*Physics > Big idea PSL: Sound, light and waves> Topic PSL4: Waves*

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| **Key concept (age 11-14)** |
| **PSL4.2: A wave model of sound** |

**What’s the big idea?**

A big idea in physics is waves because it is the key to explaining how energy can be transferred from one object to another object by radiation, even when the objects are not touching. Waves carry information that can be detected by humans or manufactured detectors. Understanding waves helps us to communicate, explore the universe, and transfer energy to where we want it.

**How does this key concept develop understanding of the big idea?**

This key concept helps to develop the big idea by building on the idea that ‘particles’ in a longitudinal wave move forwards and backwards about a mean position, parallel to the direction of the wave, in order to develop the understanding that longitudinal waves transfer energy, but not substance.

****The conceptual progression starts by checking understanding that the medium through which a sound wave is travelling does not move forward with the wave. It then supports the development of ideas about how particles move in a sound wave in order to propagate the wave. This concept leads to an understanding that amplitude and frequency do not affect the speed of a longitudinal wave, and of why they do affect the rate at which longitudinal waves can transfer energy.

**Using the progression toolkit to support student learning**

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.

**Progression toolkit: A wave model of sound**

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| **Learning focus** | As a sound wave (longitudinal wave) travels it transfers energy, as particles of the medium through which it travels are successively made to vibrate forwards and backwards along the direction in which the wave travels. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Recognise that as a sound wave travels forward, the medium it travels through does not.  **P** | Describe the movement of each ‘particle’ of a longitudinal (sound) wave as the wave moves forward.  **P** | Explain how movement of each ‘particle’ of a longitudinal wave causes a perturbation to move forward. | Compare the speed of sound waves that have a different frequency or loudness to each other and are moving through a common medium. | Compare the energy transferred by sound waves that have a different frequency or loudness to each other and are moving through a common medium. |
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| **Diagnostic questions** | Moving sound | Flame in a sound wave | Longitudinal wave | Faster sound waves | Sound bubble |
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| **Response**  **activities** | Model sound wave | | | School band | Candle in the sound |

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| Key: | | | |
| **P** | Prior understanding from earlier stages of learning |  |  |

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| **Moving sound** | **Flame in a sound wave** | **Longitudinal wave** | **Faster sound waves** | **Sound bubble** |
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| Simple multiple choice | Simple multiple choice | Confidence grid | Two-tier multiple choice | Two-tier multiple choice |
| **Model sound wave** | **School band** | **Candle in the sound** |  |  |
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| Critiquing a representation | Talking heads | Predict, explain, observe, explain |  |  |

**What’s the science story?**

Sound waves in air are described as longitudinal waves. As a sound wave passes through air, the particles vibrate backwards and forwards along the direction in which the wave travels. Placing a candle flame in front of a loudspeaker allows these vibrations to be seen.

The number of pulses produced each second (and hence the number passing any given point as the wave passes) is the frequency of sound. The higher the frequency, the more quickly energy is transferred by the sound wave. Energy also transfers more quickly if each ripple or vibration is larger (has a bigger amplitude).

Neither frequency nor amplitude change the speed of a wave. Speed of a wave depends only on the medium through which the wave is travelling.

**What does the research say?**

The transmission of sound is difficult to understand. It is common for students to think of sound as a material substance that moves from one place to another (Barman, Barman and Miller, 1996). Even at degree level Linder (1992) found that some students thought of sound as a ‘lump’ of material travelling through a passive medium, similar to a surfer on a water wave. In a study of 15- to 16-year-old science students (n=243) Caleon and Subramaniam (2010) found that over 60% thought that as sound moves through a medium, it carries or pushes the particles of the medium forward. The most common misunderstanding was that sound is an entity, passed or carried from particle to particle in a collision-like process.

Finding out exactly what students are thinking about sound can be difficult, as they often label ideas of ‘sound particles’ with scientific terms: sound waves, disturbances, or vibrations. Superficially it can appear that students have a scientific understanding when they do not (Fazio et al., 2008).

The motion of waves is hard for students to understand because waves form from large numbers of small scale events, such as the backwards and forwards movement of air particles in a sound wave. These small scale events are quite different to the form and motion of the wave (Caleon and Subramaniam, 2010). This can be seen clearly when spectators at a sports event stand up and sit down in sequence to produce a *Mexican wave,* which moves around the stadium. A model longitudinal wave can be set up similarly, with students who are standing in a line stepping forwards and backwards in sequence. This process transfers energy through a medium, but without the transfer of any bulk substance.

The speed of a sound wave depends on the properties of the medium it is passing through. It is independent of the wave’s frequency or the size of disturbance (amplitude). In their study Caleon and Subramaniam (2010) also found that a third of students thought sound waves travel faster when the sound is louder. A common reason given was that louder waves have more energy. Whilst louder waves do have more energy, amplitude does not affect the speed of a sound wave in normal conditions.

About a third of students aged 15-16 (n=243) and nearly a third of university students enrolled onto a university physics course (n=92) believed higher pitched sounds travel faster (Caleon and Subramaniam, 2010; Tongchai et al., 2011). This is perhaps because of the experience that when cars approach at a higher speed, the sound that the car makes has a higher pitch, due to the Doppler Effect. In this situation, the sound is not travelling through the air more quickly, instead it is the movement of the car that changes the frequency of sound – and it can only do this because the sound is travelling at a constant speed.

**Guidance notes**

This key concept uses the context of waves to review and build on understanding developed in key concept: PSL1.1 Production and transmission of sound.

The focus in this key concept is the development of a detailed understanding of the movement of particles in the sound wave, rather than the labelling of wave forms and the matching of wave forms to sound waves of different loudness or pitch. In these wave-form diagrams sound waves are represented in the same way as transverse waves, which can introduce or consolidate misunderstanding. Students first need the opportunity to develop and consolidate a good scientific understanding of how sound waves work.

When teaching how sound waves move through the air, we use a simplified model that does not take account of the motion of air particles described by the kinetic theory. Instead we usually describe just the movement between gas particles that results in the forward motion of a wave. This is a step that builds towards a more complete understanding, but it does not answer every question a student might ask. For example, it does not explain why loud sounds travel at the same speed as a quiet sounds; or why high pitch sounds travel at the same speed as sounds with a low pitch. The following explanation goes beyond what your students need to understand at this stage, but it may be helpful in answering these challenging questions:-

As a loudspeaker cone vibrates it moves forwards and backwards. As it moves forward it pushes against the air in front of it and squashes it more closely together into a *compression*. However, the particles in the air are already whizzing around and bumping into each other, because that is what particles in a gas do. They are moving in random directions, at an average speed of several hundred metres per second.

The air particles in the *compression* are closer together than normal - in the forwards and backwards direction. This means that as they whizz about, they are more likely to have collisions with those particles either behind or in front of them. These collisions push the particles in a compression apart - both forwards and backwards. The particles moving forward hit further air particles and push these forward in turn. The air in front of the initial compression now becomes squashed and the *compression* moves forward.

Individual particles in the moving (longitudinal) wave move repeatedly forwards and backwards as compressions move forward. Common sense may suggest that individual particles move backwards and forwards between one compression and the next, but this is not the case. Particles of air collide and bounce off each other (very roughly) every 0.000 000 1 metre, and the distance between two compressions of a typical sound wave is about one metre. Instead, the distance air particles move is determined by the amplitude of the initial vibration, and vibrations tend to be very small indeed.

An analogy that can be used to understand how particles in a sound wave move is a disco full of teenagers, dancing and bumping into each other. A wall of the room moves in and out to model the cone of a loudspeaker. As the wall moves in it squashes teenagers together in a compression, and then it moves back. The teenagers in the compression bump into each other more than usual and are pushed both back in to the space left by the wall as it moves back, and further into the room where they cause a further squash, or compression. This repeats and the compression moves across the room. The teenagers move forwards and backwards, and the speed at which the compression moves depends *only* on how quickly the teenagers are dancing and bumping into each other. The depth of the compression is relative to the amount that the wall moves in, as is the distance that each teenager moves forwards and backwards.

The speed of a sound wave is not determined by frequency of the compressions, but by how quickly the particles are ‘normally’ whizzing about and colliding with each other. When a sound is made that is louder, the number of particles in the compression is greater (more particles are pushed into the compression by the bigger vibration), individual particles move forwards and backwards a greater distance, but the compressions still move forward at the same speed.

**References**

Barman, C. R., Barman, N. S. and Miller, J. A. (1996). Two teaching methods and students' understanding of sound. *School Science and Mathematics,* 96(2)**,** 63-67.

Caleon, I. and Subramaniam, R. (2010). Development and Application of a Three-Tier Diagnostic Test to Assess Secondary Students' Understanding of Waves. *International Journal of Science Education,* 32:7**,** 939-961.

Fazio, C., et al. (2008). Modelling Mechanical Wave Propogation: Guidelines and experimentation of a teaching-learning sequence. *International Journal of Science Education,* 30:11**,** 1491-1530.

Linder, C. J. (1992). Understanding sound:so what is the problem? *Physics Education,* 27**,** 258-264.

Tongchai, A., et al. (2011). Consistency of students' conceptions of wave propogation: Findings from a conceptual survey in mechanical waves. *Physical Review Special Topics Physics Education Research,* 7(2)**,** 11.