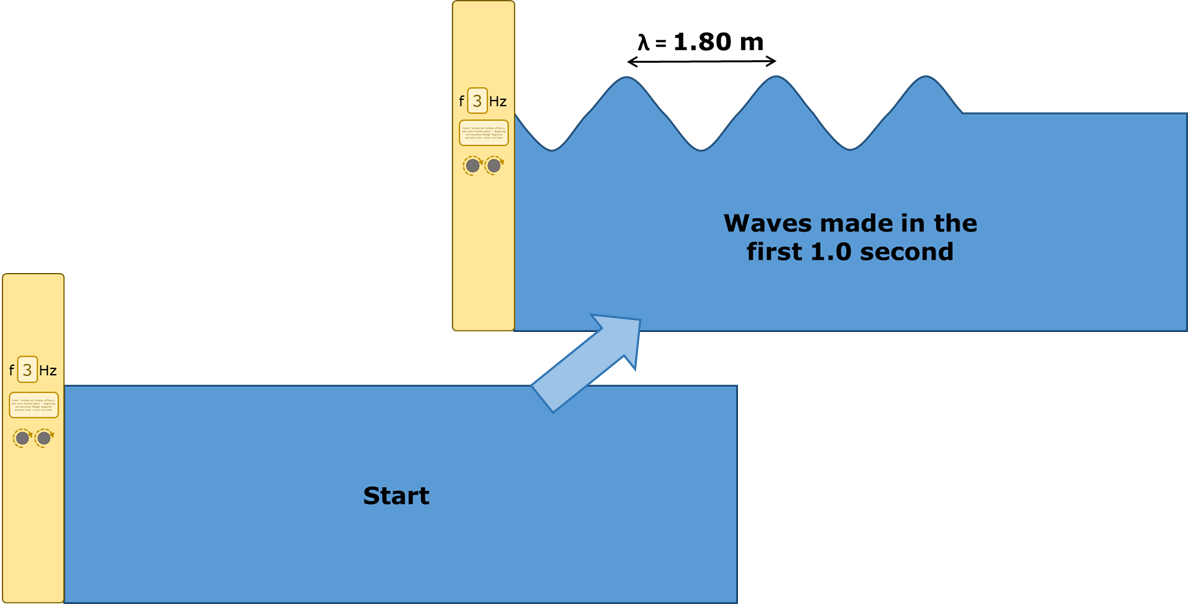
**A wave equation**

A wave machine is used to make a wave in a long tank of water.

A camera takes a photograph automatically after one second.

The frequency is changed from three waves per second (3Hz) to two waves per second (2Hz).

**a.** At a frequency of 2Hz, what is the wavelength (λ) of each wave?

*Put a tick (✓) in the box next to the best answer.*

|  |  |  |
| --- | --- | --- |
| **A** | Wavelength, λ = 1.20m |  |
|  |  |  |
| **B** | Wavelength, λ = 1.80m |  |
|  |  |  |
| **C** | Wavelength, λ = 2.40m |  |

**b.** Which of these ideas did you use to work out your last answer?

*Put a tick (✓) in the box next to the best answer.*

|  |  |  |
| --- | --- | --- |
| **A** | The wave’s shape depends only on the **wave medium**. |  |
|  |  |  |
| **B** | The wave’s speed depends only on the **wave medium**. |  |
|  |  |  |
| **C** | The wave’s speed is changed by the frequency of the wave. |  |

*Physics > Big idea PSL: Sound, light and waves > Topic PSL5: Measuring waves > Key concept PSL5.2: Speed of waves*

|  |
| --- |
| **Diagnostic question** |
| **A wave equation** |

**Overview**

|  |  |
| --- | --- |
| Learning focus: | The speed of a wave is determined by the wave medium in which it moves and can be calculated by multiplying its frequency and wavelength. |
| Observable learning outcome: | Explain why the speed of a wave is v = f x λ. |
| Question type: | Two-tier multiple choice |
| Key words: | Frequency, wavelength, wave medium |

**What does the research say?**

The speed of a mechanical wave depends on the properties of the medium it is passing through and is independent of the wave’s frequency or the size of disturbance (amplitude). In a study of (n=598) students aged 15 to 16, Caleon and Subramaniam (2010) found that over 70% held the common misunderstanding that wave speed depends on frequency. Studies by Tongchai et al (2011) of (n=324) senior high school students, Wittmann, Steinberg and Redish (1999) of (n=92) students enrolled onto a university physics course and Tumanggor et al (2020) of trainee physics teachers (n=35) all found similar results.

Caleon and Subramaniam (2010) also found that it is common for students (72% in their study) to consider the terms in the equation for the speed of a wave, v = f x λ, to be three inter-dependent variables. This is wrong, as the speed, v, of the wave is fixed by the wave medium and is independent of frequency, f, and wavelength, λ. In other words, changes to frequency and wavelength do not affect the speed of a wave.

To help consolidate understanding that the speed of a wave is independent of frequency and wavelength, Caleon and Subramaniam (2010) suggest developing a qualitative understanding of the equation v = f x λ first, before using it to calculate quantitative values. This approach supports students in understanding the physical meaning of each term and the relationships between them. It also helps move the analysis of a problem beyond a ‘brittle rote procedure’ and can promote insights that may simplify some more challenging problems (Redish and Kuo, 2015).

The context for this diagnostic question is deliberately one that students are unlikely to be familiar with. In part, this question is designed to check whether their understanding, that the speed of a wave depends only on the medium, is robust.

Students should be encouraged to explain why the speed of a wave is v = f x λ in response to this diagnostic question.

**Ways to use this question**

Students should complete the questions individually. This could be a pencil and paper exercise, or you could use an electronic ‘voting system’ or mini white boards and the PowerPoint presentation. The follow on question will give you insights into how they are thinking and highlight specific misconceptions that some may hold.

If there is a range of answers, you may choose to respond through structured class discussion. Ask one student to explain why they gave the answer they did; ask another student to explain why they agree with them; ask another to explain why they disagree, and so on. This sort of discussion gives students the opportunity to explore their thinking and for you to really understand their learning needs.

*Differentiation*

You may choose to read the questions to the class, so that everyone can focus on the science. In some situations it may be more appropriate for a teaching assistant to read for one or two students.

**Expected answers**

a. C b. B

**How to respond - what next?**

The speed of wave is dependent on the wave medium (the water), but not the frequency or wavelength of the wave. Both waves will move forward at the same speed, which means two wavelengths of the 2Hz wave will have the same total length as three wavelengths of the 3Hz wave.

Speed can be worked out by multiplying the number of waves passing a point in one second by the length of one wave. Speed however is not *determined* by frequency times wavelength.

Students who understand that different waves moving through the same wave medium all have the same speed are likely to realise that the wavelength of the 2Hz wave is longer than that of the 3Hz wave.

In several studies, around 70% of students were found to believe wrongly that changing the frequency alters the speed of a wave. In this question, these students may imagine the same shape of wave forms for both waves, and select option B in *part a* and either reason A or C in *part b*.

Students choosing option A for *part a* are probably treating frequency and wavelength wrongly as variables that are directly proportional to each other.

If students have misunderstandings about explaining why the wavelength of the 2Hz wave changes as it does, it is likely that they have an uncertain grasp of the equation v = f x λ, which may involve treating speed as a variable.

It can help to clarify their understanding by guiding them through the following three steps. Often, in text books, just the first step is covered overtly.

First, consider how the speed of a wave can be calculated from measurements of its wavelength and frequency. Perhaps ask a succession of questions about waves moving through water: starting with - how many metres a wave with a wavelength of 2m travels if there are three waves per second? (6m/s); and asking increasing complex questions whilst at the same time gradually introducing scientific terminology. A later question might be – what is the speed of a wave in m/s that has a wavelength of 150 cm and a frequency of 12 Hertz? This line of questioning should elicit understanding of why the equation v = f x λ can be used to calculate speed.

The second step is to challenge the validity of the answers to the questions in step one. Challenge students to explain whether or not it is possible for all of the different speeds of wave to be measured in the same water. Careful questioning should elicit the understanding that the wave speed depends only on the properties of the wave medium. And that although it can be calculated using v = f x λ, a change in either frequency or wavelength does not change the speed of the wave. Instead, it changes the wavelength or frequency of the wave, respectively.

Step three is to explore the proportional relationships operating within v = f x λ. This is tackled in the next step of the BEST conceptual progression *PSL5.2 Speed of waves*, from which this question is taken.

The following BEST ‘response activity’ could be used in follow-up to this diagnostic question:

* Response activity: Measuring wave frequency

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Images: Peter Fairhurst (UYSEG).

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