

Lab 5: Modeling the Movement of Ocean Waves

Previous laboratories have explored wave properties using a wave tank (Lab 2) and a mechanical wave machine developed at Bell Laboratories (Lab 3).

In the wave tank lab, when the frequency of the waves matches the resonant frequency of the wave tank, the wave amplitudes of the combined waves were greater than any individual wave. At other frequencies, reflected waves interfered with newly generated waves, resulting in an amplitude of the combined waves that was less than the amplitude of any individual wave.

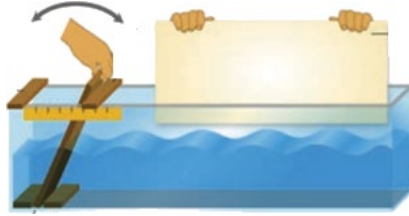


Figure 1. Transmission of a Wave across the Length of the Wave Tank

In the mechanical wave machine, a pulse caused a mechanical wave to ripple down the length of the machine. When a second wave was generated at the moment that the first wave reached the end and began to return, the two waves reinforced one another's amplitude, resulting in a combined wave that was twice the amplitude of the individual waves. At other frequencies, the waves interfered with one another, resulting in a combined wave whose amplitude was smaller than either of the individual waves.

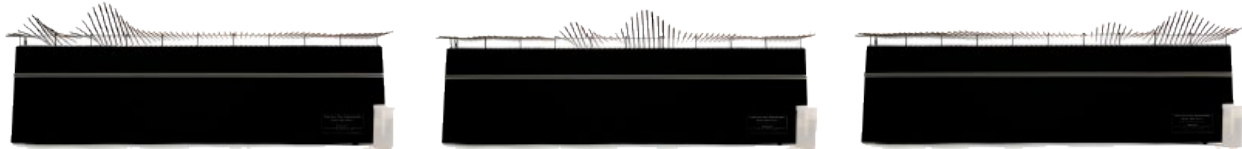


Figure 2. Transmission of a Wave across the Bell Lab Wave Machine

These two laboratories demonstrated that the properties of waves remain the same in both a hydraulic and a mechanical medium – and, by extension, in the acoustic medium of air as well.

Lab 5 is based on a model of a wave that was originally developed by a teacher in Singapore. This model was refined in further development at the University of Virginia.



Figure 3. Singapore Wave Machine

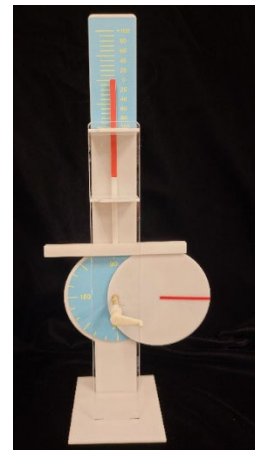
A buoy on top of an ocean wave moves in a circular path as each successive wave passes through the point at which the buoy is located. The disks in the mechanical wave machine recreate this circular path. The rod on top of each disk emulates the rise and fall of the ocean surface as the disk turns. The crucial aspect to note is that the buoy ends up close to the original position at which it began as it completes a full circle.



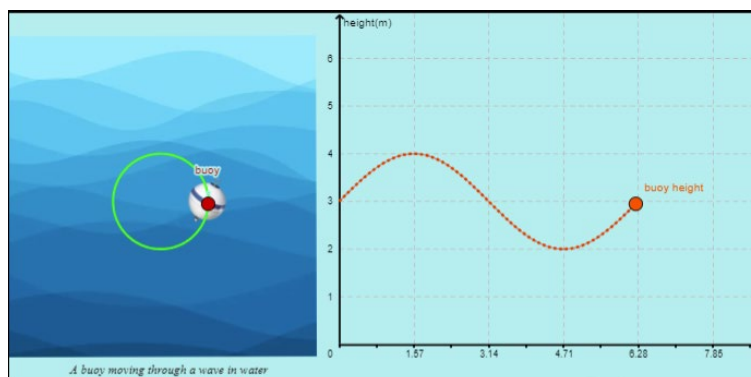
The mechanical model emulates this motion. Because the position of each cam is offset from the one before by 15 degrees, a wave (represented by the blue dots at the top of each rod) traverses the wave machine from left to right as the crank is turned. Although the blue dots at the top of the series of rods emulate the motion of a wave as the central shaft through the disks is turned, each individual rod remains in the same place.

A travelling wave is a function of both space and time. The left-to-right motion of a wave in the wave machine illustrates a wave propagating as a function of time. Distinguishing between a wave as a function of space and a wave as a function of time can be a challenging aspect of understanding wave properties. Physicists use mathematical equations to describe wave functions. However, an understanding of these aspects of waves can also be developed without the use of mathematical formulas. The mechanical model is designed to facilitate development of an intuitive sense of wave characteristics without use of advanced mathematics.

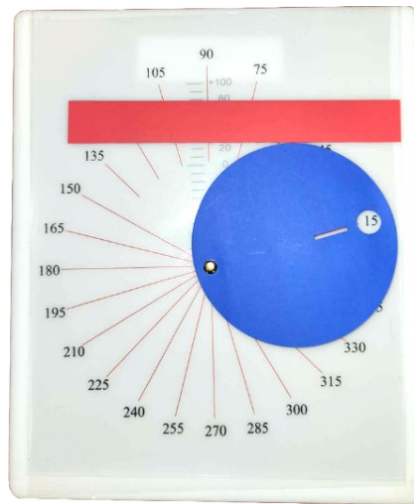
This motion of an individual particle of water in an ocean wave can be easier to understand by focusing on a single segment of the wave machine that has a single disk and a single rod expanded to a larger scale. This 2D wave segment makes it possible to develop a table recording the position of the disk at each point on the circle. The rod is at its maximum height when the disk is pointing straight up (90 degrees). It is at its minimum height when the disk is pointing straight down (270 degrees). It is at the midpoint between the maximum and minimum heights when the disk is pointing to the right (0 degrees) or the left (180 degrees).



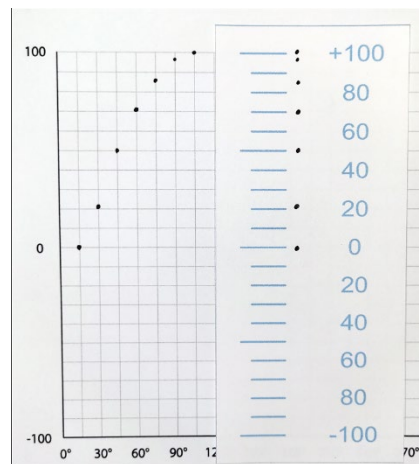
Steven Greenstein, a professor of mathematics at Montclair State University, developed a [wave simulation](#) to illustrate the path created by the movement of the buoy over time.



A two-dimensional version of this model consisting of a disk pivoting around a brad can be used to demonstrate the same result. A straight-edge such as the red bar in the illustration below can be used to record the height of the bar on a strip of paper as the disk is rotated.



The heights recorded in this manner can then be transferred to a paper grid to create a graph of the position of the top of the rotating disk at various points.



This approach to recording the heights through series of marks that are transferred to a graph makes it possible to see the pattern that emerges without use of a mathematical equation or formula. This experience provides scaffolding for further explorations that provide opportunities to develop an intuitive sense of the underlying pattern. This same pattern is found in many natural settings ranging from the movement of a playground swing to the back-and-forth motion of a vibrating guitar string.

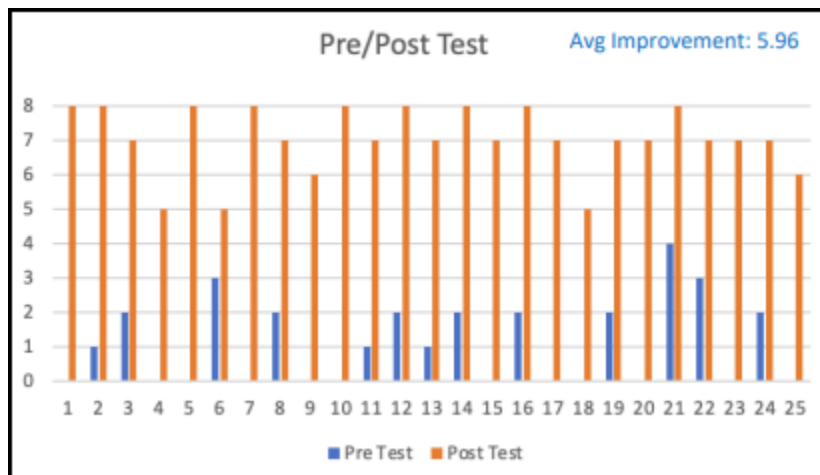
In February 2024 this activity was piloted in seventh-grade classes at Niu Valley Middle School in Hawaii. The relevant Next Generation Science Standards is MS-PS4-1:

MS-PS4-1 Waves and their Applications in Technologies for Information Transfer

This standard includes development of “a simple model for waves” by students. The accompanying explanatory text for the standard includes the following information about developing and using models

in middle school grades: “Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.”

The middle school class piloting the activity improved by an average of 6 points on an 8-point scale after completing the activity.



The teachers piloting the activity reported that it was a significant aid that helped students understand wave properties. Feedback provided by the teachers to improve the activity has been incorporated into this lab.

Summary

A wave is a disturbance which travels through a medium. Waves can consist of acoustic waves that travel through air, mechanical waves that travel through a solid medium such as wood, metal, or earth, electrical waves that travel through electrical circuits, or optical waves transmitted by light. There are many characteristics of waves that are shared across all of these various forms of waves, so an understanding of wave properties in one medium can serve as a foundation for understanding the properties of other types of waves.

Resources

- *Exploring Our Fluid Earth* is a curriculum developed at the University of Hawaii at Manoa. It has an extensive section devoted to waves:

<https://manoa.hawaii.edu/exploringourfluidearth/physical/waves>

- *Acoustics and Vibration Animations* provides an extensive series of visualizations developed by Daniel Russel for the Graduate Program in Acoustics at Pennsylvania State University:

<https://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html>

Appendix

The explorations in the activities developed around the mechanical wave machine and associated extensions (i.e., the *2D Cam Explorer* and the *3D Cam Explorer* developed in the Make to Learn Lab) are designed to be conducted without use of mathematics beyond the middle school level. However, for advanced students who may be interested in exploring further, there are many applications in physics, engineering, and mathematics that are introduced in later grades. For example, light is a wave that propagates in space and time. Its electric field may be expressed by the following equation:

$$\mathbf{E}(x, t) = A \sin(\omega t \pm kx)$$

where A is the amplitude of the wave, ω is the angular frequency, and k is the wave number. If the value of x is held constant, then E oscillates in time as the wave passes by. Alternatively, if the value of t is held constant, E oscillates in space as the value of x changes. There are many other examples of propagating waves that can be similarly expressed, such as the magnetic field of a light wave, the electric or magnetic fields of a wave propagating in a wire, an acoustic wave in air or a solid material, or a surface wave in water.

In high school trigonometry, a sine wave is graphed in space (y versus x) using the following formula:

$$A \sin [B (x + C)] + D$$

where A is amplitude, B is frequency, C is the horizontal shift, and D is the vertical shift. The formula can be used to represent a travelling wave by setting D to zero and by setting C , the horizontal shift, to be a constant times time. In this simplified version, either time or space may be addressed but not both simultaneously.

However, an understanding of the mathematical representation is not required for non-numerical, qualitative explorations that can be used to develop an innate sense of these phenomena. Since waves in water can be seen and observed more readily than acoustic or electromagnetic waves, this provides a useful starting point for hand-on experiences that will scaffold more advanced exercises in later grades.