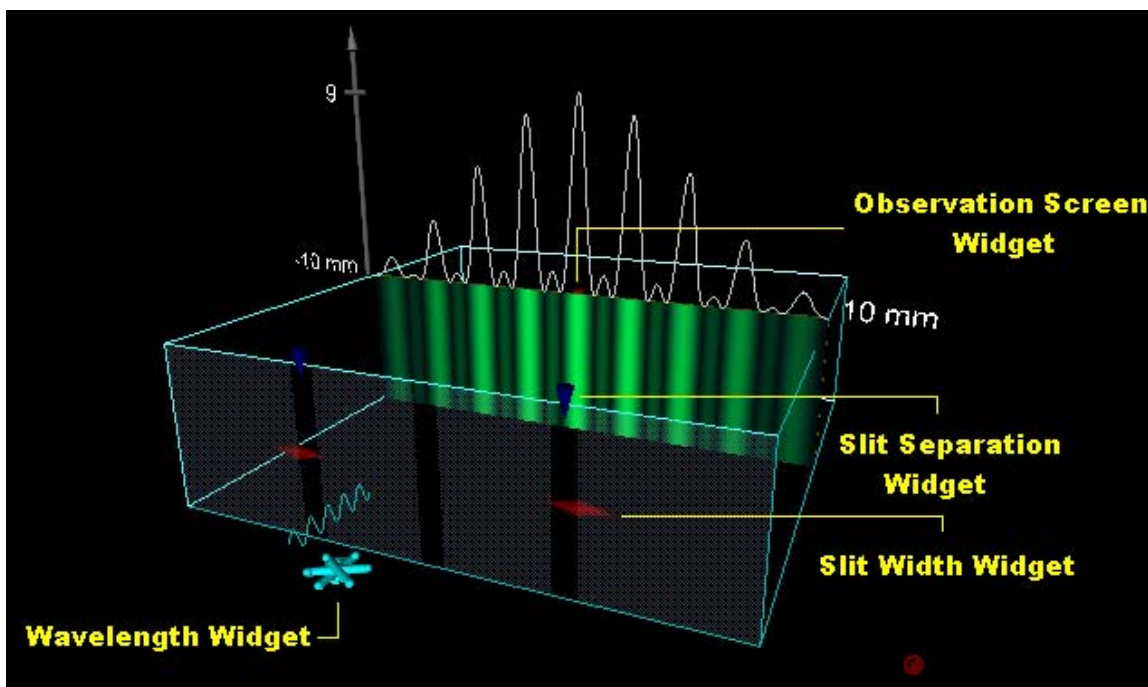


Figure 2.6 N-Slit Module

The N-Slit simulation window is shown in Figure 2.6. Light passes through the narrow slits on the mask and travels to the observation screen. The number of slits, wavelength of light, width of slit, distance between adjacent slits, and the distance from

the observation screen to the mask can be changed by entering values in the corresponding entry boxes on the console as shown in Figure 2.7.



Figure 2.7 N-Slit Module Console

The four widgets used in this module are labeled in Figure 2.6. To change the distance between the mask and the observation screen, students select the widget on the top of the observation screen, and drag the observation screen to the desired position. To change the slit width, students select the widget on the mask, and drag it to the left or right to obtain the desired width. To change the distance between adjacent slits, students select the widget on the slit, and drag it to the intended position. To change the wavelength of the light wave, students select the widget in front of the mask, and rotate widget clockwise to decrease the wavelength or counterclockwise to increase it.

### 2.2.1.3 Scripting Feature

In both the Waves module and the N-slit module, a recording panel can be found at the bottom of the window as shown in Figure 2.8. The scripting features of the recording panel can help students record their own manipulations on the modules and submit them to the instructors as homework, or help the instructors set up specific scenarios that they want to discuss. In this tutorial, only the latter application is used. In some exercises, to shorten the time for students to set up a complicated system, some

specific scenarios were recorded and loaded into the modules when the students opened the simulation windows.



Figure 2.8 Recording Panel

On the recording panel, there are six function buttons and a progress status bar. To record a series of manipulation processes on the modules, students can click on the Record button on the panel and start to manipulate the module under the pre-designed plan. They then click on the Stop button to stop the recording process. A Save WSL Script window will pop up allowing the students to select the desired directory and filename to save the script as a WSL file. This script file will record all the parameter values with time stamps. When playing back the recorded simulation scenario, students click on the Open button on the recording panel, an Open WSL Script window will pop up, allowing them to select the desired WSL file to be opened and loaded. They then click on the Play button to play the loaded simulation process.

The WSL script file can also be added as a parameter in an HTML file. This feature is used in the experimental tutorial for the complicated setups described previously. When students invoke the simulation module, the WSL file will be loaded automatically.

### 2.2.2 Implementation of WebTOP in the Experimental Tutorial

Interactive simulation is the most important component integrated into the tutorial. It is used to display the physics phenomena virtually but vividly under the circumstances which students set themselves. As mentioned above, manipulating widgets or entering values in the console can change source parameters in the Waves or the N-Slit modules. Thus, different scenarios can be set up by different parameter selections, and different view points can be chosen to get a better view, which give students a better understanding of interference phenomenon by using their direct sense of vision. But how does the simulation component work in the tutorial, and how does the tutorial implement the interactivities of the simulation modules? These questions will be discussed below.

#### 2.2.2.1 *Waves Module*

With the interactive wave simulation module, students can change the system setup easily by some simple parameter inputs on the console, or change the parameters with widgets. These can be finished in a short amount of time. What students need to do is just change the related parameters in the setup that they are studying. There is no physical involvement of real equipment such as a ripple tank or wave sources. This virtual wave module gives students an environment without any other distracting factors, e.g., there is no faulty equipment. It is an environment where only related factors will be studied. Although the simulation is a virtual environment, it reflects the real world vividly.

In the tutorial, interference topics are separated into different exercises and studied individually. To study each topic, students set up the specific scenario in the simulation modules according to the instructions in the exercise. Figure 2.9 shows an example on how students use the Waves module to study the topic of path difference. Path difference is a basic concept in understanding interference phenomenon. When studying path difference, the concept and formula for path difference are given first, then students are asked to open a simulation window and set up the system according to the instructions in the exercise. By clicking the red “3D” icon following the title, the corresponding Waves module is opened. Several questions on path difference are then asked in a step by step process which requires the students to manipulate the Waves module.

### Path Difference 3D ?

In Figure 1 below, if we take  $d_1$  to be the distance separating the location of the interference Point  $L$  from Source 1, and  $d_2$  the distance between Point  $L$  and Source 2, the path difference is defined as  $\delta = d_2 - d_1$

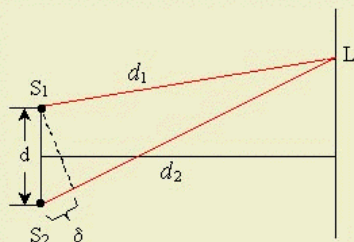


Figure 1

Please close the previous simulation window and click on the **3D** button now to open the current simulation window. This simulation features propagation of waves generated by Point Source 1 at (0,-8) and Point Source 2 at (0,8), with wavelength = 8, and amplitude = 10. Other two sources Point Source 3 at (30,0) and Point Source 4 at (30,-8) both with zero amplitude serve as observation points. since with their zero amplitude they won't interfere the propagation of other waves. Click on the Static/Animation button and the Play button to simulate the wave propagation.

Note that at Point source 4, the amplitude is zero, the water level doesn't change. Meanwhile, the water level oscillates up and down at Point source 3.

(a) What is the distance between Point source 1 and Point 4 (use the coordinate of point sources to find out the distance)?

(b) What is the distance between Point source 2 and Point 4?

(c) What is the path difference between the two waves produced by Point sources 1 and 2 at the location of Point 4 (you may use the calculator on the computer to do the math)?

(d) What is the path difference between the two waves produced by Point sources 1 and 2 at the location of Point 3?

(e) Is the path difference at Point 4 a multiple of wavelength ( $n\lambda$ ) or a multiple of wavelength plus half wavelength ( $(n+1/2)\lambda$ ) ( $n=0,1,2,3\dots$ )?

(e) Is the path difference at Point 3 a multiple of wavelength ( $n\lambda$ ) or a multiple of wavelength plus half wavelength ( $(n+1/2)\lambda$ ) ( $n=0,1,2,3\dots$ )?

Figure 2.9 Instruction and Problems in Tutorial

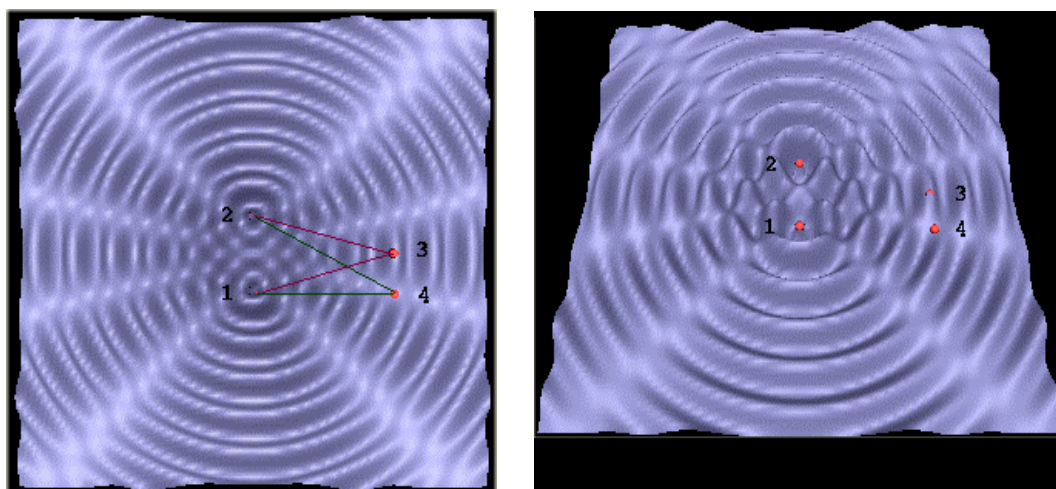
On the console in the Waves module window as shown in Figure 2.3, students set the parameter values of sources, in this case the parameters of Point Source 1 or Point Source 2. Students use the Select Source drop down menu to select Point Source 1, then set  $X = 0$  unit,  $Y = -8$  units, wavelength = 8 units and amplitude = 10 units with the appropriate keyboard entry boxes. Then they can select Point Source 2 from the Select Source drop down menu, and set  $X = 0$  unit,  $Y = 8$  units, wavelength = 8 units and

amplitude = 10 units. Students can also use the Position Widget, Wavelength Widget, and Amplitude Widget to change the point source parameters to the desired values. So far, two sources with the same wavelength, amplitude and phase are 16 units apart from each other. Students can click on the Hide Widgets button and the Animation button to simulate the two source interference pattern. If students need frame-by-frame motion of the wave propagation, they can use the “<” or “>” buttons to step back and forth. After observation of the interference pattern, students can click on the Stop button to stop the animation of the wave propagation.

To observe the maxima and minima in the interference pattern, students are asked to set up another two point sources with zero amplitude, which serve as observation points to give students a better view of maximum constructive interference and complete destructive interference. Students select Point from the Add Source drop down menu on the console, and then click on the Add button to add Point Sources 3 and 4 into the ripple tank. Students then set their amplitudes to zero and move Point source 3 to (30, 0) and Point source 4 to (30, -8). Since their amplitudes are zero, their existence won't change the interference pattern formed by Point Sources 1 and 2. They just serve as observation points, with which students can compare the water level. Students can then click on the Play button to animate the scene, and observe the water level at the locations of Point Sources 3 and 4.

After studying the detail of the interference pattern, the scene can be presented from a pre-programmed viewpoint (or viewpoints) by clicking on the Viewpoint widget. In the Overhead point of view shown in Figure 2.10 (a), the interference pattern can be

clearly seen. The places which reach maxima are bumpy so that they look dark from the overhead point of view, on the other hand the places where minima occur look bright from above. It is obvious that maxima and minima occur at certain locations or certain angles from the sources.



(a) Overhead View

(b) Front View

Figure 2.10 Maxima and Minima

From another pre-programmed viewpoint, the front view in Figure 2.10(b), another interesting phenomenon can be observed. With the animation running, the students will notice that the water level at the location of Point Source 4 doesn't change at all while that at the location of Point Source 3 oscillates up and down.

To have a better understanding of the concept about path difference, students are asked to find out the path difference between the two waves produced by Point sources 1 and 2 at observation points 3 and 4 respectively. With these questions, students are not

just manipulating the simulation aimlessly, they need to study the system they just set up by themselves and observe the detailed phenomena at certain locations to find out the inner reasons for the occurrences of the phenomena.

To calculate the path difference at the location of point 4, students need to find the distance between Point Source 1 and Point Source 4, and the distance between Point Source 2 and Point Source 4. These are shown as the first two questions on the tutorial page. By using the equation  $d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$ , the distance between Point Sources 1 and 4 is  $\sqrt{(0 - 30)^2 + [(-8) - (-8)]^2} = \sqrt{(30)^2 + (0)^2} = 30$  units; the distance between Point Sources 2 and 4 is  $\sqrt{(0 - 30)^2 + [8 - (-8)]^2} = \sqrt{(30)^2 + (16)^2} = 34$  units. With the values of the two paths, the students obtain the path difference by subtracting 34 units with 30 units.

Further questions about the path difference at the location of Point Source 3 are asked, and then two questions about the relationship of these distances and the wavelength are given. These questions lead the students to a deeper understanding of path difference and its relationship to wavelength for maxima and minima. Point 3 and Point 4 are at very special locations, the path difference at Point 4 is 4 units, that is half the wavelength of 8 units. This complies with the formula  $(n+1/2)\lambda$ , where  $n$  is integer. So at this location, waves from point sources 1 and 2 are in opposite phase, so that when they superpose they cancel out each other. When students manipulate the simulation window, they can clearly see the water level remains unchanged at the location of point 4. The path difference at Point 3 is zero units, which complies with the formula  $n\lambda$ , where  $n$  is

integer. So at this location, waves from Point Sources 1 and 2 are in the same phase, so that when they superpose they form a wave with twice the amplitude. When students manipulate the simulation window, they can clearly see the water level oscillates up and down at the location of Point 3 with a bigger amplitude.

After manipulating the Waves module simulation and observing the response, the students submit their answers on the tutorial page. The answers along with the exercises questions are shown on the next tutorial page, as shown in Figure 2.11. The answers component displays the answers status, the student's choices and the correct answers, thus providing feedback to the students.

Results		
Question	Your Answer	Correct Answer
<input checked="" type="checkbox"/> QuestionA	30	30
<input checked="" type="checkbox"/> QuestionB	34	34
<input checked="" type="checkbox"/> QuestionC	4	4
<input checked="" type="checkbox"/> QuestionD	0	0
<input checked="" type="checkbox"/> QuestionE	$n * \text{Lambda}$	$(n + 1/2) * \text{Lambda}$
<input checked="" type="checkbox"/> QuestionF	$(n + 1/2) * \text{Lambda}$	$n * \text{Lambda}$

Figure 2.11 Answer Component

Directly below the answer component, solutions to the questions are given as shown in Figure 2.12. With the formula, step-by-step calculations and graphs with marks, the solutions help students learn the concept of path difference from both tangible and mathematical ways. The solutions together with the answers serve as feedback that help

students correct their mistakes when they give wrong answers, or strengthen their knowledge if they give correct answers.

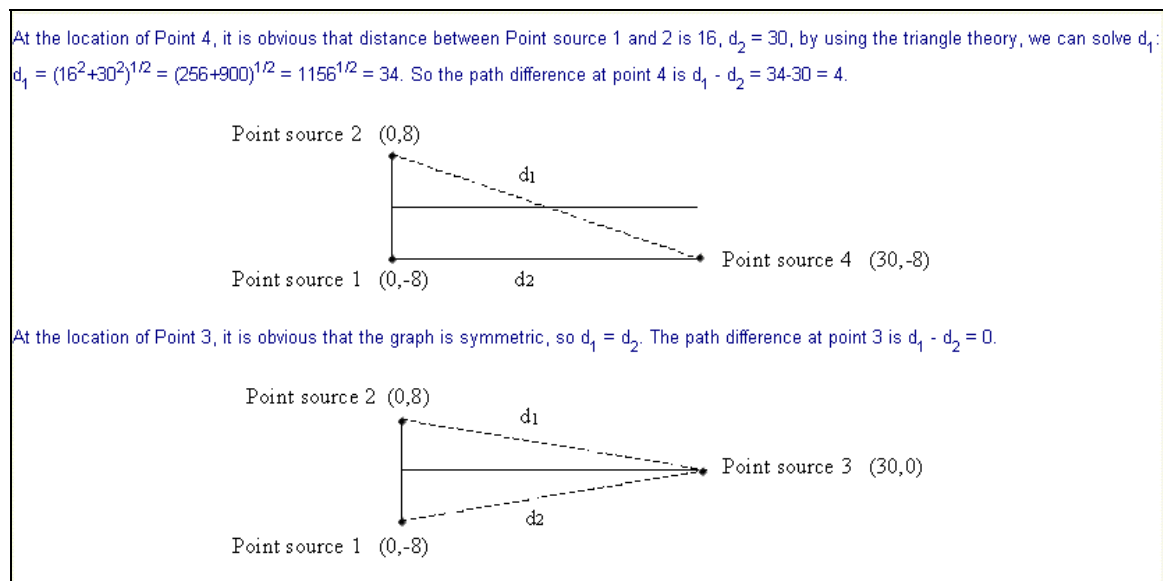


Figure 2.12 Solution Component

The tutorial provides guidance and support to students, where the simulation module is an important part of this learning environment but not the only one. It is integrated with problem sets and feedback which makes it better for student learning of the interference phenomenon.

In this path difference exercise, students can animate the scene, let the water waves move out from the sources, observe the water level changes at the locations of Point Sources 3 and 4, zoom in to have a closer look, rotate the scene to have a better view, or they can even play it with slow motion by using the “<” and “>” buttons. It all depends on the students’ preferences on how to observe the phenomenon. This 3D interactive tutorial gives the students another method for observing the real world

interference phenomenon in a high fidelity virtual environment, where the students can work on it at their own pace and using their own learning styles.

### 2.2.2.2 *N-Slit Module*

After the Waves module, interference patterns are studied in the N-slit module. Studying and comparing these two modules helps students make a proper analogy between interference in water and in light. Furthermore, it guides students to understand that light is a certain type of wave with an extremely small wavelength, and that geometrical optics cannot be used to make predictions about light passing through very narrow slits.

One set of questions, for example, investigates the effect of changing the number of slits in the N-Slit module. This problem set is shown in Figure 2.13. To answer the questions, students need to manipulate the N-Slit module. By clicking the red “3D” icon following the title, the corresponding N-Slit simulation module is opened.

**Exercise 9: More than 2 Slits - Effect of Changing the Number of Slits** 3D ?

Set the number of slits to be 2, the wavelength to be 500 nm, the slit width to be 0.005 mm, the distance between slits to be 0.10 mm, and z to be 1000 mm. Let us refer to the maxima we observe now as "major maxima". Use the "Slits" keyboard entry box to change the number of slits to 3.

(a) Did the positions of the major maxima change?

(b) Did the positions of the minima change?

(c) What happened at the locations where minima used to be?

(d) How many "secondary" maxima occur between every two consecutive major maxima?

(e) Did the major maxima become wider or narrower?

(f) Did the peak intensities of the major maxima change? (You will need to consult the scale on the white intensity graph above the observation screen to determine this.)

Figure 2.13 Problem Set on N-Slit Module

On the console of the N-Slit module simulation window, as shown in Figure 2.7, students can set the parameters of the optical system as requested in the exercise. They click on the Slits entry box, input the value 2 to set the number of slits to two; select Wavelength entry box, input the value 500 to set the wavelength of light to 500nm; in the Width entry box, enter the value 0.005 to set the slit width to 0.005mm; enter the value 0.10 in the Distance entry box to set distance between the adjacent slits to 0.10mm; to set the position of the observation screen, select the Z entry box and input the value 1000 to change the distance between the observation screen and the mask to 1000mm. Students can also use the Double-Cone Widget, Cone Widget, and Wheel Widget to change the optical system parameters to the desired values. At this point an optical system has been set up in which light with a 500nm wavelength passes through a mask with two slits which are 0.005mm wide and 0.10mm from each other to produce an interference pattern on an observation screen 1000mm away from the mask.

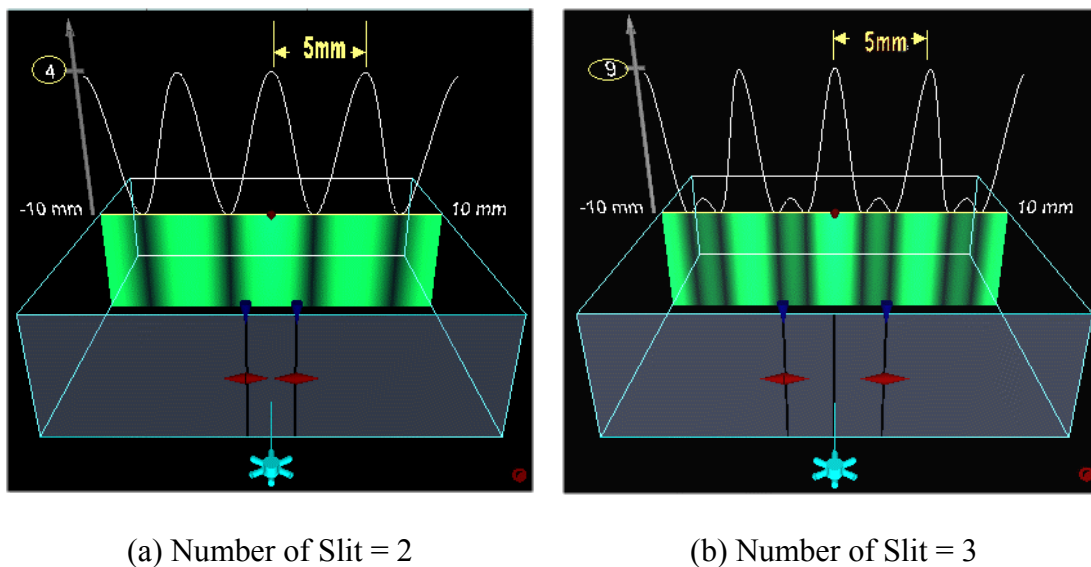


Figure 2.14 Effect of Changing the Number of Slit From 2 to 3

On the observation screen, the interference pattern is clearly shown in Figure 2.14 (a). The centers of the bright bands correspond to maxima, while the centers of the dark bands correspond to minima. An intensity graph is shown above the observation screen to show the intensity degree at different positions on the screen. Notice that the length of the observation screen is also given to help students locate the positions of maxima and minima.

To study the effect of changing the number of slits, the students need to change it from 2 to 3 by entering the value of 3 into the Slits entry box in the console and hit the Enter key to apply the new value. After changing the number of slits to 3, an interesting interference pattern shown in Figure 2.14 (b) can be observed on the observation screen.

The locations where dark bands were previously become bands that are somewhat brighter than the original dark band but darker than the original bright band.

By switching the number of slits between 2 and 3, students can compare the two interference patterns. Notice that in both cases the locations of the major maxima did not change when the number of slits was changed. On an observation screen that is 20mm wide, five major maxima occur at exactly the same locations. But when observing the positions of minima, it is obvious that the locations where minima were previously became something between maxima and minima. These are what are called secondary maxima. The minima occur between major maxima and secondary maxima. By observing the intensity graph above the observation screen, one observes that the intensity at maxima is 4 when the number of slits is 2, but it becomes 9 when the number of slits is changed to 3. Through the manipulation and observation with the N-slit simulation module, students can draw a conclusion and answer the questions in the exercise.

After submitting the answers, solutions are shown to help students correct their mistakes or strengthen their understanding of the effect of the number of slits on an interference pattern.

In this tutorial section where N-Slit simulation module is used, students can set up the optical system very quickly and easily by inputting of parameter values in the console or by manipulation with the widgets. In this specific exercise, they are asked to set up the system by following the instructions of the exercise. Thus a certain scenario is established to help the students focus on a certain factor that will affect the interference pattern of the

light waves. The N-Slit module is a high fidelity miniature of the real optical system in the lab; it clearly shows all the equipments of the system. The pattern on the observation screen is shown very clearly and accurately with some easy changes to the parameters. To help students have a better understanding of the major maxima, second maxima, and minima on the observation screen, the intensity graph serves as a good tool to interpret that.

### **2.3 *Control Tutorial***

Compared with the extensive interactivity in the experimental tutorial, the interactivity in the control tutorial is limited to web-based navigation and immediate feedback. To avoid other factors and focus on the effectiveness of 3D simulation and its interactive feature in learning interference, this control tutorial covers exactly the same content as in the experimental tutorial, but it uses static pictures of interference patterns .

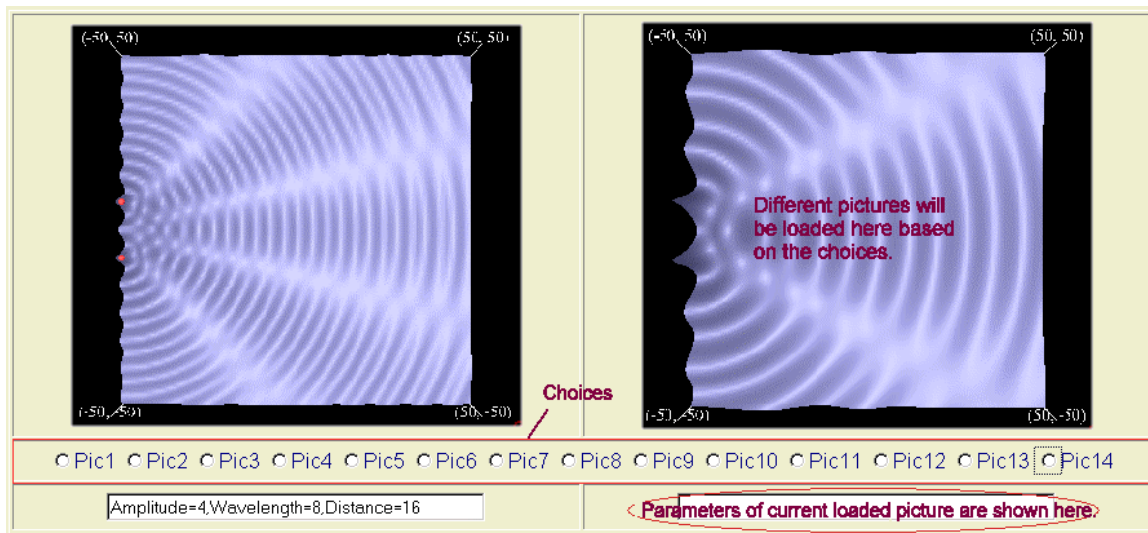


Figure 2.15 Interference Patterns from the Control Tutorial

In most of the exercises of the control tutorial (except those exercises on wave properties, wave superposition, and path difference), interference pattern pictures using different parameters are given to the students as shown in Figure 2.15 above. The picture to the left is the interference pattern being studied in the exercise; source parameters or system parameters are given in the text box below it. The picture to the right is the one you may use to compare with the picture on the left. By selecting the radio buttons below the graphs, different interference pattern pictures will be loaded. In this way, students can observe the patterns, draw their own conclusions, and learn the concepts and features of interference phenomenon.

Since learning how to manipulate and manipulating 3D interactive simulation modules are more time consuming than just clicking on the radio buttons to select different interference pattern pictures, some exercises (except those exercises on wave

properties, wave superposition, and path difference) are given twice with different values of the parameters. This helps to balance the time students will spend on both experimental and the control tutorials. The list of instructions and exercises in these two tutorials is shown in Table 2.2.

Table 2.2 Instructions and Exercises in Tutorials

Experimental Tutorial	Control Tutorial	Topic
Instruction 1	Instruction 1	Wavelength
Instruction 2	Instruction 2	Amplitude
Instruction 3	Instruction 3	Time dependence of wave
Instruction 4	Instruction 4	Wave superposition
Instruction 5	Instruction 5	Wave superposition
Instruction 6	Instruction 6	Path difference
Instruction 7	Instruction 7	Path difference and superposition at Point 3
Instruction 8	Instruction 8	Path difference and superposition at Point 4
Exercise 1	Exercise 1, 8	Two In-phase point sources: Effect of changing amplitude
Exercise 2	Exercise 2, 5	Two In-phase point sources: Effect of changing wavelength
Exercise 3	Exercise 3, 7	Two In-phase point sources: Effect of changing distance between sources
Exercise 4	Exercise 4, 6	Two In-phase point sources: Effect of changing parameters on minima
Exercise 5	Exercise 9	Two In-phase point sources: Condition for maxima
Exercise 6	Exercise 10	Two In-phase point sources: Condition for minima
Instruction 9	Instruction 9	Two point sources that are 180 degrees out of phase: Condition for maxima
Instruction 10	Instruction 10	Two point sources that are 180 degrees out of phase: Condition for minima
Exercise 7	Exercise 11, 13	Double-slit: effect of changing the distance between slits
Exercise 8	Exercise 12, 14	Double-slit: effect of changing the wavelength
Exercise 9	Exercise 15	More than two slits: effect of changing the number of slits
Exercise 10	Exercise 16	Three-slit: calculate the distance between the first order major maximum and the axis
Exercise 11	Exercise 17	Three-slit: calculate the position of the first order secondary maximum and the axis
Exercise 12	Exercise 18	More than two slits: effect of changing the number of slits
Exercise 13	Exercise 19	More than two slits: effect of changing the number of slits
Exercise 14	Exercise 20	Three In-phase point sources: major maxima
Exercise 15	Exercise 21	Three In-phase point sources: major minima

## CHAPTER III

# EVALUATION OF THE EFFECTIVENESS OF INTERACTIVITY

### **3.1 Results**

The investigation of the effectiveness of interactivity on learning interference phenomenon was conducted at Mississippi State University among students enrolled in one of three calculus-based courses (Physics I, Physics II, and Honors Physics II), which were instructed by Dr. Dunne, Dr. Winger, Dr. Ermer, and Dr. Mzoughi. The volunteers came to a computer lab with nine computers to attend the experiment which was conducted from November 12<sup>th</sup> to 17<sup>th</sup> and from November 26<sup>th</sup> to 29<sup>th</sup> during fall semester 2001. Of the 87 students whom participated, 12 students failed to complete the required activities and were excluded from the analysis. Among the qualified students, 62% of them were male, 38% were female, 63% of them had studied waves before, and 9% of them had studied optics before.

#### **3.1.1 Student's Background**

In the experiment, students were randomly assigned into two groups, the experimental group and the control group, which used the 3D interactive tutorial and the

static picture tutorial respectively. When analyzing student's background with t-test for independent measurement<sup>1</sup> at a 0.05 level of significance, no significant differences were found on gender distributions, knowledge of wave, knowledge of optics, student's GPA, ACT score, and number of physics semesters took between the two groups. But there was significant difference on ACT Math score, the experimental group had higher ACT Math score. Though no significant difference was found on knowledge of optics at a 0.05 level of significance, significant difference can be found at a 0.10 level of significance,  $t(73) = 1.99, p < .10$ . Detailed data of student's background are shown in Table 3.1.

Table 3.1 Student's Background in Experimental Group and Control Group

Background	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Gender	1.32	.47	37	1.43	.47	37	-0.952
Knowledge of Waves	1.41	.05	37	1.32	.47	37	0.72
Knowledge of Optics	1.97	.17	36	1.84	.37	37	1.99
GPA	3.17	.54	33	3.02	.62	36	1.06
ACT	27.06	4.38	35	25.89	5.25	37	1.02
ACT Math	28.09	4.36	34	25.66	5.49	35	2.03*
Number of Physics Semesters	2.05	2.69	37	1.70	.78	37	0.76

Note: In gender distribution, male = 1, female = 2; Mean<sup>2</sup>; SD = standard deviation<sup>3</sup>; n= number of subject; \* $p < 0.05$ .

<sup>1</sup> "The t statistic is used to test hypotheses about an unknown population mean  $\mu$  in situations where the value of standard deviation  $\sigma$  is unknown." "t = (sample mean (from the data)) – population mean (hypothesized from H) / (estimated standard error)" Gravetter, F.J. & Wallanu, L.B. (1997) Statistical for the behavioral sciences: A first course for students of psychology and education (4<sup>th</sup> ed.), pp289 & pp293.

<sup>2</sup> "The mean for a distribution is the sum of the scores divided by the number of scores." Gravetter, F.J. & Wallanu, L.B. (1997) Statistical for the behavioral sciences: A first course for students of psychology and education (4<sup>th</sup> ed.), pp78.

### 3.1.2 Student's Attitude toward Tutorials

In investigating student's attitudes toward the tutorials in this study, no significant differences were found between the experimental group and the control group on the interest in the tutorials, comprehension, and representation of the tutorials.

Table 3.2 Student's Attitude toward Tutorials

Attitude	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Interest	3.46	1.07	37	3.39	.89	38	0.29
Comprehension	3.00	.97	37	3.21	1.02	38	-0.92
Representation	3.49	1.07	37	3.47	1.01	38	0.05

Note: \* $p < 0.05$

### 3.1.3 Performance in Tutorial Exercises

In analyzing the student's performance in the tutorial exercises, no significant differences were found between the experimental group and the control group on the performance in the tutorials. Detailed data are shown in Table 3.2.

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<sup>3</sup> "Sample standard deviation is the square root of the variance." Gravetter, F.J. & Wallanu, L.B. (1997) Statistical for the behavioral sciences: A first course for students of psychology and education (4<sup>th</sup> ed.), pp126.

Table 3.3 Means of Percent Correct Answer in Tutorial Exercises

	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Performance	63.04	18.33	37	56.78	19.43	38	1.44

Note: \* $p < 0.05$

### 3.1.4 Performance in Pretest and Posttest

Each student was asked to finish a pretest on paper, the tutorial on computer, and a posttest on paper. The pretest and posttest were the same for both groups. Most of the questions were conceptual questions on wave properties, wave superposition, path difference and the factors that affect interference patterns. Also, there were a small number of quantitative questions on path difference. The questions in both the pretest and the posttest were based on the optics problem set developed by the Physics Education Group at the University of Washington. [17]

There were fifteen questions on the pretest: thirteen on wave properties and wave superposition, and two on path difference. On the other hand, there were twenty-three questions on the posttest: ten on wave properties and wave superposition, five on path difference, five on interference (conceptual), and three on interference (quantitative). The last question in the posttest was excluded from the analysis due to a mistake in its design, thus only twenty-two questions from the posttest were analyzed. Twelve questions from the pretest were included in the posttest. Among these twelve repeated questions, ten were on wave properties and wave superposition, and two were on path difference. The

design of pretest and posttest are shown in Tables 3.4 and 3.5 where repeated questions are marked with an asterisk.

Table 3.4 Questions in Pretest

Question Number	Topic
1*	Wavelength
2*	Amplitude
3	Wave propagation
4	Wave propagation
5*	Sine wave superposition
6	Square wave superposition
7*	Sine wave superposition
8*	Frequency
9*	Phase
10*	Length in Wavelength
11*	Constructive superposition
12*	Constructive superposition
13*	Destructive superposition
14*	Path difference
15*	Path difference

Table 3.5 Questions in Posttest

Question Number	Topic
1*	Wavelength
2*	Amplitude
3*	Sine wave superposition
4*	Sine wave superposition
5*	Frequency
6*	Phase
7*	Length in Wavelength
8*	Constructive superposition
9*	Constructive superposition
10*	Destructive superposition
11	Interference pattern
12	Quantitative Question on distance of sources
13	Quantitative Question on distance of sources
14	Effect of changing source distance on interference pattern
15	Effect of changing number of slits on interference pattern
16	Effect of changing number of slits on interference pattern
17	Effect of changing wavelength of light on interference pattern
18	Largest path difference to two point sources
19	Smallest path difference to two point sources
20*	Path difference
21*	Path difference
22	Path difference, constructive and destructive interference

The means of percent correct answer for the pretest, and the posttest are shown in Table 3.6. No Significant differences were found either between the performances of pretest by the two groups or between the performances of posttest by these two groups.

Table 3.6 Means of Percent Correct Answer in Pretest and Posttest

	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Pretest	54.41	19.60	37	49.47	23.64	38	0.98
Posttest	53.69	18.30	37	50.48	18.93	38	0.75

Note: Pretest = means of percent correct answer in pretest, Posttest = means of percent correct answer in posttest. \* $p < 0.05$

### 3.1.5 Analysis of Each Question in the Pretest and the Posttest

In analyzing student performance on each question in the pretest and the posttest, significant differences between the two groups were found only on Question 6 on the pretest and Question 15 on the posttest.

Table 3.7 Student performance on Pretest Question 6 and Posttest Question 15 between Experimental group and Control Group

Question	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Pretest Question 6	.57	.50	37	.32	.47	38	2.14*
Posttest Question 15	.41	.50	37	.18	.39	38	2.24*

\* $p < 0.05$

From another standpoint, significant differences were found with t-test for dependent measurement<sup>4</sup> between correct answer percentages of the pretest and posttest only on posttest Question 2 and posttest Question 3 done by the experimental group. This analysis shows that the experimental group did much better on posttest Question 2 and Question 3, which tested on the concept of amplitude and sine wave superposition when comparing the pretest and posttest on these two questions.

Table 3.8 Student Performance on Posttest Questions 2 and Posttest Question 3 between Pretest and Posttest by Experimental Group

Question	Pretest			Posttest			t
	Mean	SD	n	Mean	SD	n	
Experimental group on Posttest Question 2	.41	.50	37	.76	.43	37	-3.64*
Experimental group on Posttest Question 3	.59	.50	37	.86	.35	37	-3.24*

\* $p < 0.05$

### 3.1.6 Performance in Repeated Questions

#### 3.1.6.1 Comparing Performances of two Groups in Pretest and Posttest

No significant differences were found either in the percent correct answer in pretest repeated questions between the experimental group and the control group, or in the percent correct answer in posttest repeated questions between these two groups.

<sup>4</sup> T-test for dependent measurement can be used when “a single sample of individuals is measured more than once on the same dependent variable. The subjects are used in all of the treatment conditions.” Gravetter, F.J. & Wallanu, L.B. (1997) *Statistical for the behavioral sciences: A first course for students of psychology and education* (4<sup>th</sup> ed.), pp340.

Pretest and posttest means of percent correct answer in repeated questions are shown in Table 3.9.

Table 3.9 Pretest and Posttest Means of Percent Correct Answer on Repeated Questions

	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Pretest	53.60	21.11	37	50.66	24.84	38	0.65
Posttest	64.64	18.26	37	60.75	23.08	38	0.47

Note: Pretest = Pretest means of percent correct answer in repeated questions, Posttest = Posttest means of percent correct answer in repeated questions. \* $p < 0.05$

### 3.1.6.2 Comparing Performances between Pretest and Posttest

A significant difference was found with dependent t-test between correct answer percentages of the pretest and posttest done by the experimental group. Also, significant difference was found between correct answer percentages of the pretest and posttest done by the control group. Means of percent correct answer in repeated questions by experimental group and control groups are shown in Table 3.10.

Table 3.10 Means of Percent Correct Answer on Repeated Questions by Experimental Group and Control Group

	Pretest			Posttest			t
	Mean	SD	n	Mean	SD	n	
Experimental	53.60	21.11	37	64.64	18.26	37	-4.08*
Control	50.66	24.84	38	60.75	23.08	38	-3.78*

Note: Experimental = means of percent correct answer on repeated questions by experimental group, Posttest = means of percent correct answer on repeated questions by control group. \* $p < 0.05$

The analysis of repeated questions shows that even though neither the pretest nor the posttest showed any significant differences between the two groups, both the experimental and control groups made significant progresses on the repeated questions. Their posttest scores on these repeated questions were much better than that in the pretests after using the tutorials.

### 3.1.7 Final Result

In order to evaluate the effectiveness of interactivity, the ACT Math score, and the student's prior knowledge on optics, in which the experimental group did better than the control group, need to be considered as factors that could have affected the outcome

of the posttest, and need to be set as the covariances in ANCOVA<sup>5</sup>. No significant difference was found on the posttest between the experimental group and the control group,  $F(1, 73) = 0.14$  ( $F$  is F-ratio<sup>6</sup>),  $p > .05$ .

### 3.2 *Discussion*

Though no significant differences were found on the posttest between the experimental group and the control group, the fact that both groups scored higher on the repeated questions on the posttest shows that both tutorials helped students learn wave properties, wave superposition, and path difference.

When analyzing the time students spent on the tutorial, some significant differences were found. Students in the control group spent significantly less time on the whole tutorial, on each questions, and on instructions about how to use the tutorials, than the students in the experimental group did. Detailed data are shown in Table 3.11.

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<sup>5</sup> ANCOVA is an extension of analysis of variance in which group differences (or independent variable) are assessed after dependent variable scores are adjusted for differences associated with one or more covariates, variables that are measured before the dependent variable and are correlated with dependent variable.

<sup>6</sup> “ $F = \text{variance (differences) between sample means} / \text{variance (differences) expected by chance (error)}$ ” Gravetter, F.J. & Wallanu, L.B. (1997) *Statistical for the behavioral sciences: A first course for students of psychology and education* (4<sup>th</sup> ed.), pp400.

Table 3.11 Means of Time Spent in Minutes on Tutorials

Time	Experimental			Control			t
	Mean	SD	n	Mean	SD	n	
Total Time	58.63	18.63	37	47.65	18.29	38	2.57*
Average Time	2.09	.68	37	1.34	.54	38	5.34*
Instruction Time	3.44	2.87	37	.92	.49	38	5.27*

Note: Total Time = Total time spent on tutorials, Average Time = Average time spent on each tutorial question, Instruction Time = Time spent on tutorial instructions. \* $p < 0.05$

As mentioned above, in the design of the control tutorial some exercises were given twice with different numbers to balance the time students would spend on the manipulations of 3D modules in the experimental tutorial. The design of the control tutorial worked properly on balancing the time, since without it the experimental group would have spent even more time when compared to that spent by the control group. However, a problem may have occurred: students in the control group may have studied twice on the same topics than as compared to the students in the experimental group. This may be one of the possible reasons why the experimental group did not do much better than the control group. In future studies, if time balancing is still needed, some unrelated topics such as the historical background of the research on interference and applications of interference could be addressed as a way to spend student's time but not to help them to learn the related topics.

On the other hand, in the design of the experimental tutorial, most of the exercises asked students to setup the system themselves and therefore, theoretically, they could

fully use the interactivity feature of the 3D modules. Nevertheless, based on cognitive load theory, if the extraneous cognitive load due to the instructional material used to present the relevant topics is high, and the intrinsic cognitive load due to the intrinsic nature (difficulty) of the to-be learned topics is also high, their combination may exceed the students' mental resources and learning of the topics may fail to occur. [18] In other words, learning interference phenomenon costs students' mental resources, and figuring out what the question is about from its presentation and setting up the system in the 3D modules also costs them mental resources. If the combination of these two parts exceeds the students' mental resources, they won't learn from the tutorial. This may be another possible reason that the experimental group didn't do much better than the control group. To help students study, the future design of the 3D tutorial may setup the system automatically for the students to reduce the extraneous cognitive load, and thus have students focus on the real topics they need to study. [19]

Since no monitor was set up to record students' manipulations of the 3D modules, there was no indication as to on how long students spent on setting up the system which may have been the extraneous cognitive load. There was also no indication as to how long they really spent on manipulating and observing the scene to solve the questions after system setup. In further study, students' control on 3D modules should be monitored in order to get further information on how students use the 3D modules.

## CHAPTER IV

### CONCLUSION

In this research, I have investigated the role of web-based simulations in student learning. I chose waves and interference phenomena as the topics. Students were randomly assigned to complete either a highly interactive tutorial or a less interactive control tutorial. The data suggest that student learning from both tutorials was significant with no measurable difference between the two groups. The study identified several possible factors that might have affected the results and that should be the subject of further study. These factors include students in control group may have studied twice in some topics because of the design of the control tutorial; students in experimental group needed to setup system, which may have caused too much extraneous cognitive load; and the control group might have been too interactive.

Because of the significant differences between the two groups on the time students spent working on each question several questions should be raised: Why did students in the experimental group spend so much time? How much time did they spend setting up the system as opposed to interacting with the 3D modules to solve the questions? Does this extra time diminish when students become more familiar with the

module? Does the extraneous cognitive load introduced by the simulation affect student learning of the topic?

In order to solve these questions, have a better design for the instructional tutorial, and help students really benefit from the interactivity of 3D modules, a more detailed study of student behavior while conducting the experiment should be performed in which student' manipulations of 3D modules needed to be monitored. The data could ultimately be used to help design better strategies for infusing 3D simulations into tutorials. The aim is to ensure that the extraneous cognitive load does not drastically affect the total cognitive load in a particular tutorial. Furthermore, more care should be taken to ensure that the control group tutorial is an authentic equivalent to the interactive tutorial which including systems in 3D tutorial can be set up automatically, instructions course on how to use WebTOP can be given before the experiment, and another textbook based control group can be setup to get more data. These can be accomplished to ensure that the time spent learning physics is the same for both tutorials.

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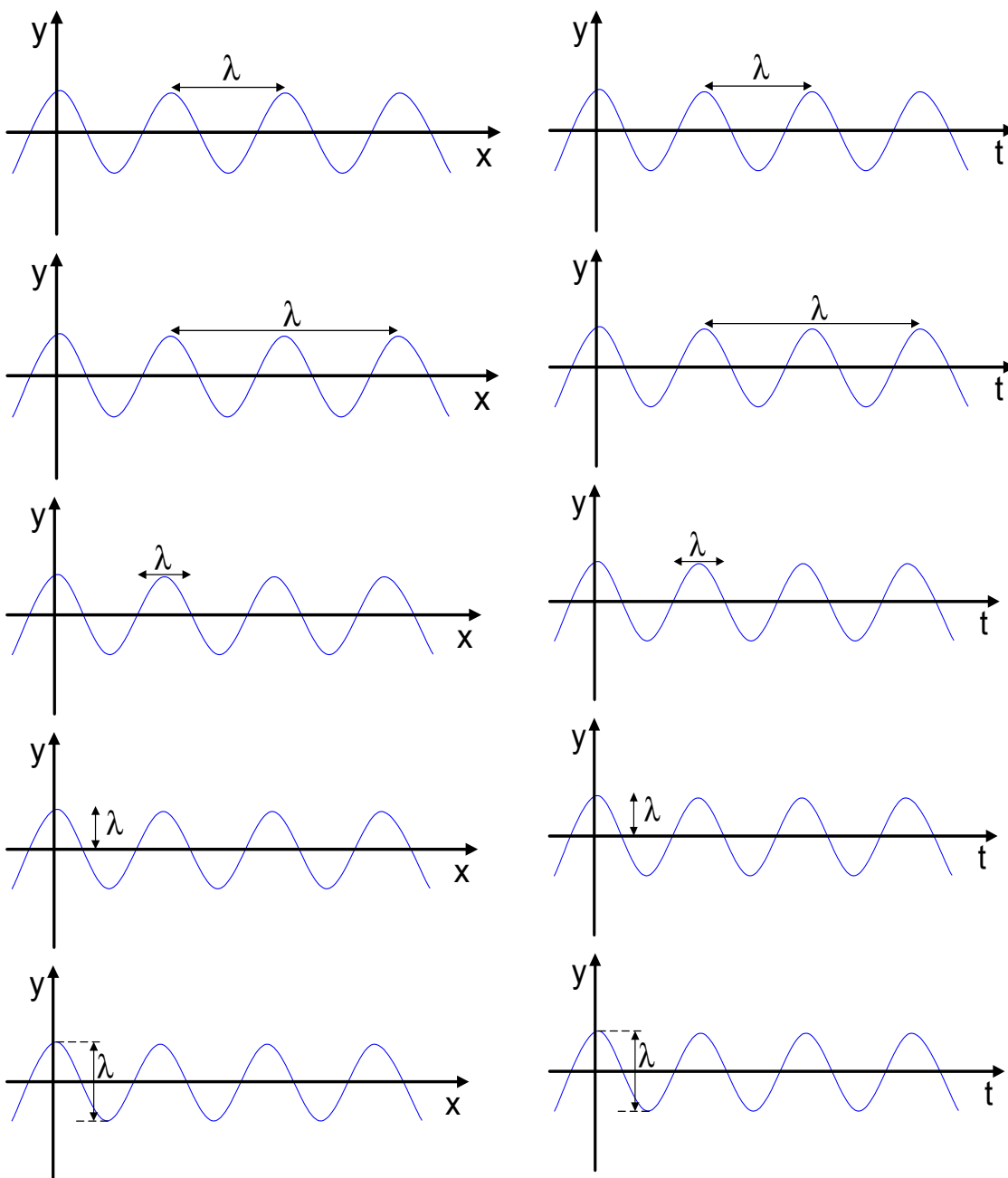
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## APPENDIX A

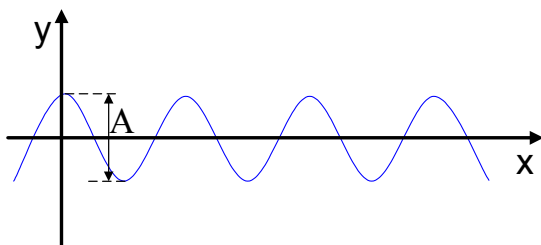
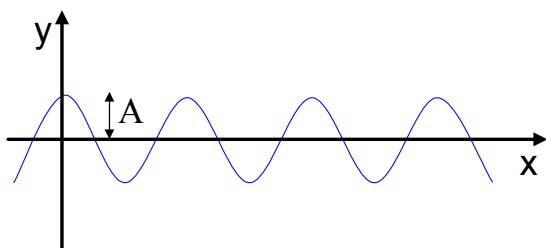
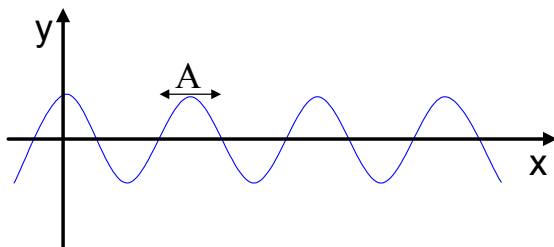
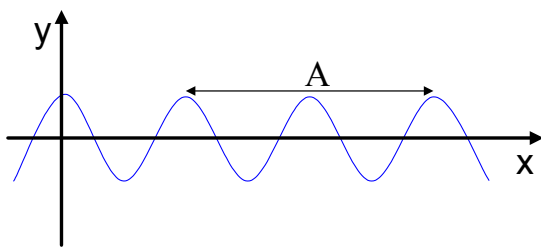
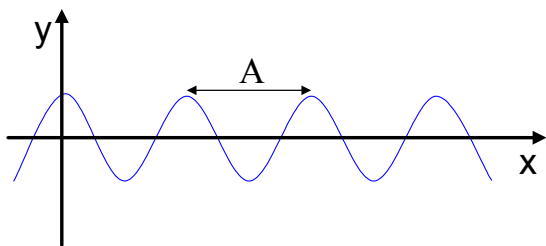
### PRE-TEST

Tutorial ID \_\_\_\_\_ Date : \_\_\_\_\_

**Question 1:** From the following graphs circle the one that best represents the wavelength of a wave. Y in this case refers to the vertical position, x, the horizontal position and t the time. The wavelength is represented by the symbol  $\lambda$ . Note that some graphs use time for the horizontal axis and some use the horizontal position x.

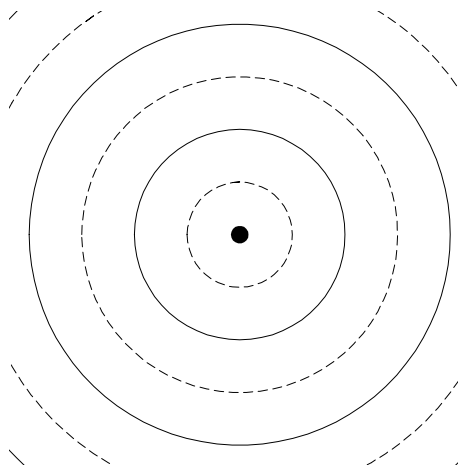


**Question 2:** From the following graphs circle the one that best represents the amplitude of a wave. Y in this case represents the vertical position, x, the horizontal position. The amplitude is represented by the symbol A. Note that the graphs use the horizontal position x for the horizontal axis.

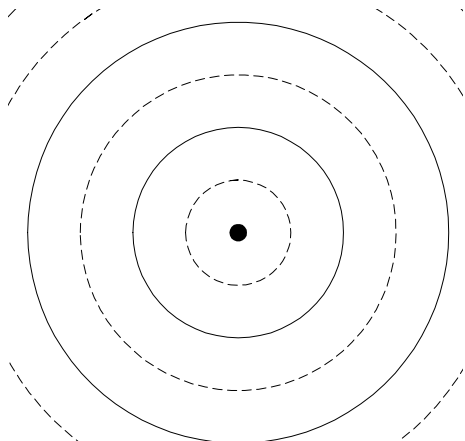


**Question 3&4:** The following two questions refer to the this situation:

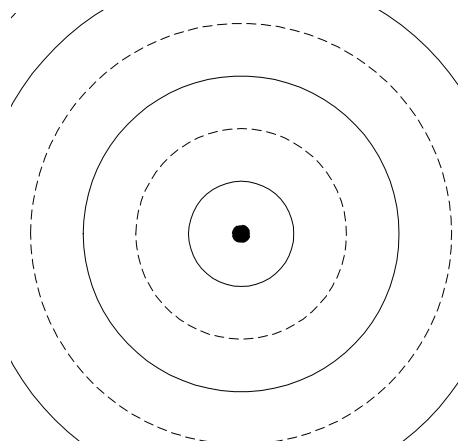
The circles in the Figure represent wavefronts of a periodic circular wave in a portion of a ripple tank. The dark circles represent crests; the dashed circles represent troughs. The diagram shows the locations of the wavefronts at one instant in time, as a photograph would.



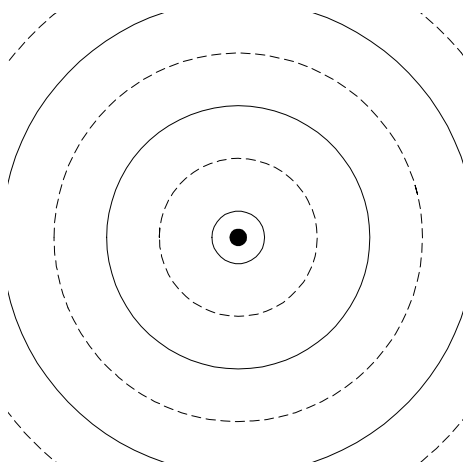
**Question 3:** How, if at all would the diagram differ one-quarter of a period later (circle the correct graph)



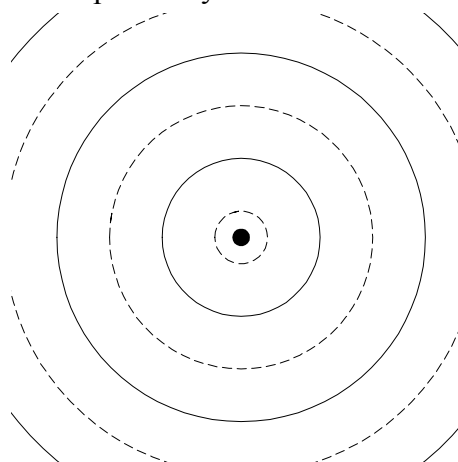
The diagram looks exactly the same.



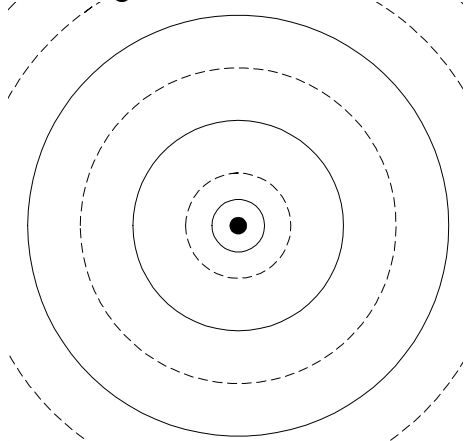
The dark circles will be replaced by dashed circles and the dashed circles will be replaced by dark circles.



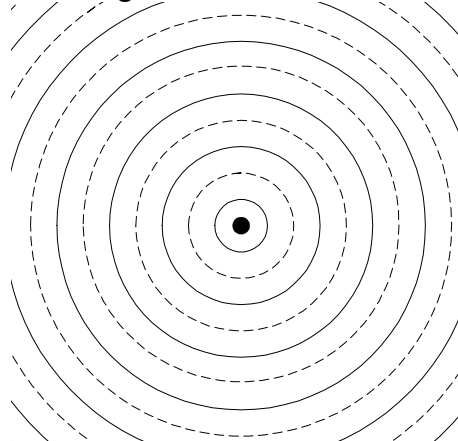
All circles spread out one-quarter of a wavelength.



All circle spread out three quarters of a wavelength.

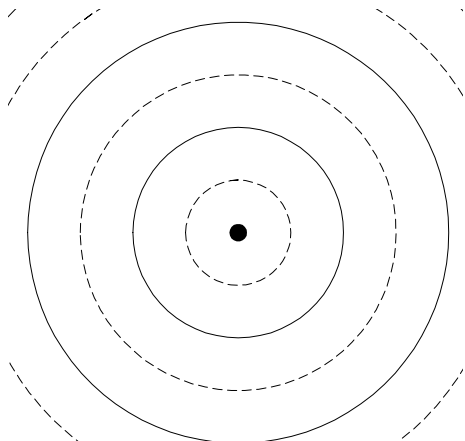


A new crest emerges at one quarter of a wavelength from the source.

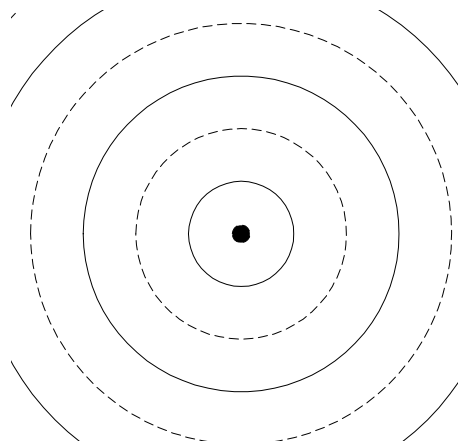


The number of crests and troughs increases.

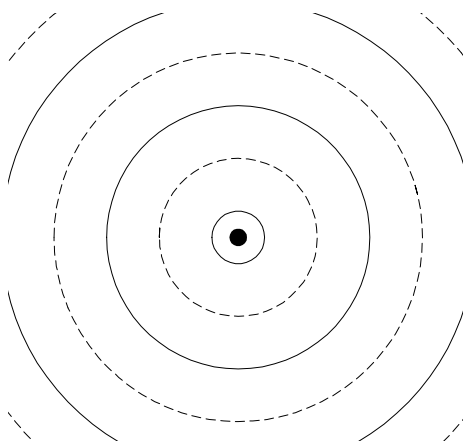
**Question 4:** How, if at all would the diagram differ one period later? (Circle the correct graph)



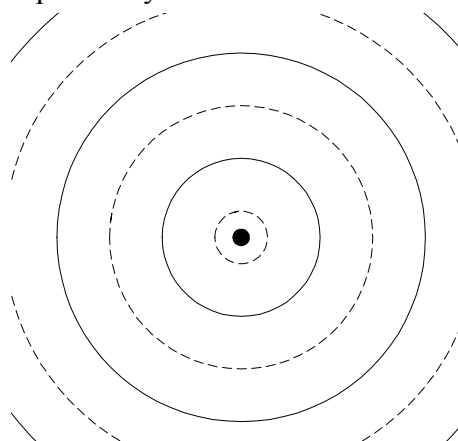
The diagram looks exactly the same.



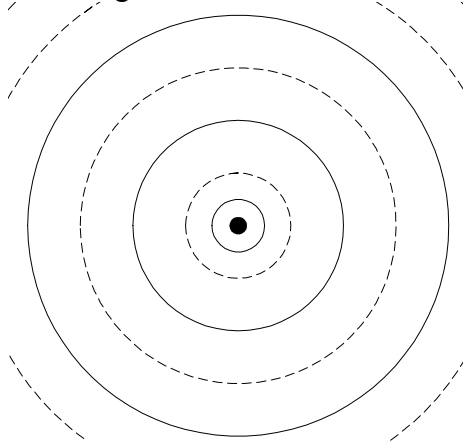
The dark circles will be replaced by dashed circles and the dashed circles will be replaced by dark circles.



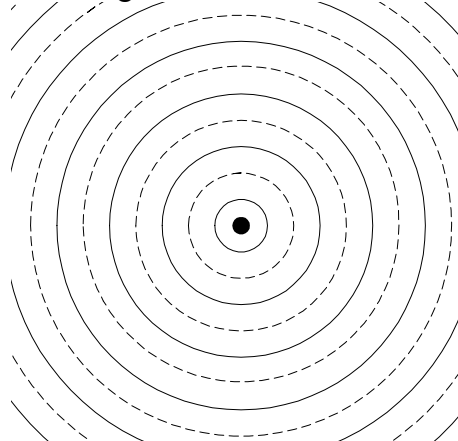
All circles spread out one-quarter of a wavelength.



All circles spread out three quarters of a wavelength.

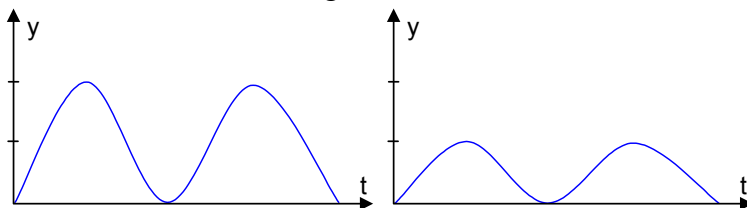


A new crest emerges at one quarter of a wavelength from the source.

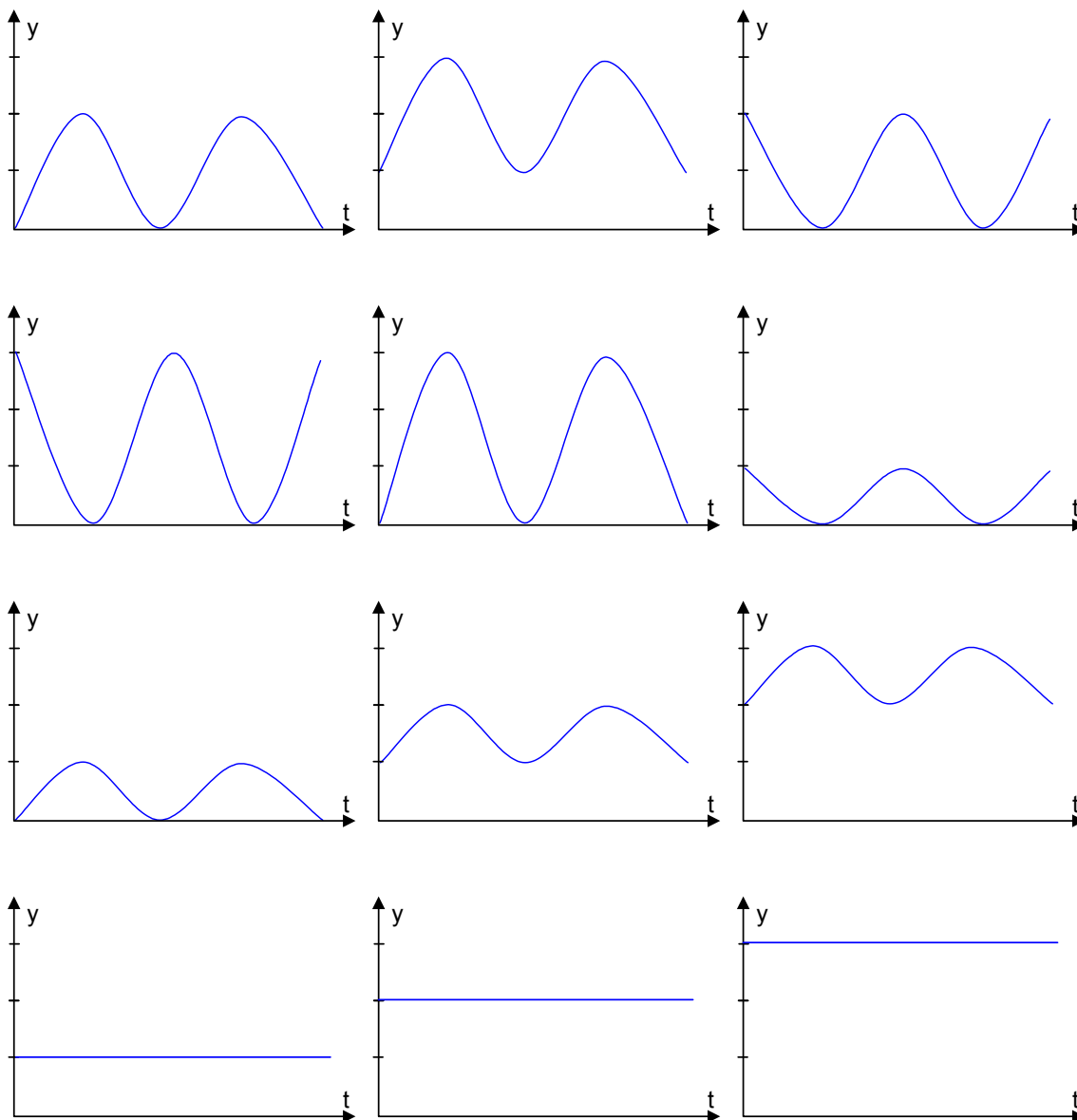


The number of crests and troughs increases.

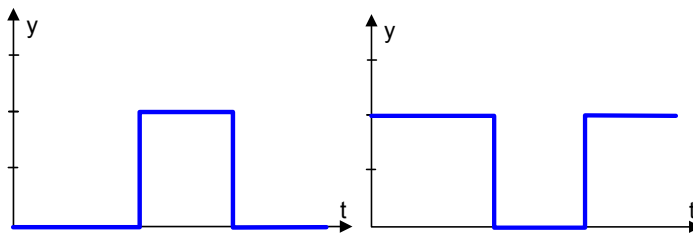
**Question 5:** The waves in the following two graphs are in phase and have the same frequency. The vertical axis refers to height and the horizontal axis refers to time.



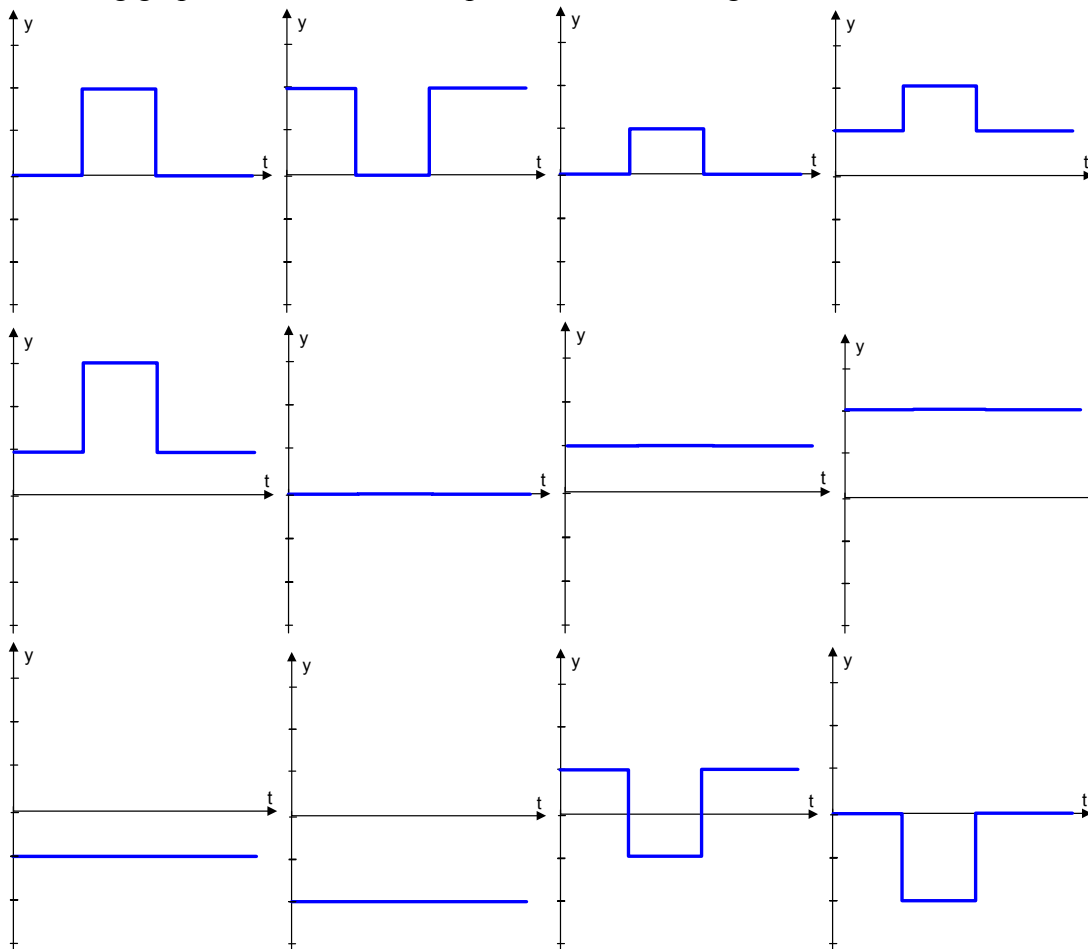
What if these two waves are superposed at a particular location? Circle from among the following graphs the one that corresponds to the resulting wave.



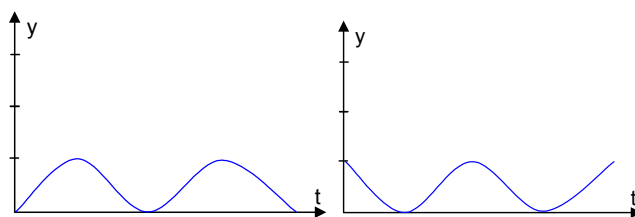
**Question 6:** The following two graphs show square waves. The vertical axis refers to height and the horizontal axis refers to time.



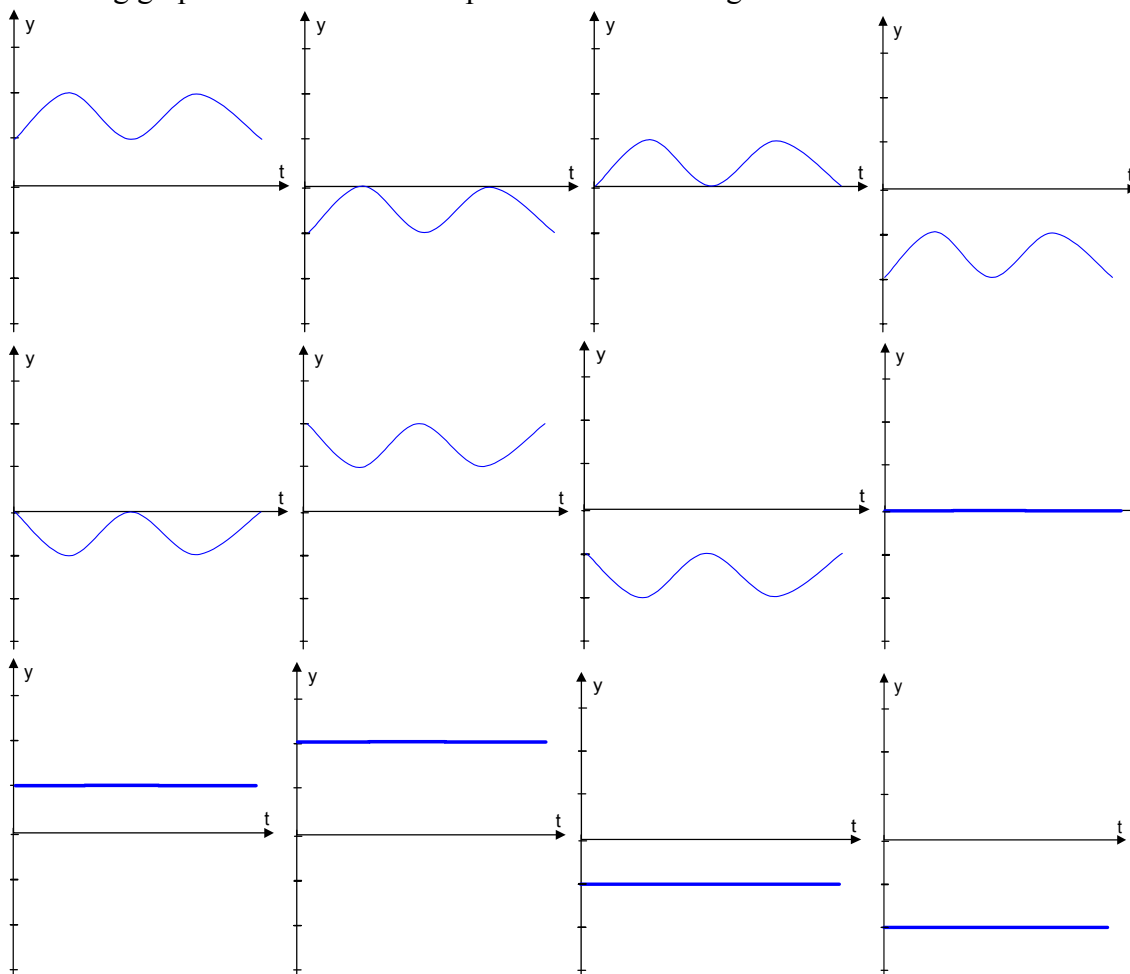
What if these two waves are superposed at a particular location? Circle from among the following graphs the one that corresponds to the resulting wave.



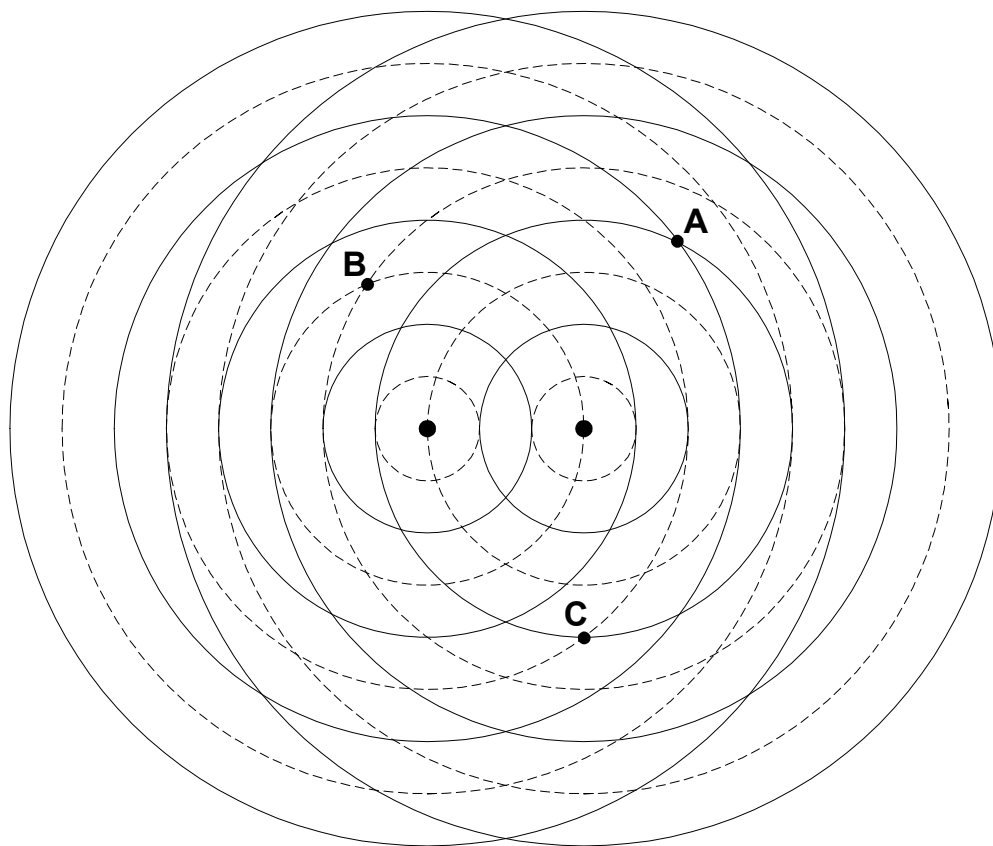
**Question 7:** The waves in the following two graphs are 180 degrees out of phase and that have the same frequency. The vertical axis refers to height and the horizontal axis refers to time.



What if these two waves are superposed at a particular location? Circle from among the following graphs the one that corresponds to the resulting wave.



**Questions 8-13:** The diagram below illustrates the wavefronts due to two small sources in a ripple tank. Assume that both sources produce waves with the same amplitude. The dark circles represent crests; the dashed circles represent troughs. The diagram shows the locations of the wavefronts at one instant in time, as a photograph would.



**Question 8:** How do the frequencies of the two sources in the diagram compare? Circle the correct answer.

- The frequency of the left source is twice that of the right one.
- The frequency of the left source is one half that of the right one.
- The frequency of the left source is the same as the right one.
- None of these answers is correct.

**Question 9:** What can you say about the phases of the sources in the diagram?

- The two sources are in phase.
- The two sources are 180 degrees out of phase with respect to each other.
- The two sources are 90 degrees out of phase with respect to each other.
- None of these answers is correct.

**Question 10:** What is the separation of the sources in the diagram? Express the answer in terms of the wavelength  $\lambda$ .

- (a)  $0.5\lambda$       (b)  $\lambda$       (c)  $1.5\lambda$       (d)  $2\lambda$       (e)  $2.5\lambda$       (f)  $3\lambda$

**Question 11:** Consider point A in the diagram. At the instant the picture was drawn, two crests meet at A. Which of the following statements describes what happens at A where a crest meets a crest? Assume that both sources produce waves with the same amplitude. Note that the amplitude is equal to the height of a crest or the depth of the trough.

- The two waves add together and form a bigger wave whose amplitude is twice the amplitude of either wave.
- The two waves cancel each other out such that the water amplitude at that point is zero (no crest no trough.)
- The two waves form a wave whose amplitude that is smaller than the amplitude of either one of them.
- The two waves form a wave whose amplitude is equal to the amplitude of either wave.
- The two waves add together and form a wave whose amplitude is larger than twice the amplitude of either wave.
- None of these answers.

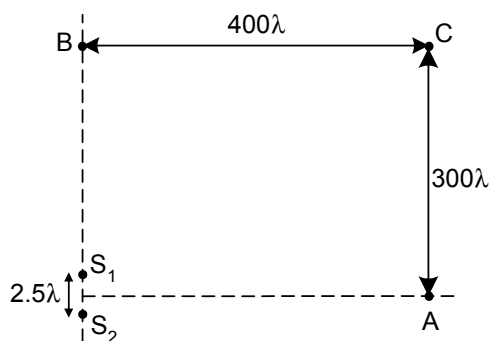
**Question 12:** Consider point B in the diagram. At the instant the picture was drawn, two troughs meet at B. Which of the following statements describes what happens at B where a trough meets a trough? Assume that both sources produce waves with the same amplitude.

- The two waves add together and form a bigger wave whose amplitude is twice the amplitude of either wave.
- The two waves cancel each other out such that the water amplitude at that point is zero (no crest no trough.)
- The two waves form a wave whose amplitude that is smaller than the amplitude of either one of them.
- The two waves form a wave whose amplitude is equal to the amplitude of either wave.
- The two waves add together and form a wave whose amplitude is larger than twice the amplitude of either wave.
- None of these answers.

**Question 13:** Consider point C in the diagram. At the instant the picture was drawn, a trough meets a crest at C. Which of the following statements describes what happens at C where a trough meets a crest? Assume that both sources produce waves with the same amplitude.

- The two waves add together and form a bigger wave whose amplitude is twice the amplitude of either wave.
- The two waves cancel each other out such that the water amplitude at that point is zero (no crest no trough.)
- The two waves form a wave whose amplitude that is smaller than the amplitude of either one of them.
- The two waves form a wave whose amplitude is equal to the amplitude of either wave.
- The two waves add together and form a wave whose amplitude is larger than twice the amplitude of either wave.
- None of these answers.

**Questions 14-15:** Consider the situation depicted in the following diagram.



The two sources produce light waves. The wavelength  $\lambda$  of the light is very small. The diagram is not drawn to scale. The sources  $S_1$  and  $S_2$  produce identical waves. They are separated by a distance  $d=2.5\lambda$ . Point A is a distance of  $400\lambda$  away from the midpoint between the sources and point B is a distance of  $300\lambda$  away from the midpoint between the sources.

We define the path difference of two waves at a particular point (for example point C) as the difference in distance separating the point from either source.

**Question 14:** What is the path difference between the two waves produced by  $S_1$  and  $S_2$  at point A?

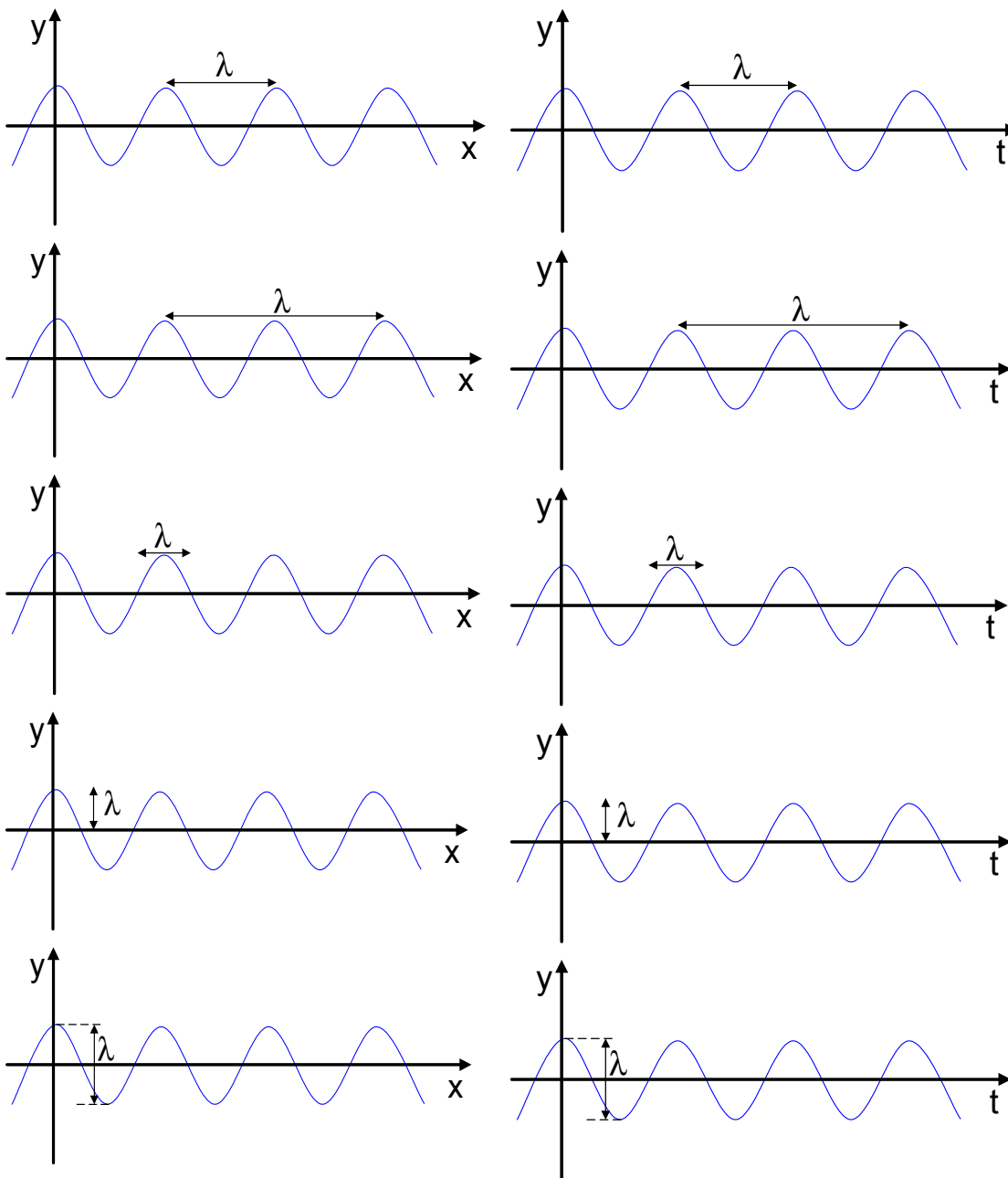
**Question 15:** What is the path difference between the two waves produced by  $S_1$  and  $S_2$  at Point B?

## APPENDIX B

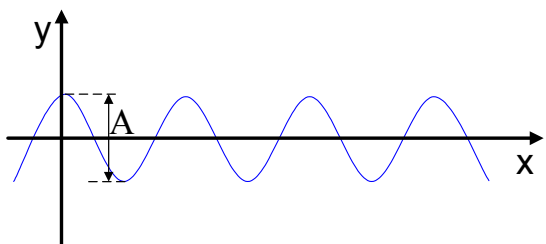
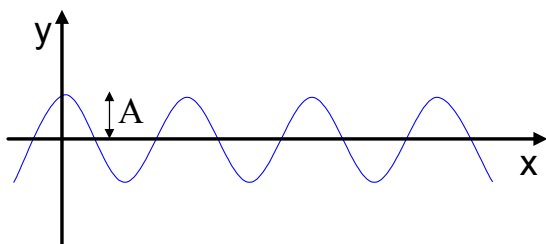
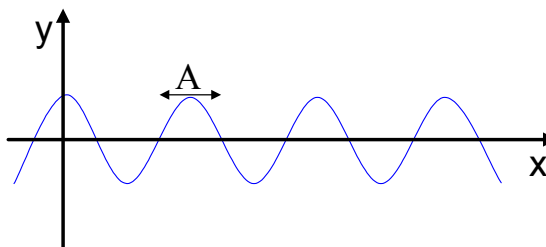
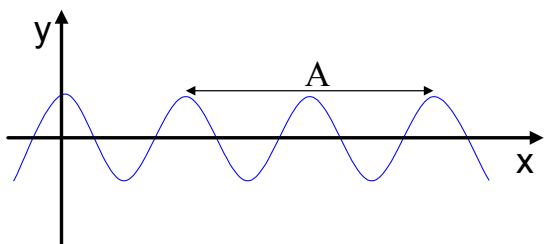
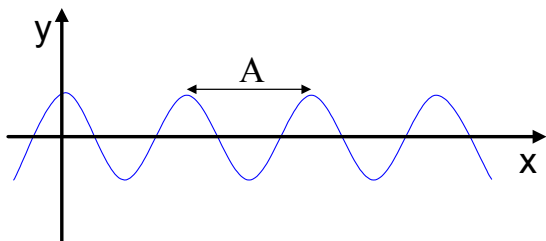
### POST-TEST

Tutorial ID \_\_\_\_\_ Date : \_\_\_\_\_

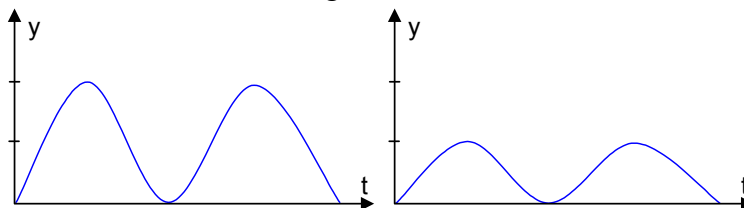
**Question 1:** From the following graphs circle the one that best represents the wavelength of a wave.  $y$  in this case refers to the vertical position,  $x$ , the horizontal position and  $t$  the time. The wavelength is represented by the symbol  $\lambda$ . Note that some graphs use time for the horizontal axis and some use the horizontal position  $x$ .



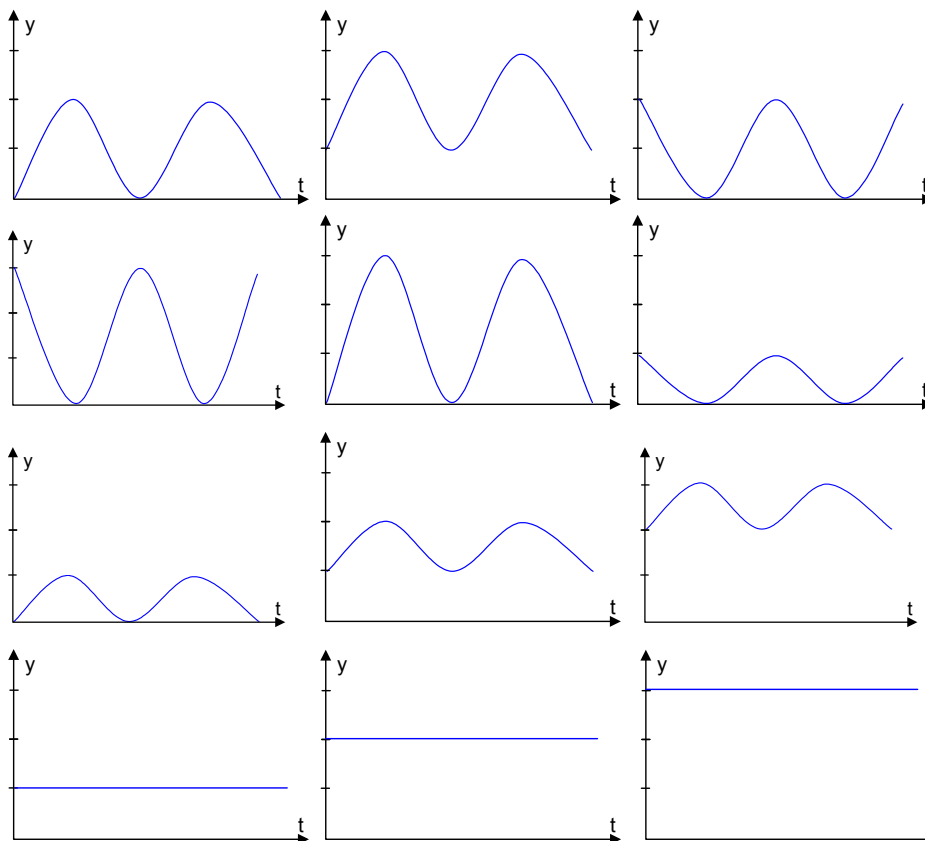
**Question 1:** From the following graphs circle the one that best represents the amplitude of a wave. Y in this case represents the vertical position, x, the horizontal position. The amplitude is represented by the symbol A. Note that the horizontal axis is the horizontal position x.



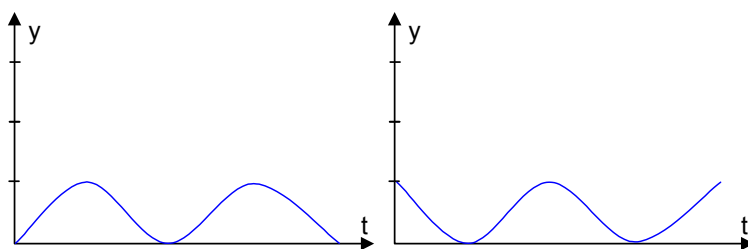
**Question 2:** The waves in the following two graphs are in phase and have the same frequency. The vertical axis refers to height and the horizontal axis refers to time.



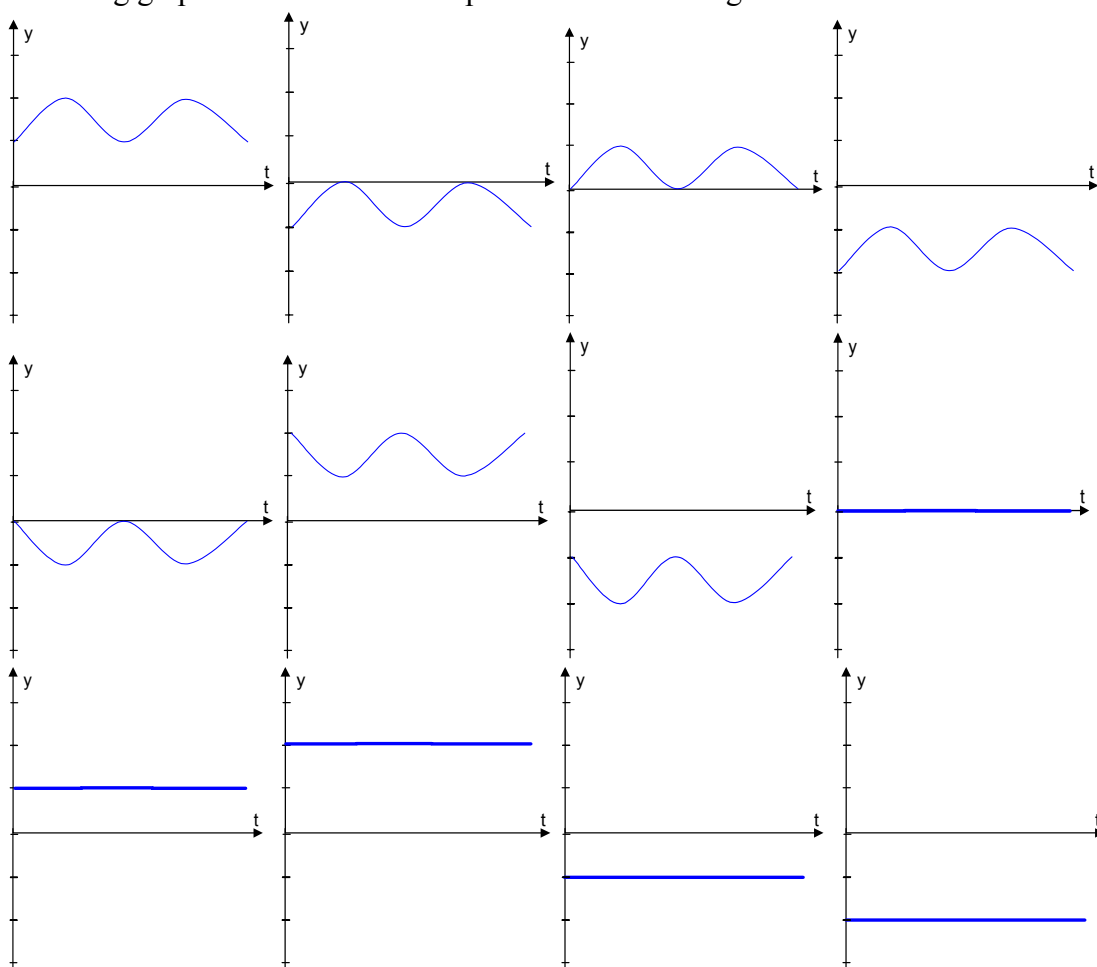
What if these two waves are superposed at a particular location? Circle from among the following graphs the one that corresponds to the resulting wave.



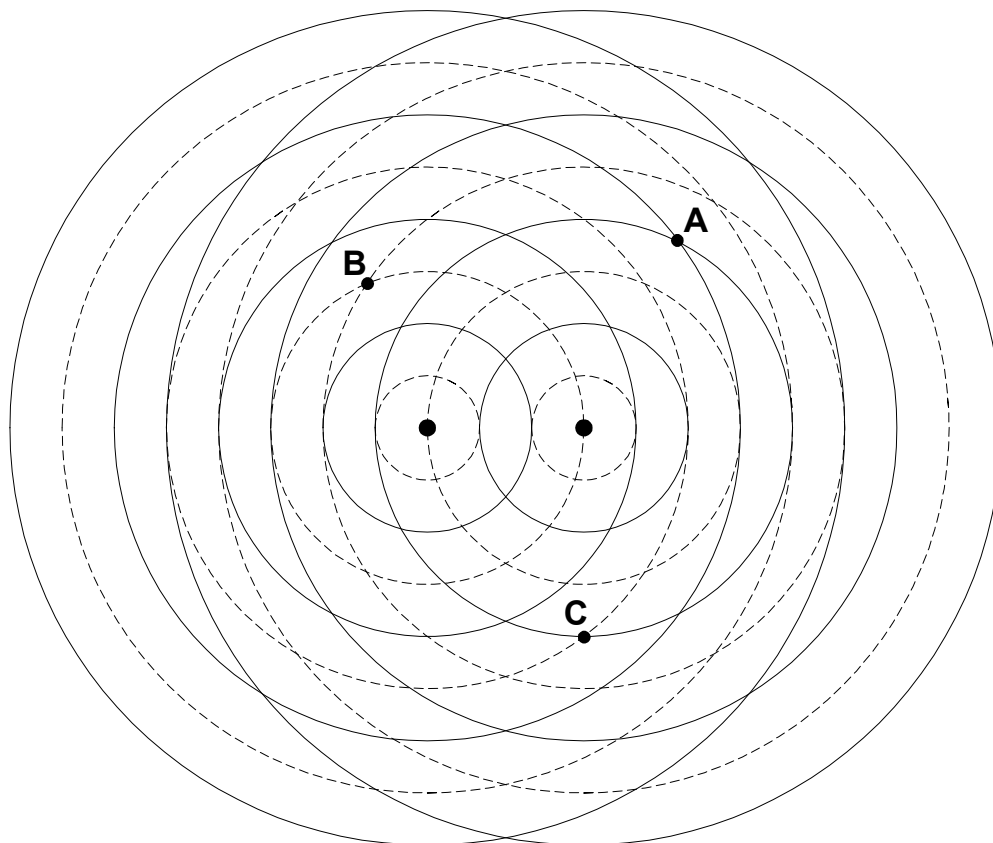
**Question 3:** The waves in the following two graphs are 180 degrees out of phase and that have the same frequency. The vertical axis refers to height and the horizontal axis refers to time.



What if these two waves are superposed at a particular location? Circle from among the following graphs the one that corresponds to the resulting wave.



**Questions 4-9:** The diagram below illustrates the wavefronts due to two small sources in a ripple tank. Assume that both sources produce waves with the same amplitude. The dark circles represent crests; the dashed circles represent troughs. The diagram shows the locations of the wavefronts at one instant in time, as a photograph would.



**Question 4:** How do the frequencies of the two sources in the diagram compare? Circle the correct answer.

- e. The frequency of the left source is twice that of the right one.
- f. The frequency of the left source is one half that of the right one.
- g. The frequency of the left source is the same as the right one.
- h. None of these answers is correct.

**Question 5:** What can you say about the phases of the sources in the diagram?

- e. The two sources are in phase.
- f. The two sources are 180 degrees out of phase with respect to each other.
- g. The two sources are 90 degrees out of phase with respect to each other.
- h. None of these answers is correct.

**Question 6:** What is the separation of the sources in the diagram? Express the answer in terms of the wavelength  $\lambda$ .

- (a)  $0.5\lambda$       (b)  $\lambda$       (c)  $1.5\lambda$       (d)  $2\lambda$       (e)  $2.5\lambda$       (f)  $3\lambda$

**Question 7:** Consider point A in the diagram. At the instant the picture was drawn, two crests meet at A. Which of the following statements describes what happens at A where a crest meets a crest? Assume that both sources produce waves with the same amplitude. Note that the amplitude is equal to the height of a crest or the depth of the trough.

- g. The two waves add together and form a bigger wave whose amplitude is twice the amplitude of either wave.
- h. The two waves cancel each other out such that the water amplitude at that point is zero (no crest no trough.)
- i. The two waves form a wave whose amplitude that is smaller than the amplitude of either one of them.
- j. The two waves form a wave whose amplitude is equal to the amplitude of either wave.
- k. The two waves add together and form a wave whose amplitude is larger than twice the amplitude of either wave.
- l. None of these answers.

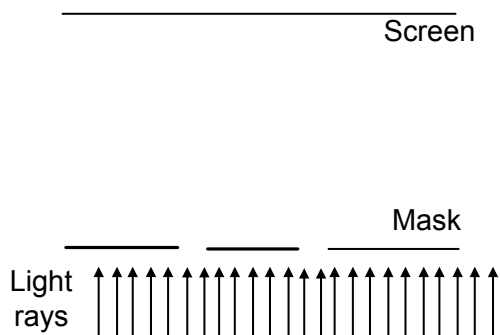
**Question 8:** Consider point B in the diagram. At the instant the picture was drawn, two troughs meet at B. Which of the following statements describes what happens at B where a trough meets a trough? Assume that both sources produce waves with the same amplitude.

- g. The two waves add together and form a bigger wave whose amplitude is twice the amplitude of either wave.
- h. The two waves cancel each other out such that the water amplitude at that point is zero (no crest no trough.)
- i. The two waves form a wave whose amplitude that is smaller than the amplitude of either one of them.
- j. The two waves form a wave whose amplitude is equal to the amplitude of either wave.
- k. The two waves add together and form a wave whose amplitude is larger than twice the amplitude of either wave.
- l. None of these answers.

**Question 9:** Consider point C in the diagram. At the instant the picture was drawn, a trough meets a crest at C. Which of the following statements describes what happens at C where a trough meets a crest? Assume that both sources produce waves with the same amplitude.

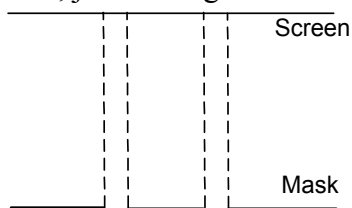
- g. The two waves add together and form a bigger wave whose amplitude is twice the amplitude of either wave.
- h. The two waves cancel each other out such that the water amplitude at that point is zero (no crest no trough.)
- i. The two waves form a wave whose amplitude that is smaller than the amplitude of either one of them.
- j. The two waves form a wave whose amplitude is equal to the amplitude of either wave.
- k. The two waves add together and form a wave whose amplitude is larger than twice the amplitude of either wave.
- l. None of these answers.

**Question 10:** Consider the situation depicted in the Figure:



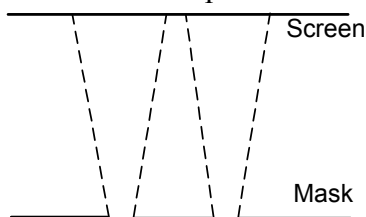
Parallel monochromatic light beams incident on a mask with 2 very narrow slits (for example, slit width = 0.005mm) 0.2mm away from each other and reach an observation screen far away from the mask. Select the answer that explains best what is observed on the screen.

- a. Two bright bands can be seen on the observation screen, they have the same width and shape as the slits, just like figure below.



- b. No light can reach the observation screen, because the slit is so narrow.

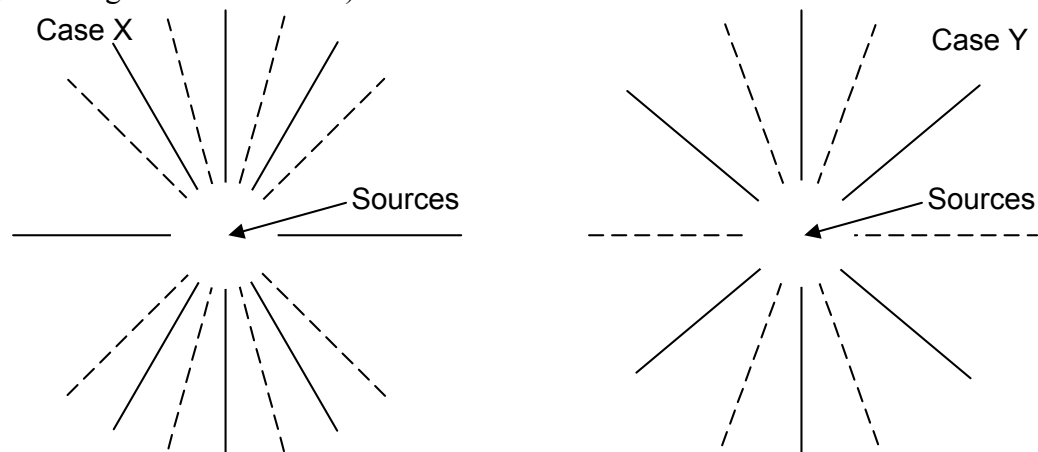
- c. Two bright bands can be seen on the observation screen, they are larger than the slits, because when light passes through a slit, it will expand just like figure below. Their shape is still the same as the shape of the slits.



- d. Some parallel bright and dark bands will be observed on the screen like the ones shown in the following figure.



**Questions 11-12:** Each of the diagrams below shows all the nodal lines (dashed) and all the lines of maximum constructive interference (solid) due to two point sources. The wavelength,  $\lambda$ , and the phase are the same for both sources. The source separation in Case X is different than the source separation in Case Y. (The sources, which are not shown, lie along a horizontal line.)



**Question 11:** For case X, the distance between two sources is:

- (a)  $0.5\lambda$       (b)  $\lambda$       (c)  $1.5\lambda$       (d)  $2\lambda$       (e)  $2.5\lambda$       (f)  $3\lambda$

**Question 12:** In the figures above, for case Y, the distance between two sources is:

- (a)  $0.5\lambda$       (b)  $\lambda$       (c)  $1.5\lambda$       (d)  $2\lambda$       (e)  $2.5\lambda$       (f)  $3\lambda$

**Question 13:** The following Figure shows the interference pattern due to two slits. What will happen if the distance separating the slits is increased?



- The interference pattern stays the same.
- The width of each bright band and dark band will become wider.
- The width of each bright band and dark band will become narrower.
- The width of bright bands will become wider, and the width of dark bands won't change.
- The width of bright bands will become wider, and the width of dark bands will become narrower.
- The width of dark bands will become wider, and the width of bright bands won't change.
- The width of bright bands will become narrower, and the width of dark bands will become wider.

**Question 14:** The following Figure shows the interference pattern due to two slits. The point marked with X mark is at maximum light intensity. Now the 2-slit mask is replaced by a 3-slit mask with the same separation  $d$  between adjacent slits. What will happen to the intensity pattern at point X after the change is made?



- Point X stays a maximum, and it becomes brighter than before.
- Point X stays a maximum, but the intensity of the light stays the same.
- Point X stays a maximum, but the intensity of the light decreases.
- Point X becomes a minimum.
- Point X becomes a secondary maximum.

**Question 15:** The following Figure shows the interference pattern due to two slits. The point marked with X mark is at minimum light intensity. Now the 2-slit mask is replaced by a 3-slit mask with the same separation  $d$  between adjacent slits. What will happen to the intensity pattern at point X after the change is made?

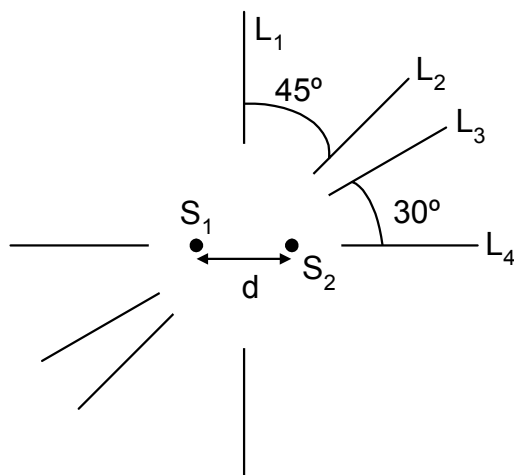


- Point X stays a minimum.
- Point X becomes a maximum.
- Point X becomes a secondary maximum.
- None of these.

**Question 16:** Yellow Light is used to illuminates two closely spaced thin slits and produces an interference pattern on screen behind. How will the distance between the bright fringes of the pattern change when light is changed to purple? (Hint: the wavelength of yellow light is larger than the wavelength of the purple light.)

- a. Distance between the bright fringes decreases. (More fringes will occupy the same screen space.)
- b. Distance between the bright fringes increase. (Less fringes will occupy the same screen space.)
- c. The pattern remains the same; it just changes color.

**Questions 17-18:** The following questions refer to the following diagram.



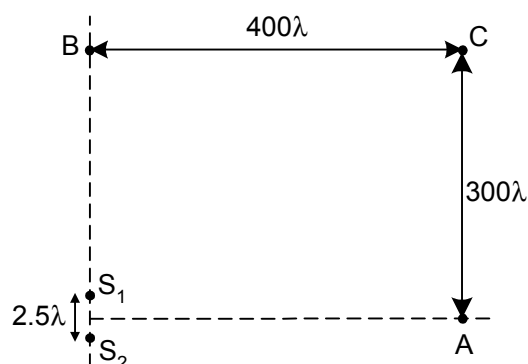
The top view diagram shown below illustrates two point sources,  $S_1$  and  $S_2$  separated by a distance  $d$ . Lines  $L_1$ ,  $L_2$ ,  $L_3$  and  $L_4$  represent positions for which the path difference ( $\Delta D$ ) is the same.

**Question 17:** Which among the following answers corresponds to the largest path difference ( $\Delta D$ )?

- Points on Line  $L_1$
- Points on Line  $L_2$
- Points on Line  $L_3$
- Points on Line  $L_4$  outside two point sources.

**Question 18:** Indicate points for which the value of  $\Delta D$  is smallest.

- Points on Line  $L_1$
- Points on Line  $L_2$
- Points on Line  $L_3$
- Points on Line  $L_4$  outside two point sources.
- Points on Line  $L_4$  inside two point sources.

**Questions 19-20:**

The two sources produce light waves. The wavelength  $\lambda$  of the light is very small. The diagram is not drawn to scale. The sources  $S_1$  and  $S_2$  produce identical waves. They are separated by a distance  $d=2.5\lambda$ . Point A is a distance of  $400\lambda$  away from the midpoint between the sources.

**Question 19:** What is the path difference between the two waves produced by  $S_1$  and  $S_2$  at point A?

**Question 20:** What is the path difference between the two waves produced by  $S_1$  and  $S_2$  at Point B?

**Question 21:** In the figure above, if the path difference at certain point is whole number multiple of  $\lambda$ , it means two waves are in phase at that point, and the interference is constructive, otherwise when the path difference is  $(m+1/2)\lambda$ , with  $m$  an integer, the two waves are 180 degrees out of phase and the interference is destructive (they cancel out each other.) What kind of interference do we have at Points A, B and C respectively?

	Point A	Point B	Point C
a.	Constructive	Constructive	Constructive
b.	Destructive	Constructive	Constructive
c.	Destructive	Destructive	Constructive
d.	Destructive	Destructive	Destructive
e.	Destructive	Destructive	Constructive
f.	Constructive	Destructive	Destructive

**Question 22:** A young's double-slit interference experiment is performed with monochromatic light. The separation between the slits is 0.50 mm, and the interference pattern on a screen 3.3 m away shows the first maximum 3.4 mm from the center of the pattern. What is the wavelength?

APPENDIX C  
IRB APPROVAL FORM



Mississippi State  
UNIVERSITY

October 30, 2001

Qiaowu Li  
Physics  
Mailstop 9538

Re: IRB Docket #01-387 – Assessing the effectiveness of a 3-D interactive environment in facilitating learning in computer-based tutorials.

Dear Qiaowu:

The above referenced project was reviewed and approved via administrative review on October 29, 2001 in accordance with 45 CFR 46.101 b(1). Continuing review is not necessary for this project. However, any modification to the project must be reviewed and approved by the IRB prior to implementation. **Any failure to adhere to the approved protocol could result in suspension or termination of your project.** The IRB reserves the right, at anytime during the project period, to observe you and the additional researchers on this project.

Please refer to your docket number (#01-387) when contacting our office regarding this application.

Thank you for your cooperation and good luck to you in conducting this research project. If you have questions or concerns, please contact me at 325-3994 or at tarwood@research.msstate.edu.

Sincerely yours,

A handwritten signature in cursive script that reads "Tracy S. Arwood".

Tracy S. Arwood  
Regulatory Compliance Officer

CC: Taha Mzoughi  
File

Office for Regulatory Compliance

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