

'Be the wave'

Concept: Exploring wave phenomena using group activities that allow children to 'be the wave'

Waves are caused by disturbances in the water:

If have swimming pool could throw something in or even get someone to do a manu (if allowed) – watch the waves coming off from the disturbance – see them spread radially and reflect off the sides of the pool – see them interact with reflections from other sides of the pool.

Maybe draw pictures with chalk of what happens at different times?

How to create the biggest wave?

[could we get lots of people in a line on one side of the pool and create a plane wave?]

Wave Speed:

Waves can travel far faster than the water that the wave travels through is moving.

Race the Mexican wave:

Find out the fastest runner in a group. Line the rest of the group up and show them how to do a Mexican Wave (Stand up and raise hands as soon as the person next to you has done this) – If you have rope you can get them to hold the rope – it looks really cool.. Practice the Mexican Wave a few times and then have a race against the fastest person in the group. Can the group beat the runner?

Check out:

<https://www.animations.physics.unsw.edu.au/jw/mexican-wave.htm#wave> This site also has different sorts of waves (transverse, longitudinal etc) and other phenomena

Relationship between amplitude and wave speed – calculate speed of waves for different amplitudes – can we relate the two? (i.e. do smaller amplitude waves travel faster?)

In deep water tsunamis can travel as fast as jet planes but the speed they go depends on the depth of the water - they slow down in shallower water

Shoaling:

As a wave enters shallower water it shoals and increases in height

A line of children holding pieces of rope between each child – spread out children are smaller waves, bunched up children are bigger waves. Start spread out slowly running in a line (maybe just taking big steps) one behind the other and have teachers or markers along the way to tell them when to slow down (smaller steps – possibly eventually heel to toe). As each child reaches a given point they slow down. This will cause the children to bunch up as the children behind catch up with the children in front. This is similar to how tsunami waves shoal (get bigger) as they approach the beach.

Could also relate this to wave length – in open ocean they could be 10s of kilometres but they are much shorter in shallow water.

Radial Vs Plane waves

Radial waves start from one point and spread outwards (like the man in the swimming pool). As they spread out they lose energy.

Same children with ropes but in circle all close together – this is the big wave from the initial disturbance. They all move outwards away from one another at the same speed. They stay in a circle but get further and further away from each other

Same children with ropes but in a line. All move in the same direction (perpendicular to the line). They don't get any further apart or closer together – the wave height stays the same...

Refraction

Have children in a line as a plane wave (either holding hands or holding ropes between each other) but walking toward the edge of the concrete/grass (in the playground say or some other obvious straight line) where they will hit the edge on an angle. When walking on the concrete they take large steps, when walking on the grass they take heel-to-toe steps. This will cause the plane wave to bend around and be more in line with the concrete/grass edge.

Because waves travel more slowly in shallower water, even if they come in at an angle to the coast they will tend to bend around so that they end up coming in more straight on to the beach.

[Note] This is tricky with children as they may have very different leg length. It works better with adults. The other tricky part is ensuring they all step in time. If you had similar heights of children and a sergeant major to keep time you could get it to work.

Reflection

[Not sure whether this would work – open to other suggestions]

Children walking towards line at an angle. Teachers/volunteers (other children?) standing with mirrors on line. As 'wave' approaches the line mirror volunteers stand where children will reach the line and hold up mirror. Wave children look at what they can see in the mirror and when they reach the line they turn around and walk towards that...

Wave guide

[Again not sure whether this one would work but it could be fun to try]

Mark a narrow path (1 m wide say – use chalk to mark?) that is the 'slow lane' Have children as plane wave, the middle child is in the slow lane, the rest on either side and they are all walking along in the same direction as the narrow path. If you are in the slow lane you walk heel to toe, otherwise big steps... What happens to the wave?

Ocean ridges are shallower than all the surrounding ocean so the wave travels more slowly there. These can create 'wave guides' that means that a lot more of the wave energy travels along them. Show bathymetry map with ocean ridges (Norfolk Ridge, Three Kings Ridge, Colville Ridge, Kermadec Ridge) – where will they point the wave energy? Not as important for TK as most of these ridges it hits perpendicular – we could show that too – have students start in line parallel to slow lane and walk 'across' it... They all slow down and then speed up again on the other side but wave stays straight..

Interference

Not sure – perhaps two plane waves walking across one another? When people from both waves are close = bigger wave? Destructive interference would be harder...

Resonance

Swings? Get someone to push other person on swing – when do they need to push? Perhaps time between pushes... Try pushing at other times? What happens? [H&S – need to make sure students don't get hit by swing trying to 'push' out of phase]

Dispersive waves?

Wave groups?

Group speed Vs Celerity

Mexican wave: how fast and how stiff is it?

A Mexican wave or stadium wave is a good example of a **vertically polarised, transverse, travelling wave**. The wave travels in the horizontal direction, the 'particles' whose motion comprises the wave move in a largely vertical direction. The wave direction and the particle motion define the plane of polarisation.

Here we report some measurements done to have a value of speed and stiffness, and investigate a variation polarised in the horizontal plane, and longitudinal waves. A periodic boundary condition was used. This experiment was by no means serious, and cannot be considered a laboratory trial: it was a participation event in [Orientation Week](#) at UNSW in 2010. This page exists to initiate discussion, which can be continued on the [Physics Questions](#) bulletin board.

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Wave speed vs particle speed

It's interesting to compare the speed of the wave itself with the speed of the particles whose collective motion makes up the wave. Anyone who has seen a wave travel around the Sydney Cricket Ground in less than a minute will have deduced that the wave can travel rather faster than the average speed of the 'particles' whose collective motion produces the wave. In this example, the wave made two complete circles in 14 s, while the runner (seen here trailing the pulse) took 20 s. At this stage, the circle of people has a circumference of 40 m and comprises 32 people,

Stiffness

In [Travelling waves II](#), we saw that the speed v of a wave in a stretched string is:

$$v = \sqrt{\frac{T}{\mu}}$$

where T is the tension in the string and the mass per unit length is μ . This specific example demonstrates some general features. Usually, it is possible to write an expression for the speed of a wave like this

$$\text{wave speed} = \sqrt{\frac{\text{restoring property}}{\text{inertial property}}}$$

giving a wave speed of $5.8 \text{ m}\cdot\text{s}^{-1}$. The runner travels an extra 6 m or so, so his speed is $4.6 \text{ m}\cdot\text{s}^{-1}$.

(Photos courtesy John Smith)



There is a restoring property that tends to return displacements to their equilibrium value. For the string, this is the tension T . To get a wave, there must also be something like inertia. Consider the moment when a vibrating guitar string is instantaneously straight. Here, its inertia carries it past equilibrium. For the wave in a stretched string, the inertial term that appears the mass per unit length is μ .

(For sound, the relevant inertial property is the (three dimensional) density ρ , while the restoring property is the atmospheric pressure times a the adiabatic constant γ , which is about 1.4 for air. So the speed of sound is $(\gamma * P_{\text{atmosphere}} / \rho)^{1/2}$.

To extend this to electromagnetic waves, we could say that the electric field has a restoring effect, because electric fields produce forces that tend to move the charges that created the field in a way that reduces the field. The magnetic field has something like an inertial property, because changes in the magnetic field produce electric effects that tend to maintain the magnetic field. So we would write that the speed of an electromagnetic wave should be the square root of the ratio of Coulomb's constant for electricity to Coulomb's constant for magnetism. Here is a [discussion](#) of the speed of light in this context.)

Like the string, the wave here is quasi-one-dimensional. Take an average mass of 70 kg per student and we have a line density of $\mu = 60 \text{ kg}\cdot\text{m}^{-1}$. Rearranging our equation to give

$$\text{restoring property} = (\text{inertial property}) * (\text{wave speed})^2$$

we obtain a 'restoring property' whose value is 2.4 kilonewtons. This is larger than the weight of a typical participant. How do you think it compares with the force required to stand up in order to be part of the wave? What other relevant parameters do you think might be involved in the speed of the wave? For instance, the participants here are seated on the ground, while those in a typical stadium are often on seats. Might this make a difference?

From this photo we could also estimate that the pulse width in this model wave is about 3 m.

Tunnelling: the Members Stand Effect

Stadium waves sometimes exhibit a process analogous to evanescent coupling or quantum tunnelling.

For example, the Sydney Cricket Ground has a section called the Members Stand, to which are admitted only a group of persons whose inertia appears to be higher than average. They do not rise to participate in the wave, possibly because of the weight in their wallets. Nevertheless, the wave seems to 'jump' across the impenetrable barrier, a little like an evanescent wave in optics or quantum tunnelling in, say, nuclear decay or a tunnel diode.

To investigate this, five people, placed consecutively in our sample, sat and pretended to be Members (no further instructions were given). This gave a prohibited region of length 4 m. The time that the wave took to 'jump' this barrier was 2.6 s, giving a notional wave speed of about 1.5 m.s^{-1} .

Polarisation



Here we observe a wave pulse with **horizontal polarisation**. At this stage, the circle had grown to 42 m and contained 41 people, so its line density was about $\mu = 70 \text{ kg.m}^{-1}$. However, a rather fraction of the mass took part in the displacement than was the case for vertical polarisation. Two complete circles now take 14 s, so the wave speed is approximately unchanged, despite the (small) increase in line density with respect to the vertically polarised wave.

$$\text{restoring property} = (\text{inertial property}) * (\text{wave speed})^2$$

we obtain a 'restoring property' whose value is 2.4 kN. Again, it is interesting to compare this with forces involved in displacing and restoring the torsos from and to the equilibrium position.

Longitudinal



For the remaining cases, the circle had accreted two more people to become 44, but retained the length of 42 m, giving an estimated μ of $70 \text{ kg}\cdot\text{m}^{-1}$.

A wave in a string is, like the two waves previously discussed, a transverse wave. [Sound](#), however, is a longitudinal wave: the displacement of air is parallel to the propagation of the sound wave. These two photos show longitudinal wave pulses: compression above and tension below. The average speeds recorded were 4.8 and $3.4 \text{ m}\cdot\text{s}^{-1}$ respectively.



One more experiment (not pictured) had the entire circle hold hands. One of the people then squeezed the hand of his neighbour, who squeezed the hand of her neighbour, etc. This wave travelled at $5.2 \text{ m}\cdot\text{s}^{-1}$.

Finally, we should repeat that the exercise was more for fun than for serious measurement. Some of the new particles joining the medium did not have the same sample preparation (i.e. explanations) as the original sample. This probably had significant effect on the results.