

# Identifying students' models of sound propagation

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## Abstract

We investigated students' mental models of sound propagation in introductory physics classes. In addition to the scientifically accepted wave model, students used the "entity" model. In this model sound is a self-standing entity, different from the medium, and propagating through it. All other observed alternative models are composed of entity and wave ingredients, but at the same time they are distinct from each of the constituent models. We called these models "hybrid" models. We will discuss how students use these models in various contexts before and after instruction.

## Introduction

Relatively recently, physics education researchers have begun to investigate students' underlying knowledge structures, often called mental models. Researchers have often used different definitions of the term "mental model." Our use of the term is consistent with Greca and Moreira [1, p.108]: "A mental model is an internal representation, which acts out as a structural analogue of situations or processes." Bao [2] has developed "Model Analysis," a theoretical framework for analyzing students' mental models. Model analysis extracts students' mental model state from multiple choice instruments or model inventories. This study is part of a research effort to construct a model inventory for investigating students' mental models of sound propagation.

Previous researchers [3] have identified the particle model and particle pulses model as the dominant alternative models. Previous research has also shown that students' answers may depend on context [4], so that students can simultaneously apply different models in different contexts [5] i.e. to be in a mixed model state.[2] Therefore, we probed students for the context sensitivity of models.

## Goals

Our research questions were:

- What mental models of sound propagation do students use?
- How do students' mental models change with context?
- How do students' mental models change after the instruction?

## Methodology

We used a semi-structured protocol to interview 16 students enrolled in a conceptual

physics class, before and after the instruction. Half of these students had taken two semesters of physics in high school. The other half had no high school physics. Twelve students were female and four were male. Students received extra credit worth 2% of their total grade for participation in the interviews. On average, our interviewees scored marginally higher than the class mean on the class exam on vibrations, waves and sound.

The study was phenomenographic [6] and we had no hypothesis in the early stage of research.

## Instrument

We investigated students' mental models in the following contexts:

Context 1: Propagation of human voice through air and its impact on air particles.

Context 2: Propagation of human voice and its impact on a dust particle in the air.

Context 3: Propagation of a constant tone and a rhythmic, beating tone from a loud speaker and the impact of these sounds on a dust particle in the air.

Context 4: Propagation of human voice through the wall at macroscopic and microscopic levels and its impact on wall particles.

Context 5: We performed an experiment with propagation of sound through a tight string with cans attached to its ends. We compared propagation of human voice through the tight string vs. air and through the tight string vs. the loose string.

## Results and Discussion

One of first things that we realized in this study was that while describing sound propagation, students frequently use the same terminology that experts do, but often with different meaning or without any meaning. We

have found that many students use a variety of statements commonly found in textbooks (e.g. “Sound waves travel through the air,” “Sound is transmitted through the air,” “Disturbance travels through the medium,” “Vibrations move through the space.”). However, these same students commonly make statements inconsistent with wave models (e.g. “sound propagates through the vacuum.”).

Due to this language ambiguity, in eliciting students’ models we restricted ourselves to a narrow set of statements that could be associated with only a single model. Using the above criteria, we identified, in addition to the scientifically accepted wave model, a dominant alternative model that we call the “entity” model. According to this model, sound is a self-standing entity different from the medium through which it propagates. Sound properties uniquely associated with entity model are:

1. Sound is independent – sound propagates through the vacuum (does not need medium).

Example:

INTERVIEWER: *Would anything be different for sound in space with and without air?*

ASHLEY: *Um...I...don't think so...unless there are things in air that like the sound waves would come in contact with, that would like obstruct where they go, kind of. And then if there...I guess if there's no air then there is nothing for them, nothing to get in the way, so they travel, like free of interference.*

2. Sound is material - sound is a material unit of substance and has mass. Example:

INTERVIEWER: *Does sound consist of anything material? (This question was posed after a student stated that sound is independent.)*

VIRGINIA: *“Yes, I don't know of what, but yes, I am sure it does.*

3. Sound passes through empty spaces between the medium particles (seeping). Example:

LORAIN: *“As the sound moves, like as the sound comes through [the air] I think it might hit...Like it might find the spaces in between the particles [of the air] but, I think eventually it might also hit one. I mean it's not like it knows exactly where it's going.”*

4. Sound is propagation of sound particles that are different from medium particles.

Example:

STAR: *“Well the, the air is what...the sound particles move through. And so in space they don't have any place to move through...”*

The entity model is the dominant alternative model and also most often the initial model in spontaneous reasoning about sound propagation. Besides the entity model, our study indicates that the only other fundamental model is the scientifically accepted wave model.

All other models that we have identified are composites of the different aspects of the entity and wave model. Vosniadou [7] identified this type of model, “which combines aspects of the initial model with aspects of the culturally-accepted model,” while exploring children’s mental models of Earth. We call these “hybrid” models, which is the term that Greca and Moreira [1] use for bifurcated spontaneous models. Our definition also requires that hybrid models contain features that are defined as incompatible with each of the constituent models. More than one student expressed any one of the following three hybrid models:

1. Shaking model – Sound is a self-standing entity different from the medium, but as it propagates through the medium it causes vibration of the particles of/in the medium.
2. Longitudinally shaking model – This is a special case of the shaking model where propagation of sound-entity causes longitudinal vibration of the particles of/in the medium
3. Propagating air model – Sound propagates so that air particles travel from the source to the listener.

There were three other hybrid models that were expressed by only one student. According to the first one, sound is again an entity different from the medium. It propagates through the air, which constantly vibrates horizontally back and forth. When the source produces sound, this perpetual longitudinal motion of medium molecules transfers the sound forward. But unlike the wave model, vibration of the air particles is identical with and without sound. Two other uniquely

expressed models describe sound as a propagation of the disturbance of an ether-like medium. The particles of this etheric medium are different from those of any physical medium and students called them sound, sound waves or sound particles.

Besides being consistent with Greca and Moreira’s definition [1], all identified models except one of the two etheric models described above, also fulfill diSessa’s [8] requirements for a mental model: They have (a) spatial configuration of identifiable kinds of things, (b) (few) principles of how system works and (c) (certain) predictive power.

Students used multiple models simultaneously (i.e. they were in a mixed model state) in only two of 32 interviews. This may suggest that mental models of sound are not particularly context sensitive. Alternatively, it is possible that since the contexts were presented one after another, and were all dealing with sound propagation, students perceived them as being more mutually correlated than they would otherwise. It may also be that our stringent criteria for identifying mental models reduced the number of observed models.

Fig. 1 shows a pattern in pre-post instruction model dynamics. Students generally begin with an entity model and finish either with the same model or somewhere closer to the wave model. Each arrow indicates a single student’s model transition. Short arrows indicate students whose models were identified either only pre- or post- instruction.

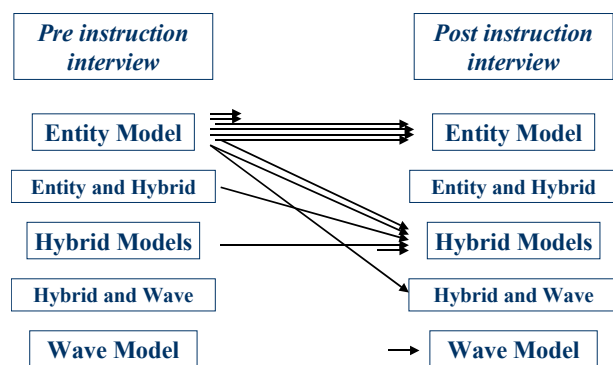


Fig. 1: The change in model states due to instruction.

## Conclusions

Our findings indicate that there are only two fundamental models of sound propagation: the scientifically accepted wave model and the dominant alternative entity model. However, students show remarkable inventiveness in fusing these two models into new hybrid models. We perceive a mental model as a mental structure built of more fundamental cognitive and knowledge elements. To form a mental model, these elements must be assembled in a coherent way and become model features or aspects.[7] In the case of sound propagation, these model features are often simply the properties of sound. The mental model(s) that students use define respective mental model states.[2] Fig. 2 depicts various model states and their relationship with knowledge elements i.e. model features. Students who use disconnected knowledge elements are in a “no model” state. Students in a “pure model” state construct a model by connecting features pertinent to this model and applying the model consistently across various contexts. Students in a “mixed model” state use two or more mental models. In each context, they apply one of these models. Students in a “hybrid model” state construct a single model from constituent features associated with different (initial and target) models. In hybrid model state they apply respective hybrid model consistently across various contexts. This makes a hybrid model state a special case of a pure model state, but very important for understanding the conceptual change in various domains.[6]

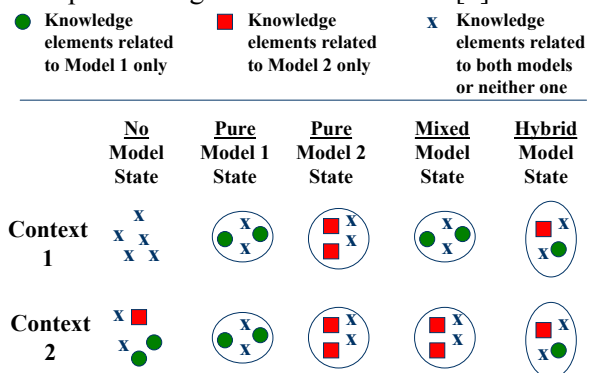


Fig. 2: Mental model states.

This study also indicates a clear pattern of model change due to instruction. Students who construct

models often start with the entity model and generally progress through the hybrid or mixed model states before finishing in the wave model state.

### Further Research

Suggestions for further research on this topic include:

1. Addressing mental models of sound propagation in algebra and calculus based introductory physics courses.
2. Creating a sound propagation inventory.
3. Constructing the analytical framework that would deepen the understanding of the fine structure of mental models and the role of this fine structure in model transition dynamics.

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### References

- [1] Ileana Maria Greca and Marco Antonio Moreira, "Mental, physical, and mathematical models in the teaching and learning of physics," *Science Education* **86**, 106-121 (2002).
- [2] Lei Bao, *Dynamics of student modeling: A theory, algorithms, and application to quantum mechanics*, Ph.D. Dissertation, University of Maryland, 1999.
- [3] Zdeslav Hrepic, *Ucenicke koncepcije u razumijevanju zvuka (Students' concepts in understanding of sound)*, Bachelor's thesis, University of Split, 1998; Michael C. Wittmann, Richard N. Steinberg, and Edward F. Redish, "Making sense of how students make sense of mechanical waves," *The Physics Teacher* **37**, 15-21 (1999); L. Maurines, "Spontaneous reasoning on the propagation of sound," in *Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, edited by J. Novak (Cornell University (distributed electronically), Ithaca, New York, 1993); Cedric J. Linder, "University physics students' conceptualizations of factors affecting the speed of sound propagation,"

*International Journal of Science Education* **15**, 655-662 (1993).

- [4] Lei Bao, Dean Zollman, Kirsten Hogg, and Edward F. Redish, "Model analysis of fine structures of student models: An example with Newton's third law," *Journal of Physics Education Research* **submitted** (2000); H. Schecker and J. Gerdes, "Messung von Konzeptualisierungsfähigkeit in der Mechanik. Zur Aussagekraft des Force Concept Inventory," *Zeitschrift für Didaktik der Naturwissenschaften* **5**, 75-89 (1999).
- [5] Keith S. Taber, "Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure," *International Journal of Science Education* **22**, 399-417 (2000).
- [6] F. Marton, "Phenomenography: A research approach to investigating different understandings of reality," *Journal of Thought* **21**, 28-49 (1986).
- [7] Stella Vosniadou, "Capturing and modeling the process of conceptual change," *Learning & Instruction* **4**, 45-69 (1994).
- [8] Andrea A. diSessa, "Why "conceptual ecology" is a good idea," in *Reconsidering conceptual change: Issues in theory and practice*, edited by M. Limon and L. Mason (Dordrecht: Kluwer, 2002), pp. 29-60.