Intervention: Concept Maps for Improving Conceptual Understanding of Progressive Waves

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Introduction

The topic of **Progressive Waves** is a key component in the Malaysian Matriculation Physics syllabus (SP015), encompassing wave phenomena in stretched strings, closed-end air columns, and open-end air columns. These subtopics are foundational for understanding resonance, wave speed, and harmonics—concepts with applications in musical instruments, acoustic design, and wave-based technologies.

Background and Rationale

Despite the visual nature of waveforms, many students struggle with abstract wave properties such as phase difference, standing wave formation, and the relationships between wavelength, frequency, and harmonics in various media. Diagnostic assessments revealed common misconceptions:

- Confusion between nodes and antinodes.
- Difficulty in applying the harmonic series formulae for open and closed tubes.
- Misunderstanding how boundary conditions influence wave patterns.

According to constructivist learning theory, students build new understanding based on prior knowledge. However, when prior concepts are incomplete or incorrect, misconceptions can persist. Concept maps are known to facilitate meaningful learning by explicitly linking concepts and encouraging students to organize knowledge hierarchically and relationally. Hence, a concept mapping intervention was implemented to support conceptual reorganization.

Methodology

Four Malaysian Matriculation students participated in this targeted intervention over two 60-minute sessions. The intervention included:

1. A pre-test with five structured questions (20 marks total).
2. A 45-minute group session on drawing and analyzing concept maps for each subtopic.
3. Guided discussion using a teacher-prepared "expert map" to address gaps.
4. A post-test with the same format and difficulty as the pre-test.

Scoring breakdown:

- 1 mark for correct identification of formula or physical relationship.
- 1 mark for correct numerical substitution.
- 2 marks for correct final answer with units and interpretation.

Resources Used:

- Concept mapping template
- Guided slides with wave diagrams and resonance models
- Real-world applications (e.g., musical instruments, tuning forks, oscilloscopes)

Results, Analysis and Discussion

Table 1: Student Scores and Normalized Gains

Student	Pre-Test Score (/20)	Post-Test Score (/20)	Normalized Gain
A	8	16	0.67
B	9	17	0.73
C	7	15	0.67
D	6	14	0.67

$$\text{Normalized Gain } g = \frac{\text{Post - Pre}}{20 - \text{Pre}}$$

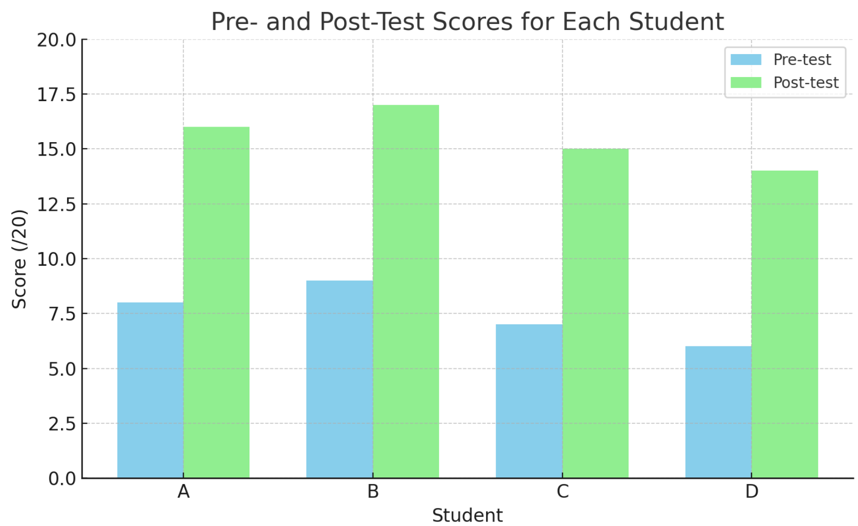

Figure 1: Pre- and Post-Test Scores for Each Student

The average normalized gain was **0.685**, indicating high learning efficacy. The concept mapping task helped students consolidate multiple abstract ideas into a coherent mental model. For example, all students were able to correctly relate the wavelength to tube length depending on the boundary condition (open or closed). Errors in identifying harmonic patterns decreased significantly.

The peer discussion during the mapping phase also revealed and corrected semantic misunderstandings (e.g., confusing "frequency" with "harmonic number"). The intervention also encouraged metacognitive reflection, as students had to explain and justify map connections.

Conclusion

This small-group intervention shows that integrating concept maps into physics instruction can substantially improve students' conceptual clarity and application accuracy, particularly in multi-representational topics like progressive waves. The combination of visual mapping, peer explanation, and immediate feedback fostered deeper learning. This method is replicable for other abstract topics and suitable for integration into collaborative learning modules.

Appendix A: Sample Pre-/Post-Test Questions

1. A string of length 1.2 m fixed at both ends vibrates in its third harmonic. Calculate the wavelength and frequency if the wave speed is 240 m/s.
2. An open pipe resonates at its fundamental frequency with a wavelength of 0.8 m. Calculate the length of the pipe.
3. A closed pipe resonates at its third harmonic. Its length is 0.25 m. Calculate the frequency if the speed of sound is 340 m/s.
4. Explain the difference in node-antinode pattern between closed and open pipes.
5. Sketch the standing wave pattern for the second harmonic in an open-open pipe.

Appendix B: Marking Scheme with Step-by-step Solutions

Q1: A string of length 1.2 m fixed at both ends vibrates in its third harmonic. Calculate the wavelength and frequency if the wave speed is 240 m/s.
Solution:
Third harmonic $\Rightarrow$ number of loops = 3
Wavelength $\lambda = \frac{2L}{n} = \frac{2\times1.2}{3} = 0.8$ m (2 marks)
Frequency $f = \frac{v}{\lambda} = \frac{240}{0.8} = 300$ Hz (2 marks)

Q2: An open pipe resonates at its fundamental frequency with a wavelength of 0.8 m. Calculate the length of the pipe.
Solution:
Open pipe (both ends open), fundamental mode: $L = \frac{\lambda}{2} = \frac{0.8}{2} = 0.4$ m (4 marks)

Q3: A closed pipe resonates at its third harmonic. Its length is 0.25 m. Calculate the frequency if the speed of sound is 340 m/s.
Solution:
Closed pipe only supports odd harmonics.
$n = 3 \Rightarrow \lambda = \frac{4L}{n} = \frac{4\times0.25}{3} = \frac{1}{3} \approx 0.333$ m (2 marks)
$f = \frac{v}{\lambda} = \frac{340}{0.333} \approx 1020$ Hz (2 marks)

Q4: Explain the difference in node-antinode pattern between closed and open pipes.
Sample Answer:
An open pipe has antinodes at both ends, forming complete loops for each harmonic.
A closed pipe has a node at the closed end and an antinode at the open end, supporting only odd harmonics.
(2 marks for each correct distinction, total 4 marks)

Q5: Sketch the standing wave pattern for the second harmonic in an open-open pipe.
Marking criteria:

- Correct labeling of open ends (antinode–antinode) (1 mark)
- Correct number of nodes (1 node between two antinodes) (1 mark)
- Accurate sinusoidal shape over the length of the pipe (1 full wavelength) (1 mark)
- Clear, labeled axes or wave structure (1 mark)

Total: (4 marks)

Appendix C: Concept Map Example (Student B)

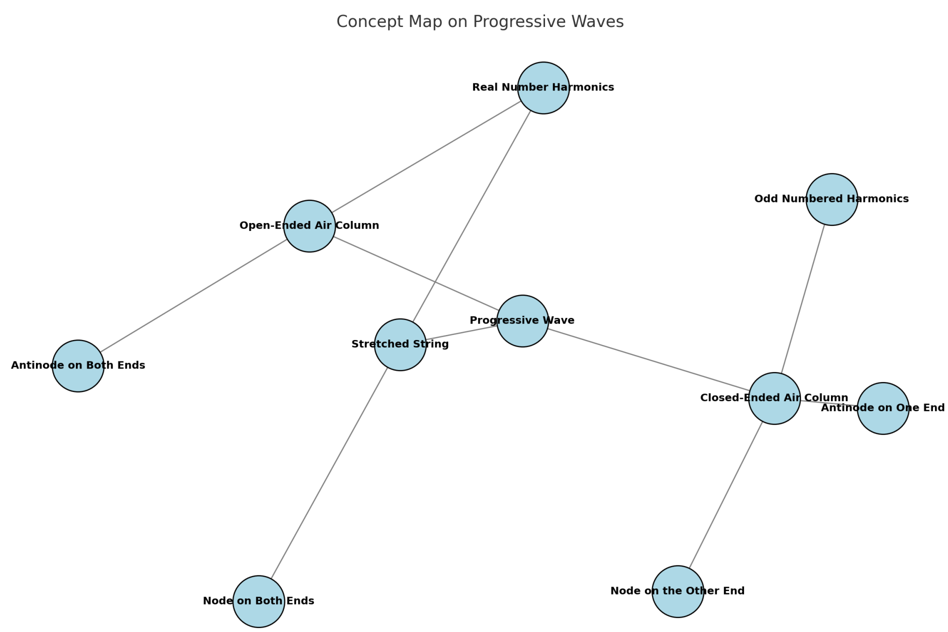

Figure 2: Annotated Concept Map on Progressive Waves (Student B)

Appendix D: Teaching Tool Summary

The concept map framework required students to define, relate, and organize:

- Wave properties (frequency, wavelength, amplitude)
- Resonance conditions for strings and pipes
- Harmonic rules (even/odd restrictions, node-antinode alternations)

Maps were color-coded to differentiate concepts (e.g., wave properties vs. boundary conditions), improving visual clarity.