Making Sense of How Students Come to an Understanding of Physics: An Example From Mechanical Waves*

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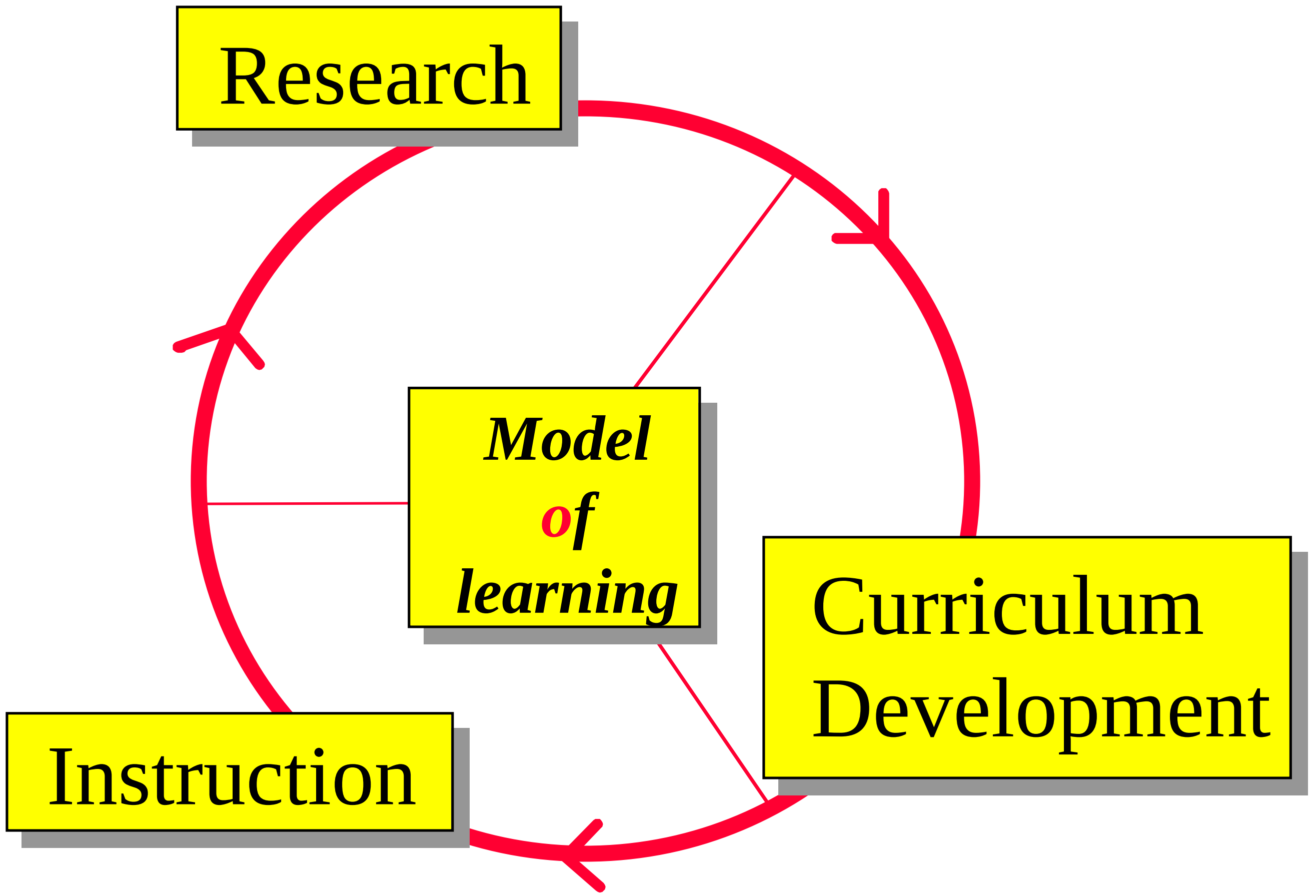
Outline

- Introduction
- Research into Student Understanding of Wave Physics
- Developing Curriculum to Address Student Difficulties
- Organizing Student Reasoning: The Particle Pulses Pattern of Association
- Investigating Student Use of Patterns of Association
- Implications and Conclusions

Research as a Guide to Curriculum Development and Instruction



Research Methods

- **Informal observations:**

  Questions in the classroom or office hours show how students approach the physics.

- **Interviews - The "State Space" of Difficulties:**

  One-on-one investigations allow deeper probing of student understanding. We develop a "state space" of possible responses from our in-depth analyses of student responses.

- **Written tests - "Weighting Factors":**

  Well-designed questions give better understanding of statistical distribution of common reasoning elements. Questions can be asked on pretests, exam questions, or specially designed diagnostic tests.

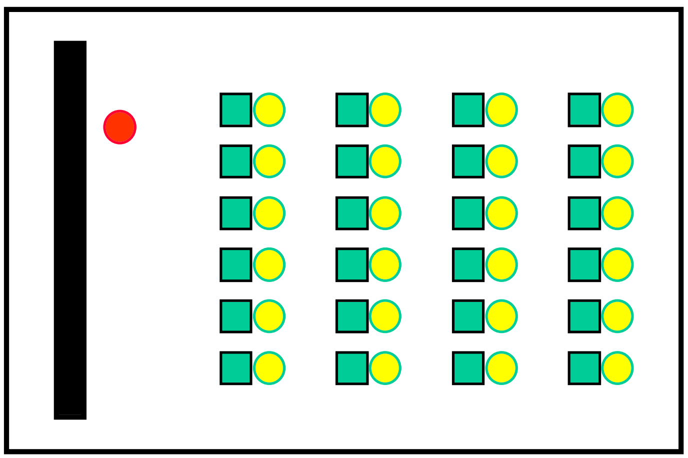
Research Setting

Introductory calculus-based university physics course:

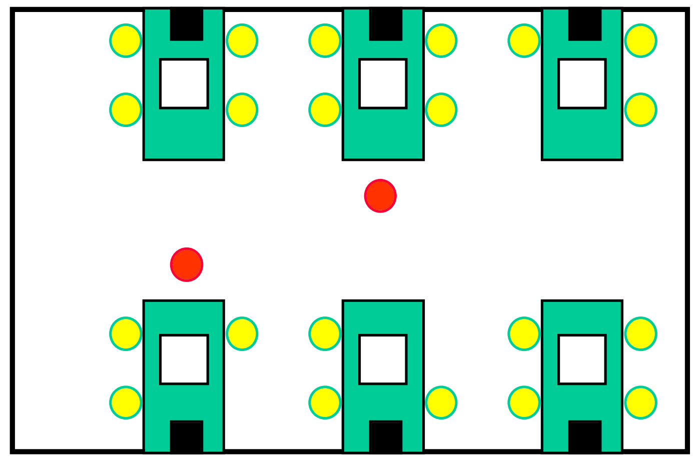
- Lecture: 3 hours
- Lab: 3 hours
- Discussion section: 1 hour

Traditional TA-led recitations or UW-style* tutorials

traditional recitation:



tutorial:



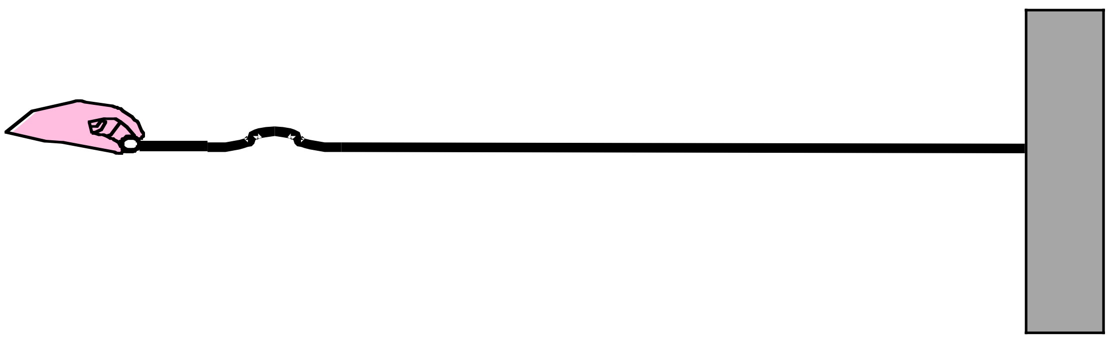
* L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics*, Prentice Hall, Upper Saddle River, NJ, 1998.

Fundamental Concepts (Mechanical Waves)

- A wave is a propagating disturbance to a system.
  - Assume small angle approximation and no dispersion.
- Propagation occurs through local interactions (e.g. between "nearest neighbors") within the system.
  - i.e. wave speed depends on the medium, not on how the disturbance was created (initial conditions).
- Superposition is addition of displacement at every location.
  - i.e. local addition carried out globally.
- Mathematical descriptions require multi-variable functions.
  - e.g. $y_1(x,t) + y_2(x,t) = A \sin (k(x-vt)) + B \sin (k(x+vt))$

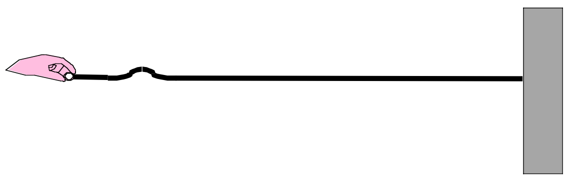
Example 1:

Student Understanding of the Physics of Propagating Waves



First Example Question: Free Response Format

Free Response Question:



A person holds a long, taut string and quickly moves her hand up and down, creating a pulse which moves toward the wall to which the string is attached.
The pulse reaches the wall in a time t_0 (see figure).

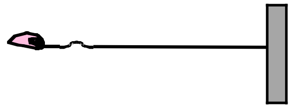
How could the person decrease the amount of time it takes for the pulse to reach the wall? Explain.

Correct Response:

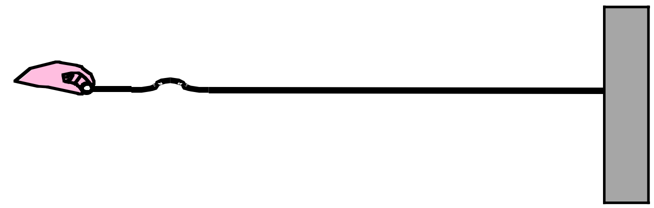
Either by increasing the tension in the string and/or changing the string (to one with a lower mass density).

Typical Incorrect Student Comments:

- *"You flick it harder...you put a greater force in your hand, so it goes faster."*
- *"If we could make the initial pulse fast, if you flick it faster..…
  It would put more energy in."*



Second Example Question: Multiple-Choice, Multiple-Response Format



A taut string is attached to a distant wall. A demonstrator moves her hand to create a pulse traveling toward the wall (see diagram). The demonstrator wants to produce a pulse that takes a longer time to reach the wall. Which of the actions *a–k* **taken by itself** will produce this result? More than one answer may be correct. If so, give them all. Explain your reasoning.

a. Move her hand more quickly (but still only up and down once by the same amount).
b. Move her hand more slowly (but still only up and down once by the same amount).
c. Move her hand a larger distance but up and down in the same amount of time.
d. Move her hand a smaller distance but up and down in the same amount of time.
e. Use a heavier string of the same length, under the same tension
f. Use a lighter string of the same length, under the same tension
g. Use a string of the same density, but decrease the tension.
h. Use a string of the same density, but increase the tension.
i. Put more force into the wave.
j. Put less force into the wave.
k. None of the above answers will cause the desired effect.

Offered incorrect responses

Analysis of Student Descriptions of Wave Propagation

Many students fail to recognize that the creation of the wave is independent of the motion of the wave through the medium.

Students describe wave speed as if:

- the manner in which the wave speed changes is similar to how one throws a ball faster.
- the effect of a larger force on the wave is to push the wave harder through the medium.
- the medium is a carrier of the wave, i.e. not directly involved in the propagation of the wave (the wave passes *through* the medium).

Student Responses, Pre-Instruction

% correct for each question:

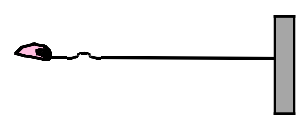
free response……13% MCMR…………86%

		Student responses on free response question			
	Speed changes due to change in:	only tension and density	both the medium and hand motion	the motion of the hand	other
Student responses on MCMR question	only tension and density	7%	1%	2%	1%
	both the medium and hand motion	1%	2%	60%	10%
	the motion of the hand	1%	1%	11%	3%

Students recognize the correct answer but do not give it on their own.

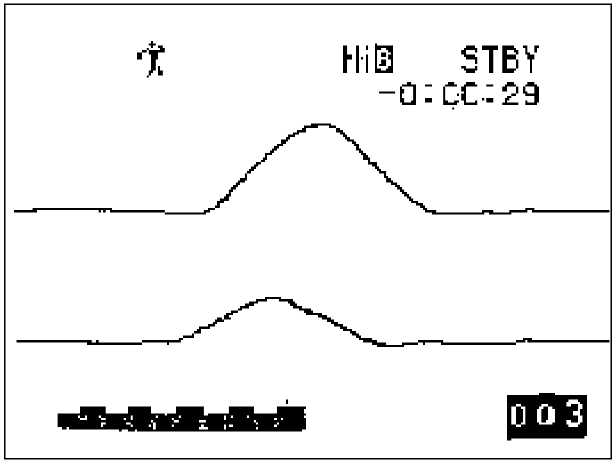
Data Details:

Fall, 1997, 92 Students answered both questions before and after instruction.



Curriculum Designed to Address Difficulties With Propagation

University of Washington-style tutorial uses video created at Dickinson College.



Active learning:

Elicit - *Confront* - *Resolve*

Students:

- verbalize their models to make predictions of events.
- compare their predictions to their observations.
- resolve discrepancies between their descriptions and observations.
- are helped to develop appropriate conclusions through consistent and clear reasoning.

Student Responses, Post-Instruction

% correct for each question:

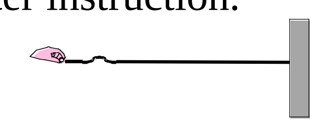
free response……70%   MCMR…………98%

		Student responses on free response question			
	Speed changes due to change in:	only tension and density	both the medium and hand motion	the motion of the hand	other
Student responses on MCMR question	only tension and density	40%	2%	2%	2%
	both the medium and hand motion	8%	17%	20%	2%
	the motion of the hand	2%	1%	2%	0%

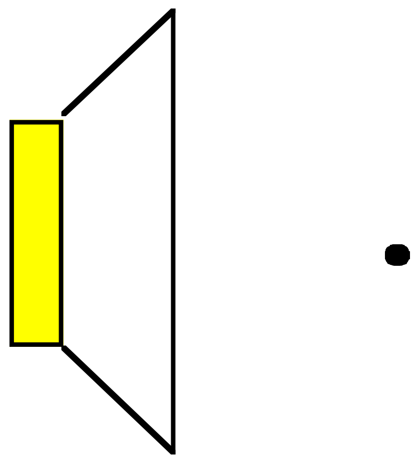
More students give the correct answer,
but many (~50%) still use incorrect reasoning *in addition*.

Data Details:

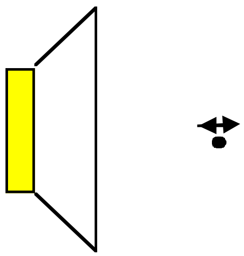
Fall, 1997, 92 Students answered both questions before and after instruction.



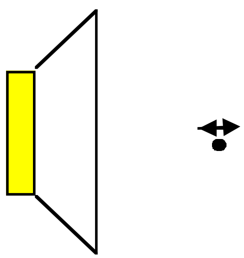
Example 2:
Student Understanding of Sound Waves



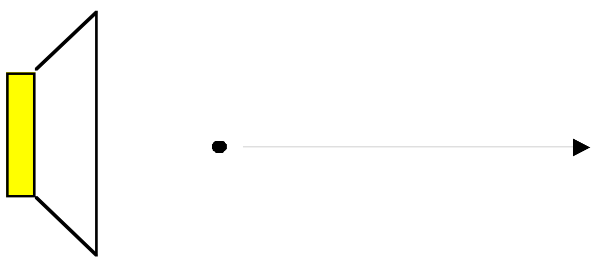
Problem to Investigate Student Reasoning with Sound Waves



Describe the motion of the dust particle after the loudspeaker is turned on and plays a note at a constant pitch and volume.



Correct Response:
Particle oscillates longitudinally due to the motion of the air around it.



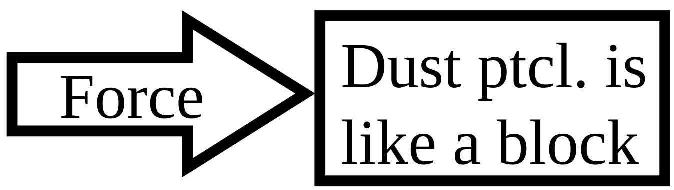
Common Incorrect Response:
Particle pushed away by sound wave.

Student Interview Quote:

Describe the motion of the dust particle?

"It would move away from the speaker, pushed by the wave, pushed by the sound wave … I mean, sound waves spread through the air, which means the air is actually moving, so the dust particle should be moving with that air which is spreading away from the speaker."

The sound wave *"hits the particle with … force."*



"If you have a box, and you apply a force, the acceleration is, force equals mass times acceleration, you can find the acceleration."

Consistency of Student Responses

How does the motion change if the speaker plays a note with a higher frequency?

> *"...the second wave which has [a] frequency which is twice as big should hit [the dust particle] twice [in the same amount of time], which should make it go faster."*

How does the motion change if the speaker plays a note at a higher volume?

> *"[The dust particle] will just move faster, once again. If you kick the thing, instead of kicking it faster, you're just kicking it harder. It's going to move faster."*

Analysis of Student Reasoning About Sound

Many students fail to recognize that a wave is a propagating disturbance to a system.

They show an inability to distinguish between the motion of the medium and the motion of the wave through the medium:

- A wave is propagating air.
- Waves push the medium forward in the direction of wave propagation.
- The effect of changing the frequency (or the volume) of the wave is to change the force the wave exerts on the medium in front of it.

Student Difficulties Not Affected by Traditional Instruction

In a preliminary investigation with unmatched students:

- a plurality of students describe the dust particle being pushed away from the speaker both *before* (45% of 104 students) and a*fter* (40% of 96) instruction.
- the “success” rate was roughly 25% at both times.

Curriculum Development to Address Difficulties the Physics of Sound

University of Washington-style tutorial uses video created at Dickinson College.

Active learning:

Elicit - Confront - Resolve

Students:

– verbalize their models by describing observations.
– use video analysis tools to develop appropriate representations of the physics.
– Use gedankenexperiments to extend their understanding beyond what is visible on the videos.

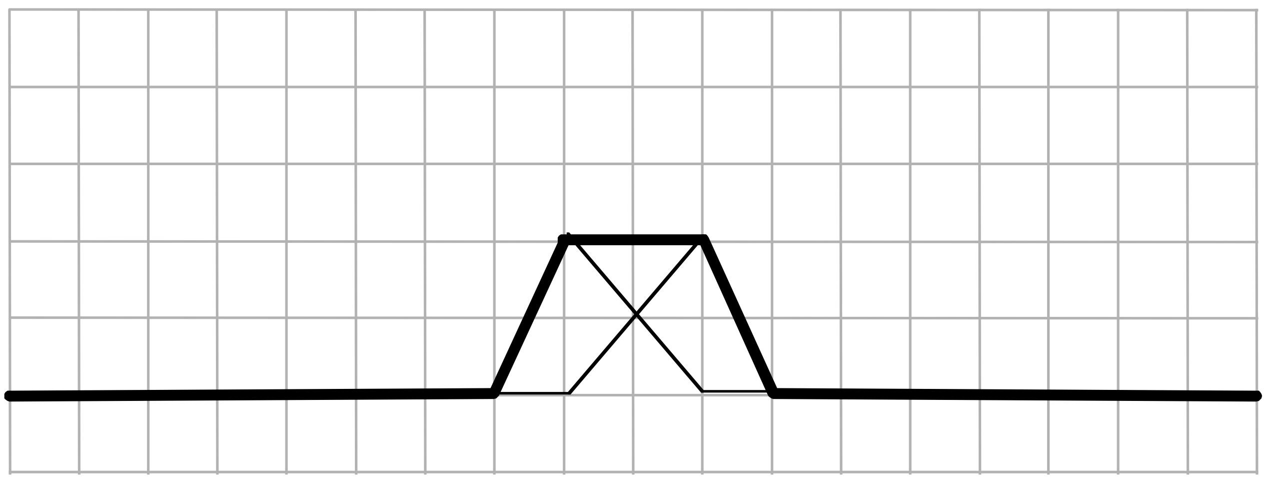
Student Descriptions of Dust Particle Motion

Time during semester: Explanation used:	Before all instruction (%)	Post lecture (%)	Post lecture, post tutorial (%)
Correct: longitudinal oscillation	9	26	61
Other oscillation	23	22	14
Particle pushed away linearly or sinusoidally	50	39	15
Other	18	14	5

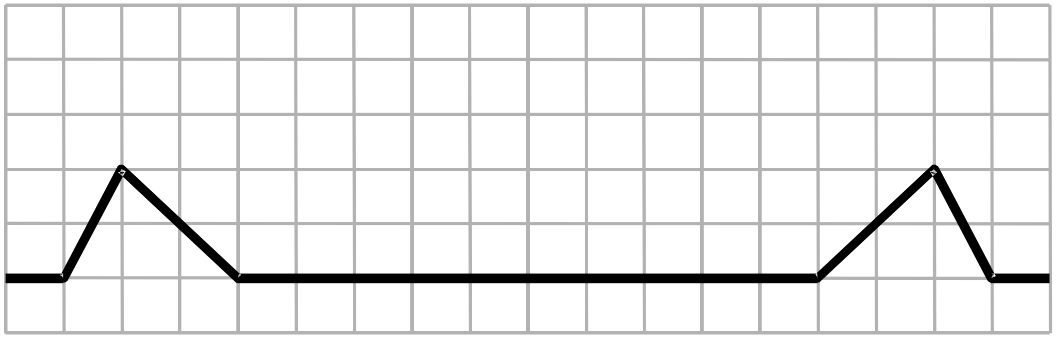
"Other oscillation" includes students who failed to specify in which direction the particle oscillates.

Fall 1997, 137 students answered all three questions before, during, and after instruction on sound waves.

Example 3:
Student Understanding of Superposition

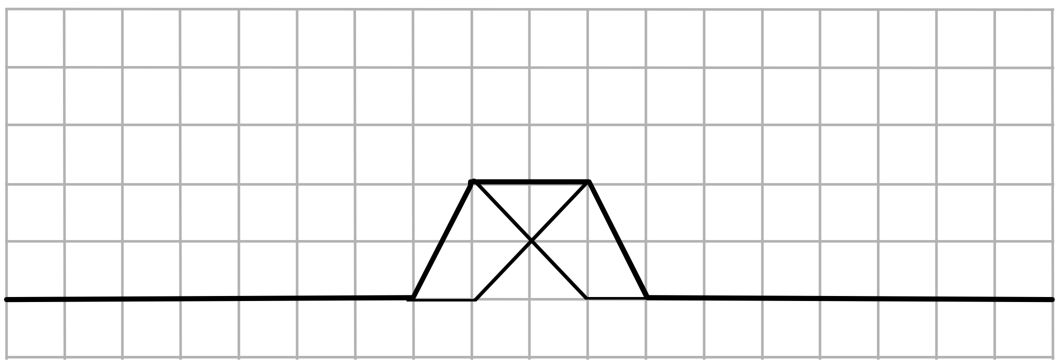


Student Understanding of Superposition



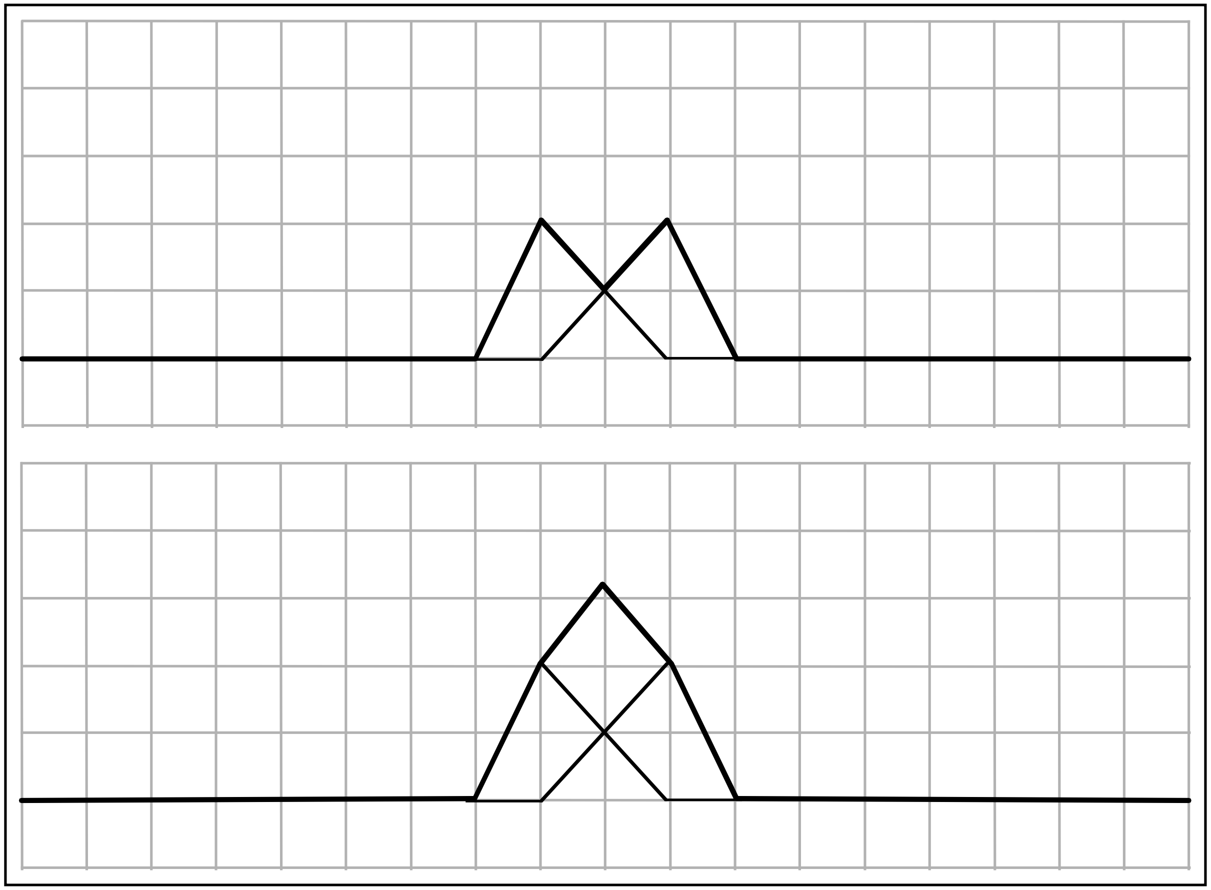
Two wavepulses are traveling toward each other at a speed of 10 cm/s on a long string, as shown in the figure to the left. Sketch the shape of the string at time t = 0.06 s. Explain how you arrived at your answer.

Correct Response:



A correct answer would show point-by-point addition of displacement in the area where the wavepulses overlap.

Most Common Incorrect Responses



"The waves only add when the amplitudes meet."

"Because the [bases of the] waves are on top of each another, the amplitudes add."

Analysis of Difficulties with Superposition

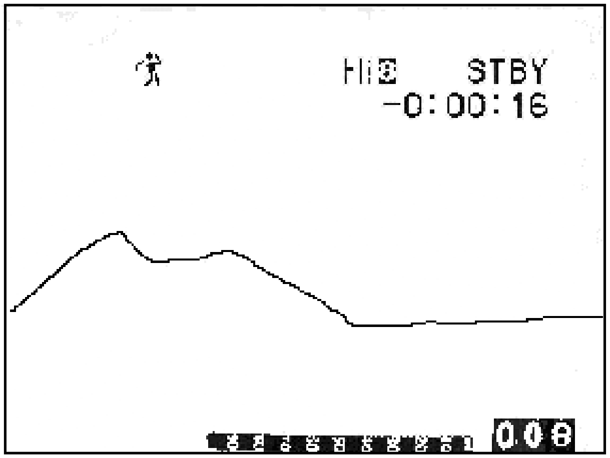
Many students fail to recognize a wave as a region displaced from equilibrium.

They show an inability to compare local and global phenomena:

- An extended region where the string is displaced from equilibrium is described only by the peak amplitude.
- The physics of superposition is associated with the single point, not every displaced point on the string.
- Otherwise, the largest displacement due to an individual wavepulse describes the string's shape…

Curriculum Designed to Address Difficulties With Superposition

University of Washington-style tutorial uses video created at Dickinson College.



Active learning:

Elicit - *Confront* - *Resolve*

Students:

- verbalize their models to make predictions of events.
- compare their predictions to their observations.
- resolve discrepancies between their descriptions and observations.
- are helped to develop appropriate conclusions through consistent and clear reasoning.

Most Common Student Responses

Time during semester: Explanation used:	Before all instruction (%)	Post lecture (%)	Post lecture, post tutorial (%)
Correct: point-by-point addition	27	26	59
Adding only one point	65	52	27
other	6	13	7
Blank	2	9	7

Fall 1997, 130 students answered all three questions before, during, and after instruction on superposition.

Making Sense of How Students Make Sense of Physics:

The Particle Pulses Pattern of Association

Building Blocks of Student Reasoning

Students use “primitives” in their explanations:

These may be appropriate (and helpful in simplifying a problem) in some settings, but inappropriate in others.

Examples

– The “Actuating Agency” primitive:

Exert a force to cause motion.

– The “Object as Point” primitive:

Simplify extended objects into single points.

– The “Ohm’s” primitive:

Use more force to overcome added resistance.

– The “Bouncing” primitive:

Objects simply bounce off each other.

Organizing Student Reasoning

We can describe student reasoning *as if* they make an analogy to Newtonian particle physics to guide their reasoning.

The set of (mis)applied primitives that guide student reasoning form the

Particle Pulses Pattern of Association

(loosely referred to as the Particle Model, PM)

Example of Student Use of the PM

On a preliminary diagnostic test, David made many comments consistent with the PM:

- The force exerted in creating the wavepulse determines its speed (actuating agency, Ohm’s).
- Wavepulses collide with and bounce off each other when they meet (collision primitives).
- Wavepulse addition occurs only when peak amplitudes overlap (object as point).

But David also gave responses indicative of the Community Consensus Model (CM).

Investigating the Dynamics of Student Reasoning

Developing a Diagnostic Test To Investigate Student Understanding

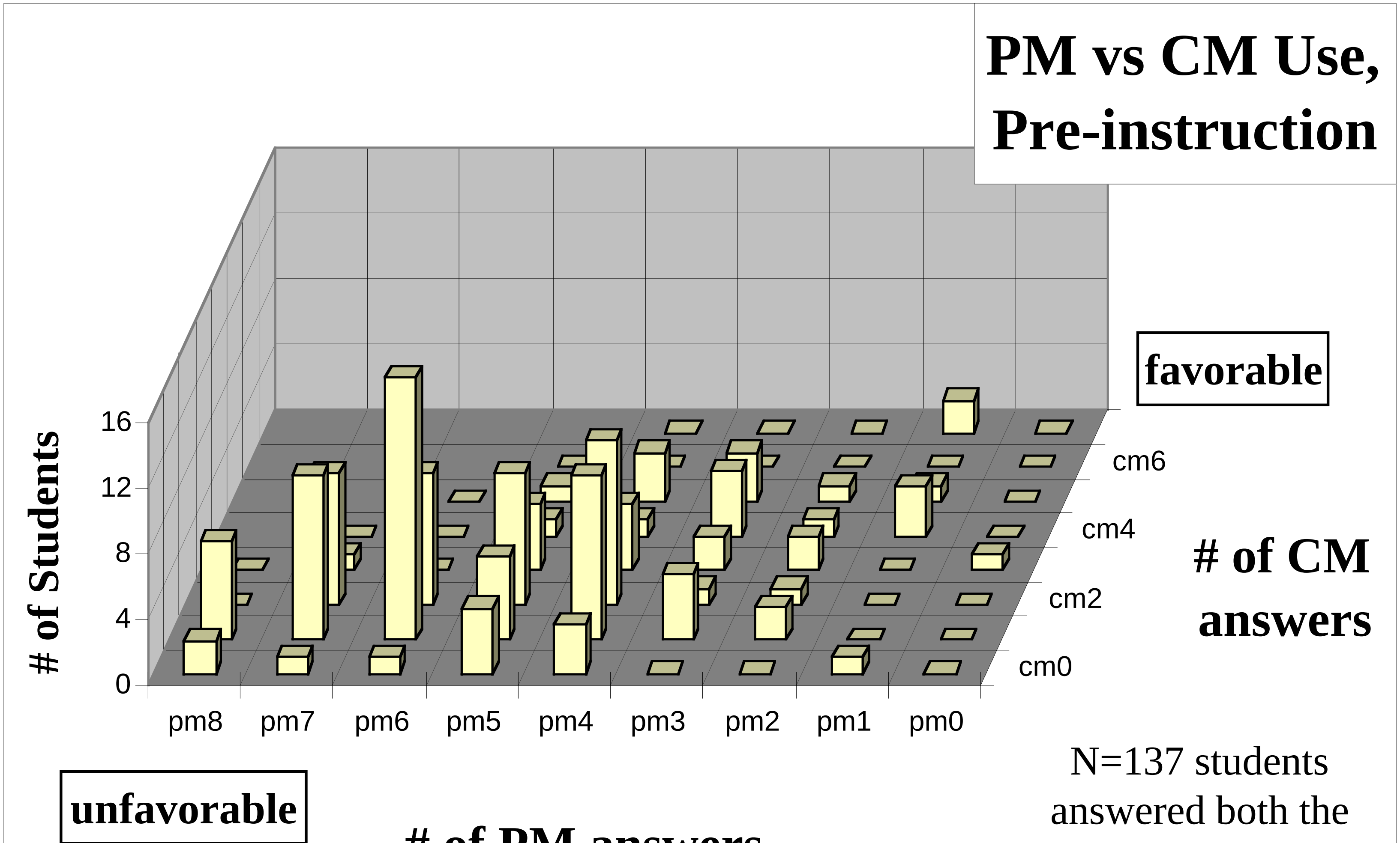
Pre- and Post-Instruction Administration of a Wave Diagnostic Test

Students answered a variety of questions (e.g. those already discussed and others) that investigated their understanding of the basic concepts of wave physics in both simple physics and “real world” contexts.

Questions:

- What knowledge do students have when they enter and leave our courses?
- Do students use consistent reasoning when describing physics material taught in the classroom?

Describing Pre-Instruction Results

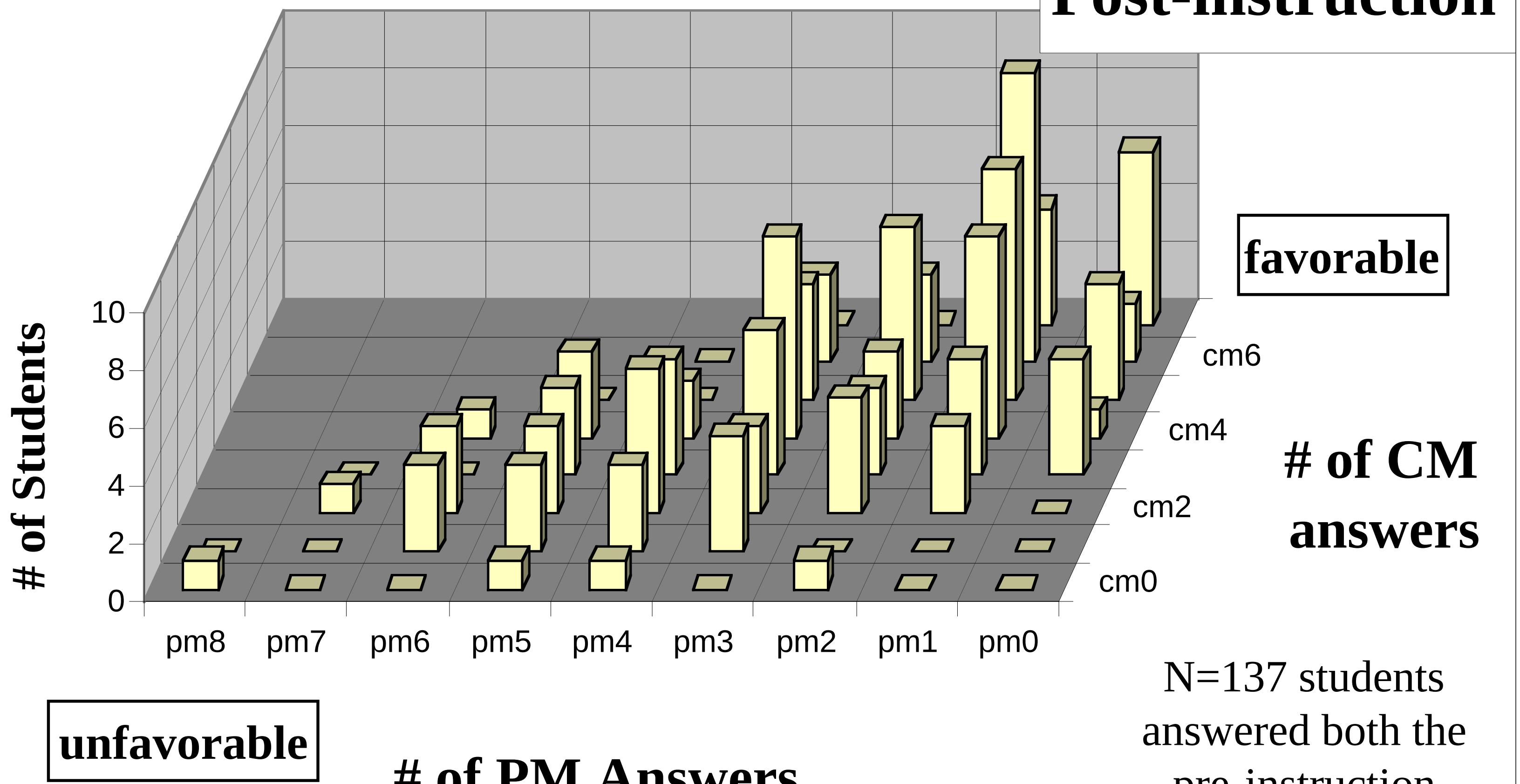


PM = Particle Pulses Pattern of Association
CM = Community Consensus Model

N=137 students answered both the pre-instruction and post-instruction wave diagnostic test

Describing Post-Instruction Results

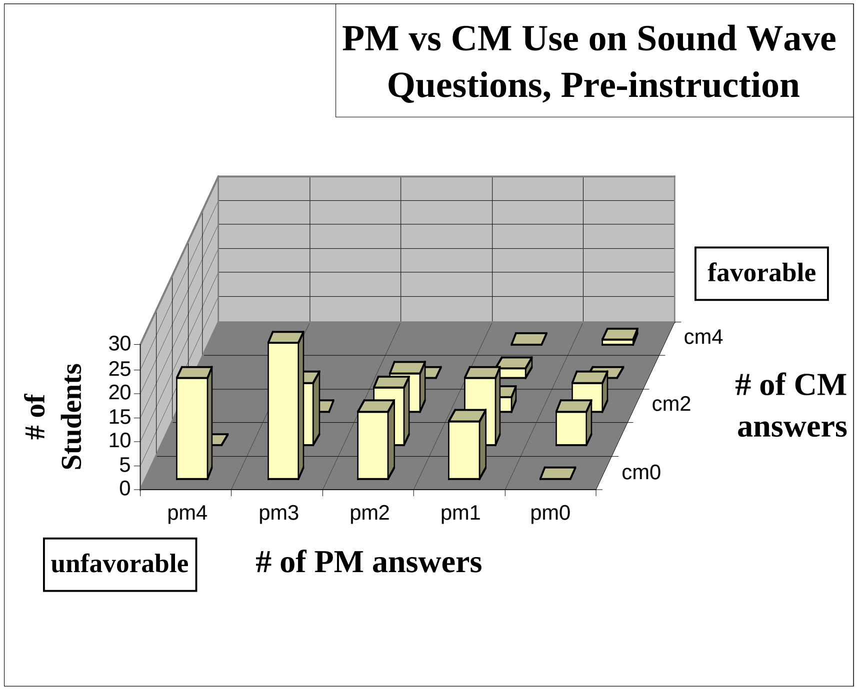
PM vs. CM use, Post-instruction

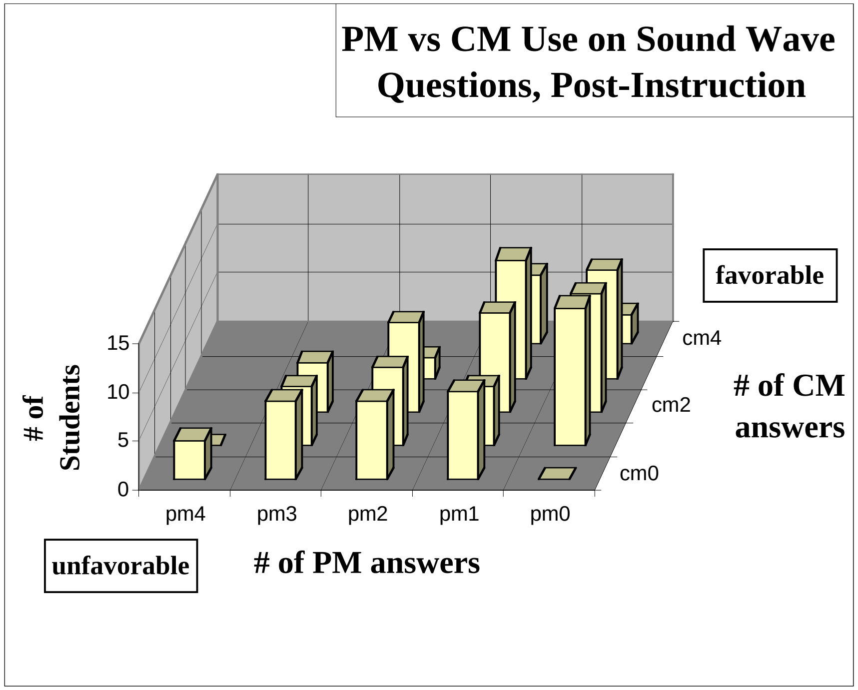


PM = Particle Pulses Pattern of Association
CM = Community Consensus Model

N=137 students answered both the pre-instruction and post-instruction wave diagnostic test

Change in Student Responses on a Single Wave Physics Topics





Students do not describe a single wave physics topic consistently after instruction

Conclusions

- Students often approach wave physics using primitives that may be appropriate in some settings but are applied inappropriately.
- The set of commonly used student primitives can be described in terms of patterns of association.
- Students make use of multiple reasoning methods when discussing the physics of a single topic.
- Curriculum materials can be developed that help students build a more appropriate and correct understanding of wave physics.