Intervention: Teaching Odd Harmonics

By Shafiq R

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Teaching Odd Harmonics: A Study on Closed-End Tube Resonance

Shafiq Rasulan

Introduction

Understanding the concept of standing waves in closed one-ended tubes is critical for students studying wave phenomena in physics. This topic combines principles of resonance, harmonics, and boundary conditions, which many students find conceptually and mathematically challenging. This intervention was designed to address common misconceptions and strengthen conceptual understanding through guided inquiry, visual aids, and problem-solving practice. The following document outlines the context, implementation, and outcomes of this instructional intervention.

Theoretical Framework

The theoretical foundation for this intervention draws from **constructivist learning theory**, which posits that students build new knowledge upon their existing conceptual frameworks through active engagement and reflection. In physics education, particularly in wave mechanics, misconceptions often arise from abstract representations and idealized conditions that differ from everyday experiences.

This study also references **the cognitive conflict approach**, wherein students confront discrepancies between their preconceived notions and observed phenomena—in this case, through simulation and demonstration. By engaging students in inquiry-based learning and promoting visual and conceptual congruence between models and observations, the intervention supports conceptual change and deeper understanding.

The principles of harmonic motion, boundary conditions, and wave superposition underlie the physics content itself. The standing wave patterns in closed one-ended tubes obey discrete conditions derived from wave theory, where displacement nodes and antinodes form at fixed positions due to the interference of incident and reflected waves. These physical principles guided the development of learning materials and assessment tasks.

Context and Rationale

A diagnostic quiz revealed that a significant portion of students struggled with identifying the fundamental frequency and higher harmonics in a closed one-ended tube. Several exhibited confusion between open and closed tube boundary conditions, particularly with regards to the formation of nodes and antinodes. Others misapplied formulas derived for open tubes or strings.

This intervention was implemented over two sessions within a 45-minute weekly physics class. The target group comprised four students aged 18 to 19, all enrolled in a Sarawak Matriculation College. While students varied in their mathematical background, most had completed introductory lessons on sound waves and wave equations.

Instructional Design

The instructional sequence began with a brief review of standing waves and resonance. This was followed by a visual demonstration using a resonance tube and a tuning fork to show the formation of a node at the closed end and an antinode at the open end. A slow-motion video showing the vibration pattern was projected and annotated live during the explanation.

To further reinforce the concept, we used the interactive oPhysics simulation (titled "Standing Waves in Air Columns (continued)") to show wave behavior in closed tubes. The simulation visually depicts the incident and reflected waves, and how standing waves form when resonance conditions are met. Students were able to vary the tube length and observe how only odd harmonics produced standing waves, strengthening their understanding of why even harmonics do not form in closed one-ended tubes.

Students worked in pairs on a guided worksheet involving:

- sketching standing wave patterns for the first three harmonics,
- deriving the relationship $f_n = n\frac{v}{4L}$ for $n = 1, 3, 5, \ldots$, and
- applying it to solve problems related to resonance frequency.

Real-life applications were introduced through musical instruments such as clarinets and some organ pipes. Students discussed how the physical structure of these instruments influences the harmonic content they produce.

Observed Challenges and Responses

During the simulation and worksheet tasks, the following challenges were observed:

- **Boundary Misinterpretation:** One student attempted to draw a standing wave with nodes at both ends, misunderstanding the boundary condition of the closed end. This was addressed by revisiting the simulation and pausing at points to identify pressure nodes and displacement antinodes.
- **Formula Misapplication:** Two students mistakenly used $f_n = n\frac{v}{2L}$ instead of $f_n = n\frac{v}{4L}$. We clarified this during group discussion by showing how wave patterns in the simulation aligned with the quarter-wavelength rule.
- **Mode Number Confusion:** One student was confused about why the second harmonic does not exist. A sketch comparing open-open and closed-open tubes helped resolve this.

The teacher also facilitated small group discussions to ensure peer explanations and clarify doubts collaboratively.

Assessment and Outcomes

A pre- and post-intervention test was administered consisting of three tasks:

1. Drawing the first three standing wave patterns for a closed tube,
2. Calculating the third harmonic frequency for a given tube length and speed of sound,
3. Explaining why only odd harmonics occur in such systems.

Student Performance (Score out of 10):

Student	Pre-Test	Post-Test	Improvement
A	4	9	+5
B	5	8	+3
C	3	7	+4
D	6	9	+3

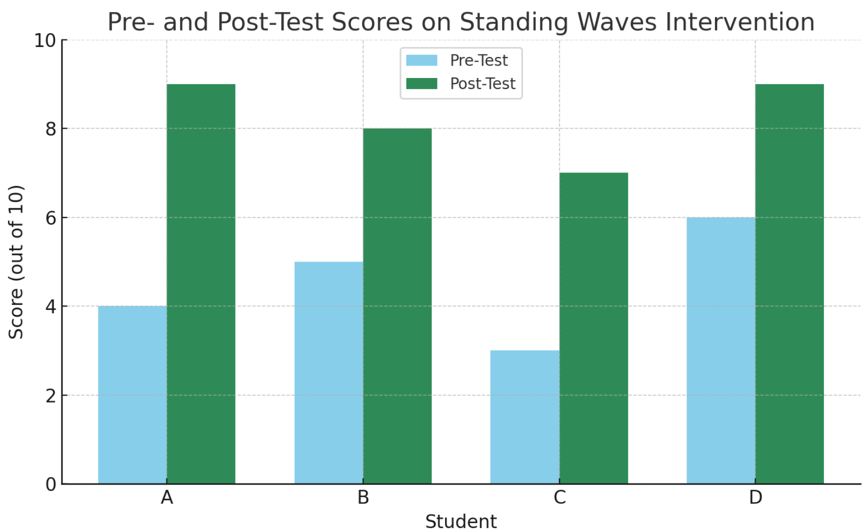

Figure 1: Improvement in test scores after intervention on standing waves in a closed one-ended tube.

Overall, student understanding significantly improved. The average score increased from 4.5 to 8.25. Students were better able to articulate the effect of boundary conditions on harmonic formation and showed more confidence in identifying valid standing wave configurations.

Reflection and Recommendations

This intervention demonstrated that combining visual, kinesthetic, and discussion-based learning strategies is effective in improving understanding of standing waves in closed tubes. Future interventions could incorporate interactive simulations or real-time graphing of pressure and displacement to enhance learning further.

It is recommended that similar diagnostic checks be used prior to instruction on topics involving wave patterns and resonance. Misconceptions are often rooted in visual misunderstanding, and thus physical demonstrations remain a crucial pedagogical tool.

Discussion

The improvement in student performance suggests that the intervention was effective in addressing core misconceptions related to standing waves in closed one-ended tubes. From a theoretical standpoint, the constructivist framework supported the learning design by encouraging students to reconstruct their understanding through active manipulation, visualization, and reflection.

Students' ability to correctly sketch standing wave patterns and apply the $f_n = n\frac{v}{4L}$ formula with odd values of n indicates that they internalized the boundary condition constraints. This aligns with the predictions of the cognitive conflict model, as students revised prior inaccurate notions—such as the applicability of even harmonics—through simulated and real demonstrations.

The post-test scores show both conceptual and computational gains. However, some residual difficulties in articulating why even harmonics are not supported suggest that further reinforcement may be needed in future iterations. It is also notable that gains varied slightly between students, possibly due to differences in spatial reasoning or prior exposure to wave phenomena.

Overall, the results affirm that combining visual, kinesthetic, and collaborative learning strategies can enhance understanding of resonance in closed tubes. The instructional model also offers a scalable template for similar physics topics where abstract principles and real-world applications intersect.

Pre & Post Test Questions and Marking Scheme

The diagnostic assessment consisted of three questions designed to evaluate students' conceptual and computational understanding of standing waves in a closed one-ended tube. Each question was worth 4 marks, divided into 2 marks for correct substitution of values and 2 marks for the correct final answer. The total score was out of 12.

Question 1: Sketching Harmonics

Question: Sketch the standing wave patterns for the first, third, and fifth harmonics in a closed one-ended tube. Label nodes (N) and antinodes (A).

Marking Scheme:

- 1 mark for each correct sketch (3 marks)
- 1 mark for correctly labeling nodes and antinodes in at least one sketch

Question 2: Frequency Calculation

Question: A closed one-ended tube has a length of 0.85 m. If the speed of sound is 340 m/s, calculate the frequency of the third harmonic.

Solution:

$$f_3 = 3 \cdot \frac{v}{4L} = 3 \cdot \frac{340}{4 \cdot 0.85} = 3 \cdot 100 = 300 \text{ Hz}$$

Marking Scheme:

- 2 marks for correct substitution: $f_3 = 3 \cdot \frac{340}{4 \cdot 0.85}$
- 2 marks for correct final answer: 300 Hz

Question 3: Conceptual Explanation

Question: Explain why only odd harmonics are present in a closed one-ended tube.

Expected Answer: In a closed one-ended tube, the closed end is a displacement node while the open end is a displacement antinode. This boundary condition only allows standing waves that have an odd number of quarter wavelengths ($\lambda/4, 3\lambda/4, 5\lambda/4, \ldots$) to fit, hence only odd harmonics are present.

Marking Scheme:

- 2 marks for identifying boundary conditions (node at closed end, antinode at open end)
- 2 marks for correctly stating that only odd multiples of $\lambda/4$ fit in the tube

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