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 as they have one or more features that are incompatible with both – entity and wave model. We called these models "hybrid" models. We will discuss how students use these models in various contexts and 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 (2002, p. 108): "A mental model is an internal representation, which acts out as a structural analogue of situations or processes." Bao (1999) have 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 (Hrepic, 1998; Linder, 1993; Maurines, 1993; Wittmann, Steinberg, & Redish, 1999) have identified the particle model and particle pulses model as the dominant alternative models. Previous research has also shown that students' answers may well depend on context (Bao, Zollman, Hogg, & Redish, 2000; Schecker & Gerdes, 1999), that students can simultaneously apply different models in different contexts (Taber, 2000) i.e. to be in a mixed model state (Bao, 1999). Therefore, we probed students for the context sensitivity of models. Our

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 16 students had taken two semesters of physics in high school. The other half had no high school physics. Twelve students were female and 4 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 and we had no hypothesis in the early stage of research.

Instrument

We investigated students' mental models across broad 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 sound and a rhythmic, beating sound 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 a macroscopic and microscopic levels and the impact of this sound on wall particles.

Context 5: We performed an experiment with propagation of sound through the 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. through 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 "starting point 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 (1994) 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 (2002) use for bifurcated spontaneous models. In addition to Vosniadou's definition that they are composed of ingredients of initial and target model, we require from hybrid models that they need to be at the same time distinct from each of the constituent models by one or more features that are by definition characterized as incompatible with each parental model. 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. Vibration of the air particles is identical with and without sound. Other two uniquely expressed models have in common that sound is propagation of the disturbance created in ether-like medium, whose particles are different from the particles of physical medium. These etheric particles were called sound, sound waves or sound particles.

Besides being consistent with Greca & Moreira's definition (2002), all identified models except one of these two etheric models, also fulfill diSessa's (2002) requirements for mental model: They have (1) spatial configuration of identifiable kinds of things, (2) (few) principles of how system works and (3) (certain) predictive power.

Students used multiple models simultaneously (i.e. they were in a mixed model state) in only 2 of all 32 interviews. Although this may be interpreted in a way that mental models are not particularly context sensitive in this domain, there are also strong alternative explanations. It is possible that since contexts were presented one after another, and were all dealing with the same topic, students perceived them more mutually co-related than they would otherwise. It may also be that our restrictive analysis approach reduced the number of observed models.

Fig. 1 shows a strong 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 only post- instruction.

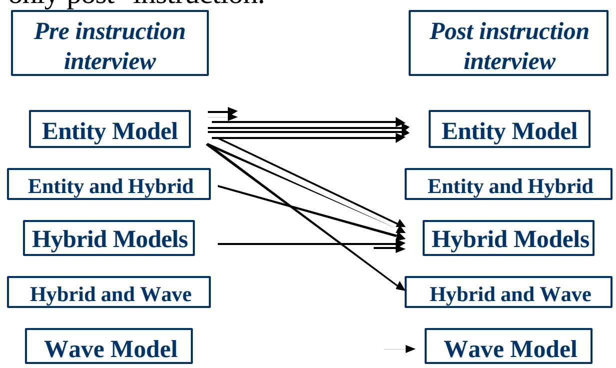

Fig. 1: The change in model states due to instruction.

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. This observation lends new perspective to Marton's (1986) claim that when student learning of a particular physics topic is explored through systematic qualitative research, researchers are often able to identify a small, finite set of commonly recognized models. We perceive mental model as mental structure being built of a more fundamental cognitive and knowledge elements. If they form a mental model, these elements are assembled in a coherent way and become model features or aspects (Vosniadou, 1994). In the case of the sound propagation, model features are often simply properties of sound. Metal model(s) that students use define respective mental model states (Bao, 1999). In Fig 2. we represented hybrid model and corresponding model state through hybrid model's relation with parental models and students' usage of model(s) in different contexts. Circles around model features in Fig. 2. indicate their coherent interrelations. Although a hybrid model state is just a special case of a pure model state, it is very important for understanding the conceptual change in various domains (Vosniadou, 1994).

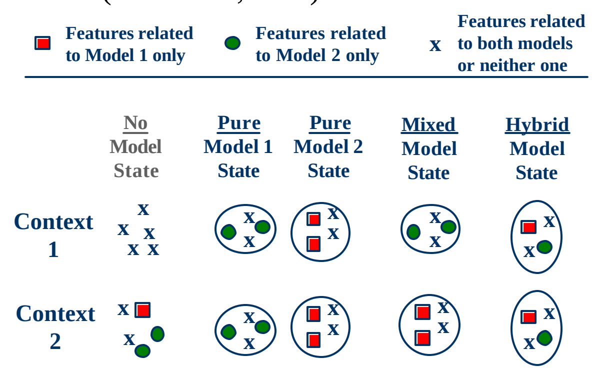

Fig. 2: Mental model states.

This study also indicates a clear pattern of model change due to instruction. When models exist, the overall dynamics of the model change starts with the entity model and generally progresses through hybrid or mixed model state finishing with the wave model.

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 model inventory on sound propagation.
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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