APPENDIX A

INTERVIEW PROTOCOLS

KANSAS STATE UNIVERSITY
PHYSICS EDUCATION RESEARCH GROUP

Propagation of sound
Pre Instruction Interview Protocol
(Interviewer copy)

Date:
Interviewee:
Interviewer: Zdeslav Hrepic

Introduction before pre-instruction interview

Hello. Thank you for being here. I really appreciate your participation.
My name is Zdeslav Hrepic and you may call me "Z" for convenience. And your name is… Nice to meet you….

Let me reassure you that our conversation is completely confidential and will be use only for the purpose of this research and the answers you give here will not affect your course grade in any way. Also if you choose to terminate your participation at any time, it will not affect your grade in this or any other class in which you are enrolled.

Related to this we have to do our paperwork before we start. This paper basically says that you are participating voluntarily in this research. Please take a look and if everything is all right with you please sign it behind.

SIGNING THE CONSENT FORM

Let me tell you what we are going to do today. Basically it will be a conversation about sound and how it propagates.

Hopefully through our conversation I will understand how do you perceive process of sound propagation, so in this research there are no right or wrong answers to these questions – just your opinion. I am not interested either in right or in wrong answers. I am interested in your answers.
Simply try to explain your reasoning in a way you would explain them to some of your friends.
While you are doing that I encourage you to draw on the pictures that we will go through as it will be great help for me to interpret our conversation later.
One more thing before we start. You have noticed that I am not native speaker so if happens that you do not understand something I say - please ask me to clarify.

Explanation for recording:
You have probably noticed the recorder.
As you may guess, the reason of recording our conversation is simply my inability to remember all that was said during half of an hour ☺.
But contents of the tape will not be disclosed to anyone with your name or any identifying feature, so do not let it bother you.

As we go along it may happen you want to add something. If so please feel free to interrupt and add whatever you want.

Introduction before post-instruction interview

Hello again. Thanks for being here. Hope you had great time since I saw you last time.

Today we will basically continue our discussion about sound and how it propagates.

Let me again assure you that our conversation is completely confidential and will be use only for the purpose of this research and the answers you give here will not affect your course grade in any way.

Hopefully through our conversation I will understand how do you perceive this process now and is it changed with respect to previous interview.
Again, in this research there are no right or wrong answers to these questions – just your opinion. I am not interested either in right or in wrong answers. I am interested in your answers therefore your answers are right answers.

While you are explaining I encourage you again to draw on the pictures related to situations that we are talking about. That will be great help for me to interpret our conversation later.
If happens that you do not understand something I say - please ask me to clarify.

As we go along it may happen you want to add something related to your previous answers. If so please feel free to interrupt and add whatever you want.

SITUATION 1. Voice – Ear

We have two people in the situation as in the picture below. As one of them talks, the other one hears him or her. **Please try to describe as fully as possible how the sound propagates in this situation. Please feel free to draw on the picture as you are explaining.**

SPEAKER **LISTENER**

Depending on the answer:
Would anything be different for sound in the space without air and in the space with air?

Does the air play any role in process of sound propagation? (What is the role of the air in process of sound propagation?)

As the sound propagates, does it affect the air in any way?

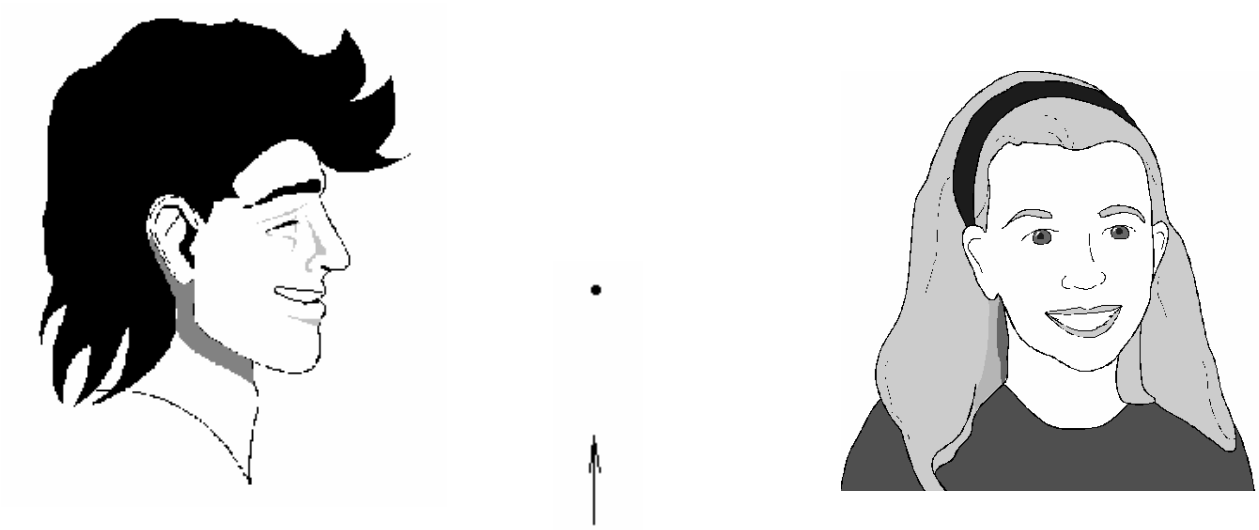
If Yes:
How?
If movement of air particles not mentioned before:
Does sound propagation influence the movement of air particles in any way?

How do the air particles move when compared with sound?

If No:
Please explain why?

SITUATION 2. Voice – Dust Particle

Now suppose we have a dust particle floating motionlessly in front of the silent speaker (see figure). There is no wind in the room. Then, speaker starts to talk.



SPEAKER **DUST PARTICLE** **LISTENER**

If this dust particle was previously still, will sound of speaker's voice have any influence on the dust particle?

If Yes:
How do you expect this particle to behave due to the sound and why?
Please feel free to draw on the picture to describe your explanation.

If sound is long enough, will this dust particle eventually reach the listener in situation like this?

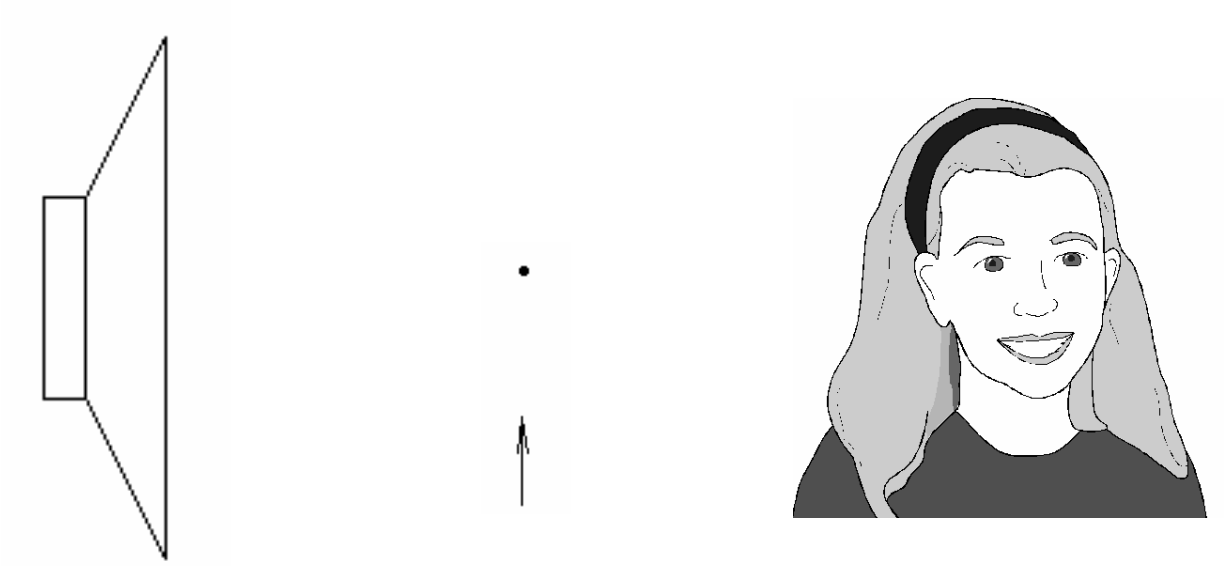
What actually pushes the dust particle and it moves.

How does the dust particle move when compared with sound?

If No:
So it will stay motionless?
Could you explain why?

SITUATION 3. Loudspeaker – Dust Particle

Let's consider now the following situation in which we have loudspeaker instead of human voice as the sound source:



LOUDSPEAKER DUST PARTICLE LISTENER

Now the dust particle is in front of the loudspeaker playing a single constant tone. Suppose at first moment the particle was motionless and then we turned the loudspeaker on.

Do you expect that this sound would affect the dust particle?

If Yes
Will this constant sound of loudspeaker affect the dust particle differently than the sound of voice in previous situation (suppose they are equally loud)?

Would anything be different in the motion of the dust particle if the loudspeaker will be playing a slow rhythmic beats in on-off sequence? Like very slow drum beating.
(Would there be any difference with respect of continuity of movement of the dust particle for constant sound and slow beating sound.)

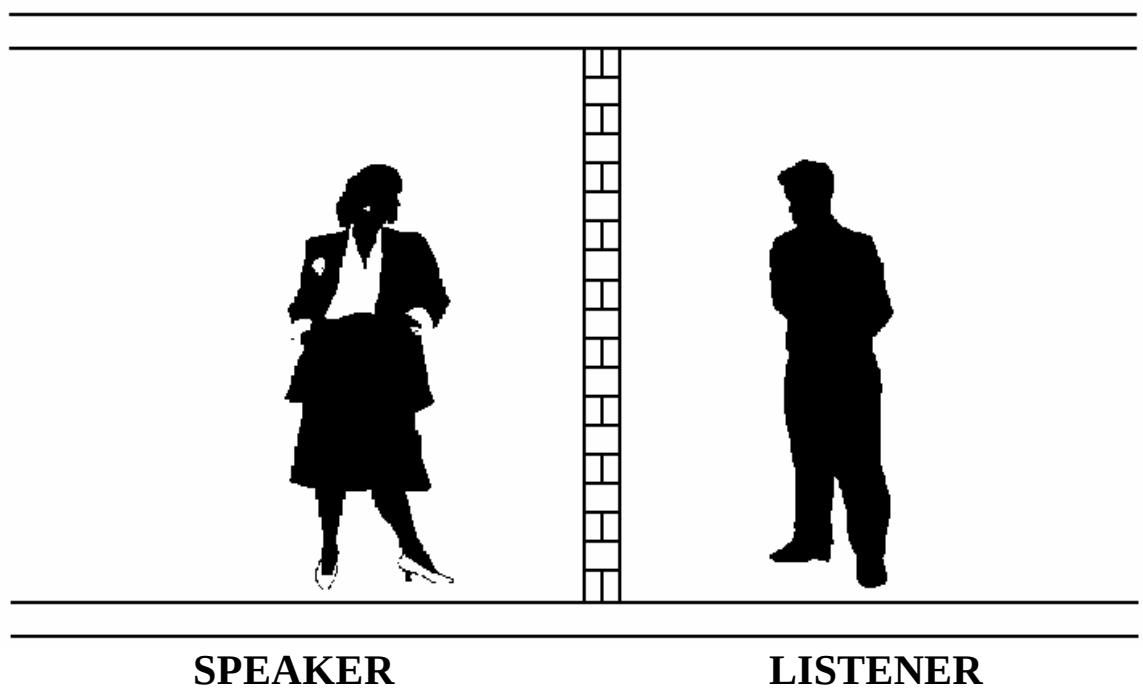
What will happen with dust particle when sound is on and what when it is off?

Can the sound of loudspeaker cause that dust particle gets closer to loudspeaker than it was originally due to sound propagation?

If No
Why

SITUATION 4. Voice – Obstacle - Ear

Now we have two people in two different rooms separated with wall. The wall is made of solid full bricks and the ceiling and the floor are made of concrete.



What would you say about the possibility for those two people to hear each other's voice if they talk loudly and wall is relatively thin?

If hearing possible
How does the sound reach the listener on the other side in this situation?

If through the wall:
How sound propagates through brick wall?

How does the thickness of the brick wall influence the loudness of the sound received by the listener in another room?

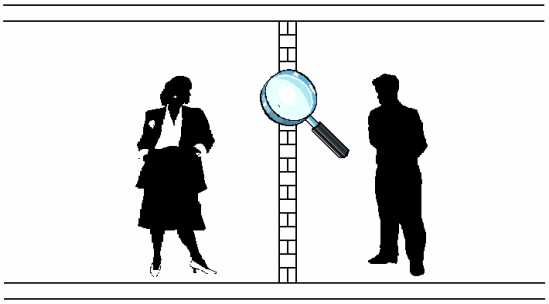
How is loud sound physically different from quiet sound?

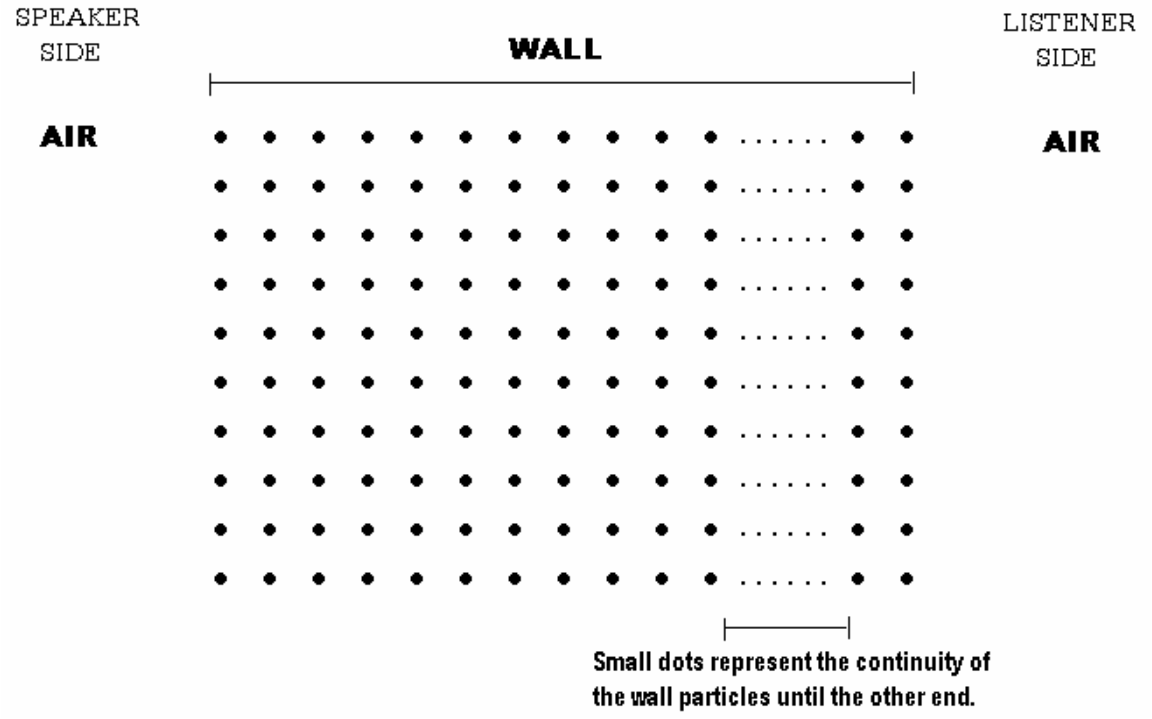
How is sound of high frequency (pitch) physically different from sound of low frequency (pitch)?

If hearing not possible
Why?

SITUATION 4a. Voice – Obstacle - Ear

Now let us suppose we have examined the microscopic structure of the wall and found out that the particles of which this wall consists are arranged in the way shown on the picture below.





What happens on this microscopic level as the sound reaches the wall?

Depending on the answer:
How would you describe this propagating entity - sound? (Is this traveling entity - sound something material or not?)

Does the propagation of the sound affect the motion of the particles of the wall?

Depending on this answer and if before was said it could move the dust particle:
In which way it moves the particle (of wall /dust particle)?

Why is sound quieter on the listener's side of the wall than on the speaker's side of the wall?

SITUATION 5. Voice – Two Cans and String - Ear

Now each of us will hold one of these two cans that are connected with rope (approximately 10 m long). I will go in another room as far as necessary to have this rope tighten between us and I will be in the position where we can see each other through the door.
I will speak into can on my side of the rope and you lean the ear on the opening of the can on your side. After that we will remove the cans and I will speak normally (without cans) so that you can compare how do you hear me in these two cases. O.K?

SPEAKER **LISTENER**

(For those who did not have interview before):
Before we actually do this let me ask you do you expect you will hear my voice better WITH or WITHOUT whole this setting if I speak equally loud?
Please explain why do you think so?
Perform the experiment

(For those who had interview before):
Do you remember this experiment and it's outcome?
Perform experiment if necessary.

For all:

Did you hear it better with or without these cans and rope?

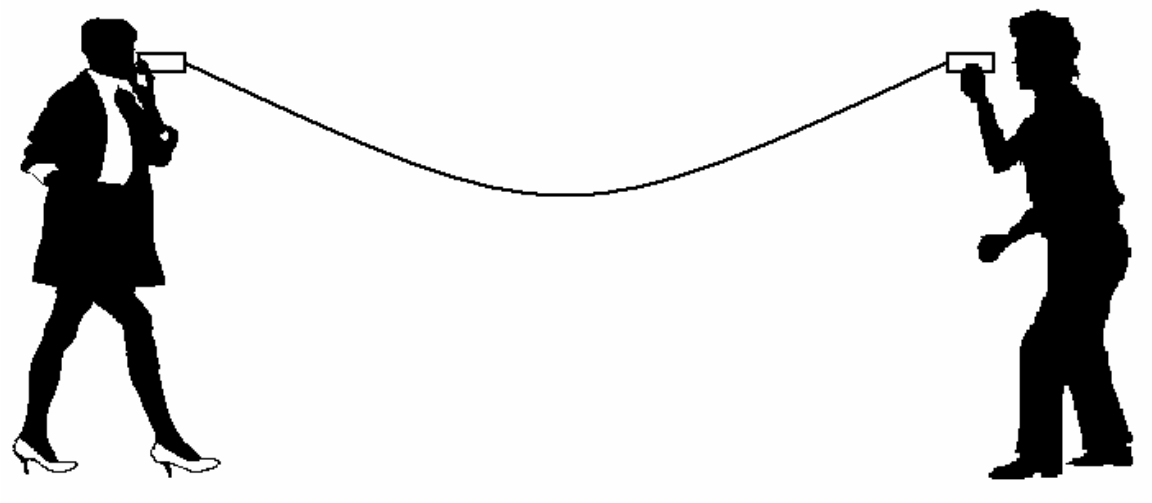
How do you explain that?

How do you explain that this time we hear the sound better with some material between us and in the previous case wall was diminishing the loudness of received sound?

SITUATION 5a. Voice – Two Cans and String - Ear

If we repeat this experiment, would you expect to notice any difference in the loudness of the sound you receive if the rope is NOT tightened and if it IS tightened?

Why?



SPEAKER **LISTENER**

(For those who did not have interview before):
Perform the experiment

(For those who had interview before):
Do you remember this experiment and it's outcome?

For all:

Did you hear it better with tightened rope or with loosened rope?

How do you explain that?

APPENDIX B
PROPERTIES OF SOUND AS DEFINED BY STUDENTS

In this section we have listed the sound properties as students declared them. As stated earlier, they are labeled as if they were second part of the sentence beginning with "Sound is…", and are grouped into thematic clusters.

PROPERTY CLUSTER: DEPENDENCY (Existential dependence of sound)
Independent – Sound propagates through the vacuum, self-standing, self-sufficient (does not need medium). Medium plays no role in sound propagation.

- I: And would anything be different for sound in space with air 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.
- BIC: I would assume without air there would be nothing to cut it down and it would kind of travel…for…ever. I would assume like in a vacuum because there is nothing in a way to stop it so it just keep vibrating forever.
- JORDAN: (Pause) Probably it'll [sound], it wouldn't a…it wouldn't slow down [in space without air], it'd just keep traveling.

Dependent – Sound needs medium o propagate, associated with material "base" – medium

- MR.T: If we are in a vacuum the wave wouldn't be able to move the air particles so the wave wouldn't travel.
- DAVID: It [sound] couldn't move [in space without air] because if there is no air, no anything, sound can't move without something in there.
- BIC: Well if there is no air then there's just nothing to vibrate I think it would be very difficult to have sound in that case.

PROPERTY CLUSTER: MATERIALITY
Material – The sound is material unit, of substance, has mass.
Note: Statement that sound is material was appearing only in interviews in which sound was also perceived as independent.)

- I: Does sound consist of anything material?
  VIRGINIA: Yes, I don't know of what, but yes, I am sure it does.
- I: I mean…is it something material, not material….
  BIC: Oh…
  I: …located, not located?
  BIC: Material because it can be measured, you can measure how louder, softer how far it's traveled or something.
  I: OK.
  BIC: But just in this situation…
  I: You can measure it's mass?

BIC: Um, yeah. I would assume so…

Nonmaterial – The sound is not of substance, doesn't have mass, is not tangible.

- JEWEL: Sound is not something material that you can like pick up and grab. You know. It's not definite. So, I don't know why it does that, though.
- I: Is it [sound] related to air, is it related to something material…or is it like…?
  MEG: I don't think it's anything physical.
- STAR: Then, when I say something that's what gets it [sound] vibrating.
  I: OK.
  STAR: That is a vibration.
  I: OK. And is that…is there anything material that vibrates?
  STAR: No.

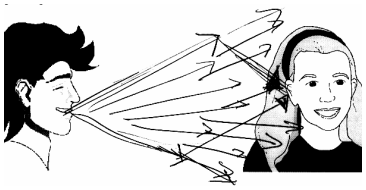
PROPERTY CLUSTER: TANGIBILITY

Containable – sound can be bounded by material objects within defined space

- TARA: They [particles of the string] kind of keep the sounds in it…Kind of barrier things.
- ASHLEY: If it's not loud enough [sound] then they [sounds, sound waves] would eventually just kind of be gulfed in the wall and not make it through to the other side.

Separable – (Countable) – Sound can become disunited or disjointed, one removed from others, number of sounds can be determined. Identifying words: less, few, several, certain, other, some of sounds, all of sounds, less of sounds…
For this purpose identifying words are not: some sound, more sound, less sound…

- TARA: Yeah, but string connecting them could carry the sound waves better and so less of them would twine off.
- I: So what actually…what those arrows actually represent?



ASHLEY: Um, just the sound traveling, like it started there and then the sound waves just all spread apart and travel outwards in all different directions.

Corpuscular – Sound has spatial volume, structure. Can be dissolved/broken into pieces (stated by only one student).

- I: OK. And why is it [sound] quieter on the other side [of the wall]?
  DONNELIZER: Because it has more to go through. The sound just kind of…it kind of …this with wall, this hard thing, it kind of breaks it up and it just looses a little piece. It just looses a little bit less sound as it gets through it. And so that's why it ends up not as strong. 'Cause it could be…I thought of it as of thickness, you know, like sound is this big [shows with hands wide area] when the speaker talks and as it gets through it kind of gets broken up where by the time it gets here, you know right here, it might only be this big [shows with hands small area].

Invisible – Sound cannot be seen

- KAYLA: I mean, like when they show the pictures of stuff you can see it. That's because like, I mean, when they draw or whatever, I mean like that's not the actual sound that you see.
  I: Yeah.
  KAYLA: And that's why they have machines to record it because otherwise you can't see it.
  I: I think sound wave is like a clear thing but I think it is definitely traveling. We just can't see it.
  …
  GUNZ: But it definitely travels through from person to person. We can't see it, but we know it's there because one of our senses just picks it up.
  I: OK, so how it travels through? Basically I'm coming back to the question I've asked before?
  GUNZ: OK. It's gonna come out of his mouth and nobody will be able to see it, but it'd travel through the air and would come out, and people will pick it up in their ears.

PROPERTY CLUSTER: TRANSFERRING (EXCHANGING) AND POSSESING FORCE/ENERGY (Sound properties related to Energy/Force):

Energy transferring (receiving from, transferring to, loosing) - sound receives the energy from the source, which enables it to travel

- KAYLA: It hits, like it hits dust particle and stuff, like it looses some of the energy because it makes the dust move.
- I: why sound diminishes as it travels?
  BIC: It just…it…only moves a particles so much. It can't…it…decreases every particle it gets to. So eventually it runs out…of a energy to move the particles with.

Energy possessing (having, containing) - Sound is energy bundle.

- I: And so how is sound wave different from some kind of particles that would be moving?
  ASHLEY: Um.
  I: How is it different?
  ASHLEY: I…because the waves are, like, made up of energy not made up of substances.
  I: OK. So they are kind of entity but not made up of mat…substance but of energy?
  ASHLEY: Right.

Force transferring (receiving from, transferring to, loosing) - it receives a force from the source, which enables it to travel, and this force is spent while it propagates through medium.

- JEWEL: If you are screaming, there's more force you are putting more into it, it would be able….more likely it would be able to take on the thicker objects and go through (laughs).

Force possessing (having, containing)

- I: OK. How sound actually pushes dust particle?
  DAVID: Um, it's just like a…it's a wave…it's a…(pause). I don't know it's…kind of like when you hit like a peace of metal and you feel on the other end just that, force, the vibration and the force just keeps pushing the particles.

PROPERTY CLUSTER: MASSIVENESS/VOLUMINOUSNESS

Inertial – Sound tends not to change direction of propagation. String looses sound because of the curvature.

- TARA: Right. Sound kind of, drifts off of it [the can]. Like, the sound waves and… goes into the air versus to the can [on the other side].
- ASHLEY: Um. I think it [sound] would be louder when the rope is tight [than loose], because they'd [sounds, sound waves] all be going in the same direction, but when the rope…the…string is loosed then they'd travel down there, but when it switches direction some of them probably won't go with it. Like they will get lost in that direction and so fewer will travel up that way, because some of them will go off in that other direction.

Gravity sensitive – sound curves downward while propagating

- VIRGINIA: When we have it [string] looped, it's more effort for it to go down and then come back up into the listener's ear.
- JORDAN: It'll have to…probably like…(pause)…probably the waves would be going down and trying to come back up…(pause)

Buoyancy sensitive - Supported upward by air – sound falls down without air to support it.

- JENNIFER: And maybe I see sound just being carried further [in air] or being held or moved because there's actual air there. With no air I see it falling (laughs), I don't know, I don't know how to describe it, like I don't see it…like being supported…
- GUNZ: I would say that maybe um…the air can keep the sound wave up so it'll be louder to the person's ear [than without air].

PROPERTY CLUSTER: EMERGING (spreading out, beginning of propagation):

Produced by a source – the source makes, produces sound

- STAR: Just like…my voice box is making noise and then you hear it.
- BIC: It just goes from the one thing to the other.
  I: What goes from the one thing to the other?

BIC: Um, the noise that's being made by the sound or by the initiator.

Emerging from the source – Sound is going out from the source, Coming out from the source) – Sound goes out from the source.

- SALLY: He talks and the sound waves come out from his mouth and they enter her ear.
  I: OK. So what are the sound waves?
  SALLY: Um…(pause)…whatever comes from his mouth…sound.

Spreading in all directions – Sound goes out from the source in all directions

- KAYLA: Like it'd be a longitudinal wave.
  I: OK. OK, but is it only here or you just…
  KAYLA: No it goes out everywhere.

PROPERTY CLUSTER: NATURE OF PROPAGATION

Traveling (moving, going across) - self propelled

- BIC: OK. So basically if I understand this right, sound starts from the speaker…
  I: Uh huh (Yes). And then…it…?
  BIC: Travels over to the listener's ear….
- MR.T: Sound is traveling through the wave I guess.
- I: How does sound propagate in this situation…(Irr.)?
  SALLY: Um…(laughs silently). Isn't it just going into her ear?

Traveling through (moving through, going through, following the string across, traveling along) - self propelled

- JENNIFER: I think it goes through the wall. Like the part of the…waves, like the sound waves go through the wall.
- MEG: Um…I guess, I think that the brick wall, when the wavelength hits the brick wall some of it still goes through, some of the wavelength, the sound, the vibration.

Guided (by), Following - directed by air, string

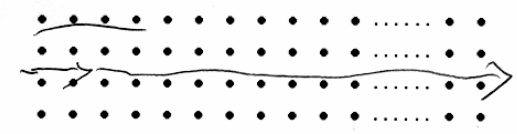
- KAYLA: It's [sound] able to follow the string all the way across"
- VIRGINIA: Like I said it traveled directly down the string and didn't…loose much because it had a direct path and knew exactly where to go.
- JENNIFER: I don't want necessarily say [sound is] going through it [the string] but I mean its following this path, it's been led.

Seeping – Sound passes through empty spaces between the medium particles. Passes through the holes that are bigger than itself. May be curving around and flying straight in between medium particles. No air within the wall particles mentioned.

- I: So what happens on this microscopic level as the sound reaches the wall?
  VIRGINIA: …Well I would say that it's somewhat like a maze for the…for the sound. It just kind of works it's way through until it gets to the other side and

that's what's causes it to get…not sound as loud as if you were standing right next to the speaker. Is that it?

- DONNELIZER: Oh, these are particles of the brick. Yeah, I'd just think it'd get into those little spaces, because it's gonna be little space…



I: Uh huh (Yes).
DONNELIZER: …in between them. They're not gonna mash together when there's nothing.

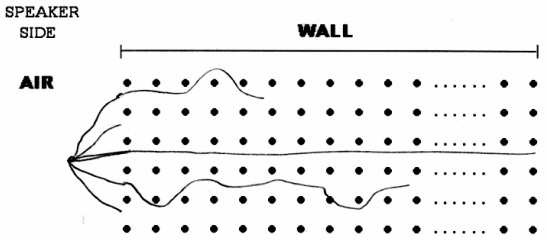
- I: So how does sound get on the other side [of the wall]?

  …

  JORDAN: I've heard it…I don't know actually how…(pause)…probably because there's…a like little tiny, there's little tiny crakes in the brick.
  I: OK.
  JORDAN: And little tiny holes because the brick is not perfectly solid.
  I: Yes.
  JORDAN: And the waves…it just…sort of like seeps through…and eventually the listener is gonna hear…(pause).
- 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.

Air pocketing (in between wall particles) – Sound propagates through the air pockets in between wall particles and does not affect the wall particles. This is seeping through the air pockets in wall.

- TARA: …like the particles…in between the particles there's like little spaces and so then the air or the sound waves can travel through the air spaces.
- JUAN PACO: well…there's got to be, like it can't be a perfectly sealed space…So then the sound would be…traveling through…through those less then air tight spots in the wall.
- I: What happens on this microscopic level as the sound reaches the wall?
  LORAIN: I think the sound would penetrate and might go through the air.



  …

  LORAIN: The sound doesn't know the difference between air here and air down here, I mean they just kind of go where they can fit.

Getting collected – by object that catches it.

- KAYLA: **"**Can is like catching the sound and it's carrying it across"

- ASHLEY: Um. Because if you're talking to the can it would concentrate all…it would like direct all the sound waves in the one direction and have them more concentrated instead on being traveling out in different directions.

Sound is propagation of sound particles - Sound is propagation of sound particles that are different from medium particles, and which may and may not affect the medium.

- VIRGINIA: I think all particles probably…affect each other…the wall particles probably…are acting as a blockades so that sound particles have to move it around a little…[She meant here "move around it" and stated this later correctly – "sound just moves around them"].
- STAR: (Pause) Well the, the air is what…the sound particles move through. And so in space they don't have any place to move through so… (pause).
- MARK: But she can hear what's coming out of his mouth. So it's not that the air…the air doesn't actually move. It'll…just the particles will move through the air I guess.
  I: What particles?
  MARK: The um…like a…sound particles.

Sound propagates so that air particles travel from the source to the listener.

- JEWEL: The air particle is just gonna continue to go through [the wall] to the listener causing hearing.
- HOPE: I think that air molecules vibrate among the brick molecules, but…do you want me to draw all this for you?
  I: Yes sure, please.

HOPE: I think they kind of go in and through all of this, bouncing off of the brick molecules and come out on the other side.
I: OK.
HOPE: So they can listen and hear it.

Sound is a self-standing entity different from the medium, through which it propagates.

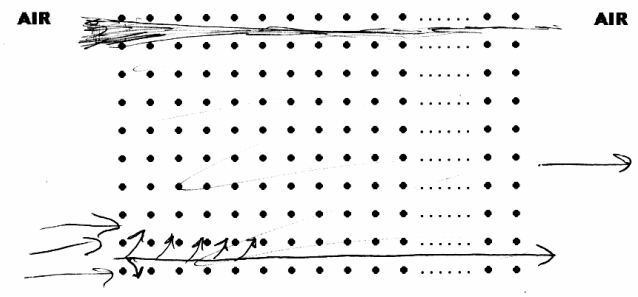
- SHEILA: So I'd say it goes through the medium but…it moves the medium but I don't know what it is.
  I: OK. So it's something that travels through the medium?
  SHEILA: Uh huh (Yes).
  I: Different from medium?
  SHEILA: Yes.
  I: So, yes or no [Sheila stopped just for a moment before this yes statement]?
  SHEILA: Yes.
  I: OK.
  SHEILA: But I can't say what it is because I don't know.
  I: OK, but it is different from…

SHEILA: Yes.
I: OK

- I: Did you say that you perceive it as moving through something?
  JENNIFER: Yeah. Like it's being carried by…
  I: Or being carried. That's different thing.
  JENNIFER: Being carried.
  I: Being carried by the substance or whatever?
  JENNIFER: Right, yes.
  I: Now without this substance it cannot be carried?
  JENNIFER: Right.
  I: So what is actually carried? How would you describe it? What is carried?
  JENNIFER: I have no clue. (Long pause) Just the pitch like the tone, what you're hearing is being carried. It is, I don't think it's an "it" or an object. It's just something you hear but it's…what's taking it to you is the mass or the matter or the…I don't know (laughs).
  I: OK. So basically that's kind of entity…
  JENNIFER: Uh huh (Yes).
  I: …which is carried by medium molecules?
  JENNIFER: Right.
- BIC: (Pause) It just it…As it goes, as it travels, it moves…it takes the air with it when it goes…(pause).
  I: OK, so how is it different from air?
  BIC: How's what different from air?
  I: Sound.
  BIC: It travels through air, so it's…sound uses air to get where it's going.
  I: Uh huh (Yes). And if…OK. If it uses this to go…if you would compare with something would sound be something that kind of floats through this air or, I mean is it something material that…
  BIC: No, sound no.
  I: OK. Because it goes through the air like…I mean submarine goes through the water.
  BIC: Uh huh (Yes).
  I: So it that kind of…?
  BIC: Yeah, kind of I guess. Yeah, it would be the same thing. They both move in something.

Flowing - Flows continuously

- I: In case of constant tone, this motion [of the dust particle] would be more or less…
  BIC: Steady.
  I: Steady.
  BIC: Steady stream of sound. So steady stream of flow.
- MARK: Um…so it'd have to go through I mean, the particles…it will just flow through the particles of the wall and come out on the other side. ANN: Drawing only - Parts of the sound deflects away from the main stream [Mistakenly erased tape]



- I: Is there any possibility to create the sound, which would make the dust particle go back toward the loudspeaker?
  DAVID: (Pause) Umm…I don't believe so because your sound is always traveling away from the vibration. I know I said before it could because I was thinking of a different wave but it's just a solid stream.

PROPERTY CLUSTER: MAINTAINANCE OF PROPAGATION

Pushed by source – the source makes sound to move. Once started, sound propagates through the medium without external source of energy/force

- VIRGINIA: …Once again…the speaker is pushing it through [the wall]… and then pushing it, I am sure it's dulled by the time it does get to the listener.

Propelled by (an outer agent) - Sound is propelled by agents like tightness of the string, the frequency, the force, air.

- KAYLA: The frequency makes it move.
- DAVID: The tightness pushes it or forces it to go through [the string].
- JENNIFER: I think it's carried by the air or carried by the wind or…propelled maybe.

Self-propelled - Working its way (through the brick wall) - exerts effort to get through

- DONNELIZER: It just kind of works its way through [the wall].
- BIC: You're talking person to person through a brick wall like this, then there's like ceiling, it doesn't have anything to go through so it's got to fight to get through the wall.
  I: OK.
  BIC: So it has to exert a lot more effort to get through to the other person than in free space to travel through.

Self-propelled - Finding its way

- BIC: It [string] concentrates it [sound] at one end whereas instead of you just talking and it's going out in the air and it has to find it's way to me through everything.

Self-propelled - Moving itself (expressed only by one student)

- DONNELIZER: …It's just moving…the sound is just moving itself through the, you know like, I guess if you are thinking of waves in this terms like in the wave pool, you know how you if you're right…it just…it keeps moving itself like…I

don't know. It's creating its own waves from how loud person talks, how soft person talks.

Carried (by) -carried by various agents

- I: So if air plays role in the propagation of the sound, what's the role?
  TARA: Um, it contains the particles, which…vibrate and carry the sound wave.
- I: So how air allows sound to travel?
  JAMES: Or doesn't…um…it just…I guess it kind of carries sound then, like since it travels through the air molecules, it would just, it's kind of the… the mechanism that carries the sound.
  I: How is sound different from air? Is air some kind of carrier or it's, you know when you said carries, is it like ship on the water?
  JAMES: I would say it's almost like the messenger. Like a….like it carry…(long pause)…it just…. I guess air mol…. It just travels from one molecule to the next. So it's….it just carries the sound, I don't know how to put in the other way.

Transmitted – Sound is transmitted through the medium (it is not clear what does transmission mean to students who use that word)

- JEWEL: His words are…his voice is transmitted through, I guess the air to her ear.
- DAVID: The sound goes in [the can], goes in here and then it's transmitted through a string.

Transferred (by medium molecules), by vibration of medium molecules - conveyed by set of "middlemen" as water bucket.

- TARA: Um…the wall like helps them [sound waves] through. The wall is like the middleman between them and it kind of relays the sound waves.
- MARK: It's [vibration of air particles] like a…it's like the um, the transport for the sound.
- I: So how does this sound get on the other side?
  HOPE: Through the vibrations. Like…um…my vibrations…there's molecules everywhere, so the molecules will take the vibrations and transfer the sound to the other side.
- I: OK. So how how those particles enable sound to move?
  JANE: Um…because it goes from one particle to the next particle and I don't really, don't know how or why. I just know that that's what happens (laughs).

Transferred - by vibration of medium molecules that vibrate longitudinally with and without sound (expressed by only one student).

- I: OK. So what happens when loudspeaker plays slow rhythmic beats, like slow drum beating you know, it's not anymore constant tone…
  HOPE: Right.
  I: But: bum…bum…
  HOPE: Same thing. It doesn't move, it just vibrates back and forth.
  I: All the time?
  HOPE: Yeah.

I: I mean when there is sound and when there is no sound?
HOPE: Right, and the vibrating is what helps make the sound transfer, it's not moving the dust particle anywhere else.
I: OK, so does it move when there is no sound at all?
HOPE: Yeah.
I: OK. Is this movement the same…
HOPE: Yeah.
I: …as when the sound propagates?

Domino effect (in vibration of air particles, in longitudinal vibration of air particles)

- JEWEL: It's like…it's like a domino effect, it like, the first one goes on and then the like vibrations from it goes to the next one and moves on, and on down the line until it reaches the listener.
- ASHLEY: Um, like they create a wave by the…the sound makes the air particles vibrate back and forth and when the first one like starts vibrating then it…since it's kind of connected to the second one it, starts the second one vibrating so then it sets the vibration, like the wave of vibrations across.
- TARA: (Pause) When the vibrations come out of his mouth it moves like the air particles closest. Then that particle moves the next one, and so on down the line.
  I: OK. So vibration of what?
  TARA: (Pause) The air particle.

Domino effect (in one way movement of air particles, in frontal collision of air particles)

- DAVID: Um, it's just like a…it's a wave…it's a…(pause). I don't know it's…kind of like when you hit like a peace of metal and you feel on the other end just that, force, the vibration and the force just keeps pushing the particles. Um…Not the same particle. One particle might bump into another, which would bump into another. But that one particle doesn't travel all the way.

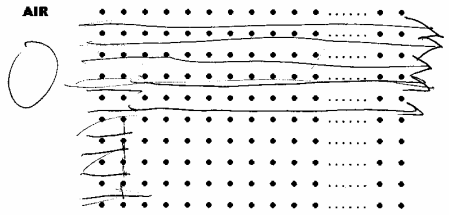
Domino effect (of sound waves – a sort of etheric particles that hit each other as they vibrate) (expressed by only one student)

- STAR: (Pause) I just understood that it's …these [vibrating dots] like…the sound waves that are traveling through across from each person. They bounce back and forth. They are hitting each other and they're causing it to travel…when it hits the next one.

PROPERTY CLUSTER: TRAJECTORY OF PROPAGATION

Straight traveling – In a homogeneous medium sound travels in a straight line.

- JUAN PACO: Well I would say that it would just go straight through each…Each section and each one…



Sine curving – travels along the sine curve in a homogeneous medium

- KAYLA: The wave, the sound wave is the wave…path of the wave, it just goes that direction.

I: OK, so this is direction [referring to straight arrow] and this is the way it moves [referring to sine-like curve]?
KAYLA: Yeah.
I: OK. This wavy line is the way it moves?
KAYLA: Yeah.

- I: Can this sound of loudspeaker in any of these cases cause this dust particle to go closer to loudspeaker than it was originally? Is it possible to arrange things that that happen?

…
DAVID: Um…It's possible in a sense that if you have a particle here and it maybe gets hit in a certain way like that which could cause it to fly back, but I think it will be very, very, very minimal, because if it goes that way, it's gonna hit, it's bound to hit another one.

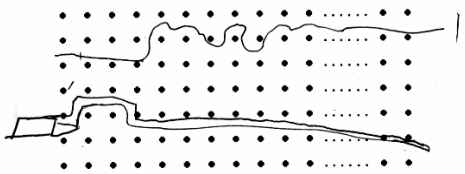
Zigzagging – zigzags in a homogeneous medium as bounces off its particles while keeping the main direction

- KAYLA: "It would go down and hit the particle and back up, hit the particle. Like it'd bounce off the particle here [referring to dots on the beginning of the wavy line as a particles on her drawing]."

Meandering – continuously changes direction in a homogeneous medium as affected by particles of the medium and other on its way.

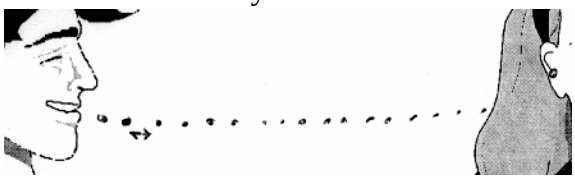
All can be directly associated to trajectory of any object and also to the normal of the wave front, which can be curving as wave diffracts or reflects.

- I: So what happens on this microscopic level as the sound reaches the wall?
  VIRGINIA: …Well I would say that it's somewhat like a maze for the…for the sound. It just kind of works it's way through until it gets to the other side.
  …
  VIRGINIA: I don't think sound can move them [particles of the wall]. I think sound just moves around them.
- DONNELIZER: It travels through just a little stuff. It just kind of works its way through, kind of like this [drawing] finding any of the little open areas that it can, until it gets to the listener.



Sound is moving back and forth – sound (sound wave) moves back and forth

- I: What happens and listener hears the speaker?
  JEWEL: OK. There…it causes like…the noise from his mouth like causes the disturbance and they vibrate back and forth…like this (drawing).



  I: What vibrates back and forth?
  JEWEL: The sound…and then…it goes all the way…until it reaches her ear.
  …
  I: OK. And what vibrates?
  JEWEL: Just the sound from his mouth…It doesn't really move but just vibrates back and forth so the sound gets from his mouth to her ear.

PROPERTY CLUSTER: SPEED OF PROPAGATION

Moves slower in denser medium (Slows down more in a denser medium)

- STAR: (Long pause) OK. I'd think now that…(laughs), I would say that the more the particles the more it's [sound] gonna slow down the speed.

Moves faster in denser medium

- ASHLEY: If there's more particles in the air then they'd be…more, like more air particles in it and then the sound … the sound would travel faster because there'd be more particles that would be vibrating.
- ASHLEY: Um, they said that…the sound actually moves faster through the solids so it'd move more quickly because the particles are closer together through the wall.

Moves faster if louder (Louder sound is faster sound)

- DONNELIZER: But the louder I am, the faster you're gonna hear it so it's gonna move faster, because it's louder…

Moves faster if medium particles vibrate faster (stated only by one student)

- I: OK. So louder the sound, faster it spreads and…
  ASHLEY: Yeah.
  I: Those air particles, is their vibration different?
  ASHLEY: Yeah, I would think that if the wave is moving slower than the vibrations are slower too.

Moves faster in vacuum than in air (stated by only one student)

- I: Yeah, where you would expect it to be faster [with air or without air – as previously stated it propagates through vacuum]?
  DONNELIZER: With no air.
  I: With the no air because…?
  DONNELIZER: Because there is no anything to affect it. It can just go from point A to point B.

Moves slower in vacuum than in air (stated by only one student)

- I: So it will be more difficult in space without air?
  VIRGINIA: Right. Yeah, I think it would maybe take longer for the listener to hear the speaker.
  I: OK, because there would be no air particles at all?
  VIRGINIA: Right.

Moves faster than air particles (both in direction of propagation)
Moves faster than dust particle (both in direction of propagation)

- I: OK. Is, is this movement of dust particle different than movement of air particles around it?
  BIC: Um, yeah. I would say the air particle probably move further and faster than the dust particle.
  …
  BIC: Yeah, the speed of sound would be the fastest.

PROPERTY CLUSTER: EASINESS OF PROPAGATION

Moves easier in solids and liquids than in gases

- JEWEL: Um, because, something in class it was like…steel and air…and it would be more likely…it's easier to travel through steel than air I think
- VIRGINIA: Sound does travel better through solids, so it travels better through, through this brick wall…

Moves easier through the string than through the air

- I: So it's better for him to travel through the rope than through the air?
  STAR: (Pause) Yeah, because dust particles are gonna slow it down, and if it's traveling on the rope then nothing will slow it down, probably.
  I: How about particles of the rope?
  STAR: (Pause) I guess they'd slow it down…a little.

Moves easier in less dense medium (Slows down more in denser medium)

- BIC: Oh, thicker the material, the more dense I guess, it would be harder to go through.
- JAMES: (Pause) Um…all of the…or maybe the denser is the air or something maybe the slower the sound would….move.
  I: OK. So why it actually slows down going through the air?
  JAMES: Because of the…air molecules or something.

Moves easier in denser medium

- I: So if particles are further apart sound will spread faster, easier…?
  HOPE: It'd make it more difficult.
- JANE: When it [sound] goes out of the wall into the listener's side, it is then reaching again for particles and the particles are harder to find and…I'm making it sound like it's something grabbing it, but you know the waves have to find the particles to travel so it's having a harder time or…there aren't as many on the listener's side so…

Moves easier in air than in vacuum (stated by only one student)

- I: And in space without air, would anything be different for the sound than in space with air?
  VIRGINIA: Well as far as I can understand from the lecture that…it would be more difficult because it doesn't have those particles to travel against or with, or however we want to say that.

Moves easier in vacuum than in air

- I: OK. So this is impact of sound on air and impact of air on sound would be?
  JORDAN: It will be to change it and to weaken the disturbance eventually as it moves along.
  I: OK, so without air…?
  JORDAN: It'd just keep moving, without any change.
  I: OK, so would it go basically infinitely in that situation, totally without air?
  JORDAN: Uh huh (Yes).
- LORAIN: I'd almost think [in vacuum sound would propagate] better [than in air], because there would be nothing to hinder it at all. I mean, there would be nothing to affect where it went, because there is nothing.
- DONNELIZER: I think that if there was no air in the room, it would just be…sound would come out louder to the person.

Moves easier through thinner objects

- MR.T: Thicker the wall, loudness of the sound is less.
- HOPE: I think the thicker it is [the wall] then the less you will hear.

Moves easier through tight than loose string

- BIC: It's a tighter rope, so it's easier to vibrate.

Moves easier along straight path - Travels easier through the straight path than through the curved path. (This property is similar but not identical with Inertial property related to sound)

- BIC: So because it was a direct route it was louder through the can.

Moves farther than air particles and dust particle (all in direction of propagation) – (stated by only one student).

- I: OK. So how does the sound move when compared to movement of air particles and dust particle?
  KAYLA: The sound moves farther.

Louder sound moves medium particles back and forth faster (stated by only one student).

- VIRGINIA: Maybe it's just not moving the particle back and forth as fast, so it doesn't sound as loud.

PROPERTY CLUSTER: AFFECTABILITY

Affectable – Sound can be affected

- LORAIN: Um…I would say…I don't think that it influences the air. I would guess that the air actually influences the sound waves.
- DONNELIZER: Would sound affect air? No, I think air affects the sound.

Affectable – hindered (slowed down, stopped, blocked – by), the wall acts as a barrier - An outer agent hinders it's propagation, slows down, stops, blocks.

- I: OK. And what would you guess, why is sound quieter on the listener's side than on speaker's side?
  SALLY: Because some of the sound is blocked.
  I: OK. How is that?
  SALLY: From the particles.
  I: From what particles?
  SALLY: In the wall.
  I: OK. So what do they do to sound…particles of the wall?
  SALLY: Block sound.
- GUNZ: Air might slow down the sound wave or something like that.
- LORAIN: The wall is thick, it's [sound] not gonna make it all the way through because eventually it's gonna hit a particle or it's gonna hit something that's gonna cause it to stop.
- TARA: So therefore they [particles of the wall] kind of stop the sound waves but some of the sound waves still make it through the wall.

Affectable – distorted (muffled) - Sound changes its features, clarity, distinctness

- JENNIFER: I think the sound would be muffled for the person on the other side [of the wall], like it won't be sharp or distinct.
- JAMES: You might hear the sound [on the other side of the wall] but it's gonna be distorted. You…you're not gonna understand. I'd say the words…it's not gonna be words it's just gonna be a sound.
- JEWEL: I think he might be able to hear the noise [on the other side of the wall] but not distinguishable…

Affectable – dispersed (spreads out) - Sound spreads out in various directions when encounters medium particles of particles in medium

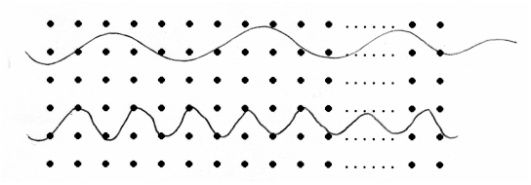
- KAYLA: It hits particles [of the wall] and so like when it hits particles it'll go in different direction."
- HOPE: Um, the sound, it spreads out through the rest of the molecules [of the wall], more in the solid than in the air.

Affectable – bounces off objects (bounces off macroscopic objects, bounces back off objects)

- DAVID: Yes, so there will be the wall there and it'd hit the wall and bounce back to you. Or, I mean it bounces around and hits you I mean that's why I can still hear you.

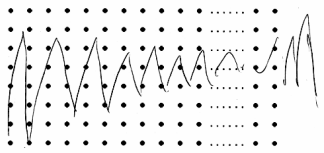
Affectable – bounces off medium particles

- JUAN PACO: Um…(pause) maybe it would just go…(pause) it will go from particle to particle, like that…(pause). Yeah, that's what they do [refers to bottom line drawn on the picture].



Affectable – absorbed (gets lost within the wall, goes into the wall particles, dies off in the wall) An outer agent can "use it up" or absorb.

- KAYLA: Some of it [sound] would go into the wall…particles.
- I: So what this drawing represents?
  SHEILA: It represents how…the sound is absorbed in the wall.



Affectable – weakened (looses strength, gets quieter, looses vibration, looses sound, dissipates)

- KAYLA: "…maybe it [sound] would hit the particles [of the wall] and loose some of it's vibration."
- JAMES: When it…this waves hit the wall it tries…then it tries harder to move the…the molecules of the wall, they can't so it becomes weaker…I don't know.
- MEG: It's because it takes away some of the (laughs), some of the sound like...not particles but…it takes away some of the sound so she's gonna hear less.

Non-affectable - can not be affected by outer agent

- ASHLEY: Umm…I don't…I don't know. It doesn't seem like it [air] would interfere at all with the sound waves going and it seems like they can go through the air freely.
- MEG: It travels through the air, fine, bit then when it hits the bricks, the brick absorb the sound wa…the sound [this "wa" was probably beginning of waves].

Non-affectable – desensitizing - objects are getting used to sound (stated by only one student)

- KAYLA: Like it [dust particle] gets used to, I mean I don't know how is that, but it gets used to the sound [and that is the reason constant sound moves the dust particle only when it first encounters it and then it does not move it anymore].

Facilitated by (helped by) – The medium or an outer agent helps the sound to move, vibration of air particles moves sound

- BIC: Because there is something, the string is helping carrying the vibrations to me and it's also amplified by the…the can.
- DAVID: The air keeps vibrating with it [sound], which helps it travel.

- TARA: Well, air particles um…they vibrate which will help…carry the sounds.
  I: And so is sound something that air particles carry?
  TARA: (Pause) They don't carry it because the sound moves, but it [air] helps it [sound] travel.

PROPERTY CLUSTER: INTRUSIVENESS

Intrusive (moves objects - air particles, dust particle, wall particles) (possibility: with interruptions when there is no sound) – sound moves, or affects the movement, of objects it encounters but in an unspecified way.

- JORDAN: As you're sending sound across through them, it [dust particle] would have to move somehow.
- TARA: The noise like moves the air…in a wave like pattern.

Intrusive - hits (objects, collides with objects, bounces objects off) - Comes forcefully into contact; strikes:

- JORDAN: I just, I think they [sound waves] would just sort of move in a wave like motion and then sort of just hit it [the dust particle] and then shake up a little bit and then just go right through it…and it would just continue on its path.
- DAVID: It's sitting there just like the air and it's just kind of dead, motionless until sound hit's it [the dust particle] and causes it to move like part of the sound actually.

Intrusive – disperses (objects) – kicks off different particles in random directions away from path of movement

- TARA: It could go in any direction [dust particle] except for I don't think it could go back [due to sound propagation].
- DAVID: It's just from a sound and a wave. It would just kind of cause it [dust particle] to fly off, going in any type of direction…and most of the wave actually catches back up to it after it moved it once and it'd just kind of go off and kind of…and…it might keep bouncing around everywhere because you know sound travels everywhere, but that…it would just be random fly-off in different directions.

Intrusive – pushes (objects) – Moves particles in a direction of a sound propagation. Never moves particles backwards.

- JORDAN: It'd probably keep pushing it until the sound…will shut off…until the source of sound will shut off.
- DONNELIZER: Because the sound waves would hit it [the dust particle] and just move it, like move it along, just pushing it.

Intrusive – displaces (objects) – Sound changes the position of object one point to another- in our case all the way to the listener

- I: OK. Suppose sound is long enough, would it eventually reach the listener, would air particle eventually reach the listener?
  ALLEY: I believe it would, if it's long enough.

Intrusive – (objects) vibrate - sets encountered objects into vibration, shakes objects

- KAYLA: It's like when he hit the drum and stuff, like you can feel, wherever you are standing you can feel the ground shaking and so that would make the dust particle move.
- JORDAN: As the sound goes trough the particle it just vibrates it. I don't know how though it does that.

Intrusive – (objects) vibrate longitudinally – along the direction of propagation ("back and forth")

- I: OK. So how air particle move?
  TARA: Back and forth with the err…longitudinal wave.
- ASHLEY: OK. Um…I think as he speaks, like the…sound waves come out and like it goes through the molecules that are in the air, like air molecules, and they vibrate back and forth creating the wave all the way and the little molecules do that until they get all the way to her ear.

- I: So how air moves?
  MARK: (Pause), Yeah, it's gonna…move like a…side to side.
  I: Like back and forth?
  MARK: Yeah, like back and forth, like the spring moving back and forth.
- I: So in which way? What happens to air molecules as the sound propagates?
  JENNIFER: They move. I just see them moving.
  I: Ok. How?
  JENNIFER: Back and forth.

Intrusive – (objects) vibrate transversally – perpendicularly to the direction of propagation ("up and down")

- KAYLA: Probably. OK. It's probably like in the wave, like it'd [dust particle] go up and down, kind of like that.

- I: As it goes through the wall would it move wall particles? In any way? Would it influence wall particles at all?
  ALLEY: Um…(long pause)…I am not sure. I think maybe they would move up and down.
  …
  ALLEY: I mean I would expect it to move more forward a little bit, I mean I can't imagine it, I mean just from experience I've never known anything like that. Like if you sit here and blur loudspeaker in front of just a plain brick wall it's not gonna move, and we won't be able to see it really.
  I: So they would just go up and down?
  ALLEY: [Affirmative nodding with head]

Intrusive - pushes (objects) + (objects) vibrate longitudinally (stated by only one student)

- MEG: It's going [air particle] kind of with the vibrations, so it's like going back and forth, but as it's kind of going back and forth it's moving across slowly.

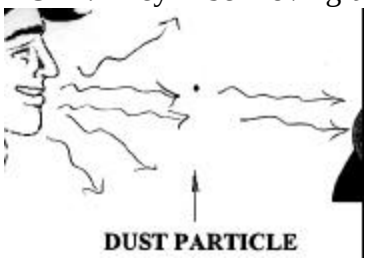
Intrusive - pushes (objects) + (objects) vibrate transversally

- JENNIFER: But now (laughs), I mean it [dust particle] could go up with the beat and stay there and then go up again with the beat when the beat comes and continue to do that.
- I: Can you draw how it'll move. The dust particle?
  ALLEY: (Pause) Umm…let's see…(pause)…mm, like I think it would just move up and down with the sound wave and the slightly along with the, it'll slightly carry it.

I: And in the same time it'll go…?
ALLEY: To the right, it would go closer to the listener, I would think.

Intrusive – pushes (objects) along sine curve – Moves particles in a direction of a sound propagation along sine-like curve. Never moves particles backwards

- I: How air molecules are moving and how dust particle is moving?
  HOPE: They'll be moving this way. [Draws horizontal wavy lines].



I: OK.
HOPE: Because you're speaking that way…
I: Good.
HOPE: …and so the dust would also just, kind of, get wrapped up in all this, and also will be going this way.
I: When you drew this wavy line, why is this movement wavy?
…
HOPE: Because I don't believe that molecules travel in a straight line.
…
I: But similarly like what you drew?
HOPE: Yeah, something like that.

Note: All intrusive actions may also be with pauses (interruptions) in periods without sound (context 3a)

Non-intrusive (for medium particles and particles in medium - air particles, dust particle, wall particles) – sound does not affect the movement of particles it encounters.

- I: Now we have this dust particle in front of the speaker. The question is now if his sound will affect the dust particle?
  KAYLA: (Pause) No, because it's not material and dust particle is material."
- JENNIFER: But I don't think it [the sound] affects the air, I mean I think it travels through it, but I don't think it affects it.
- I: OK. And would this sound influence movement of the particles of the wall?
  JORDAN: (pause) Probably not, because it'd just go…It'll find the way in between them.
- MEG: I don't think that sound coming out of your mouth is something that can move something physically in the air.

APPENDIX C
EXAMPLES OF MODELS EXPRESSED BY MORE THAN ONE STUDENT

In this appendix I will give one more example of entity and wave models and example of hybrid models that were expressed by only one student.

Example of entity model:

Informant's (Ashley's) demographic info: main population student, had no high school physics, section taken from pre-instruction interview transcript.

CONTEXT 1a.

"I: So, as the sound propagates, does it affect the air in any way?
ASHLEY: No.
I: OK. And would anything be different for sound in space with air 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.

MODEL: Entity: Independent

I: OK. So when would you expect sound to propagate kind of easier?
ASHLEY: Um, when there is like no objects in its way, when it's…just has free room to travel.
I: OK. So in case…in case when we have situation with air and without air…
ASHLEY: Uh Huh (Yes)
I: …when it propagates easier?
ASHLEY: Without air.

MODEL: Entity: Independent

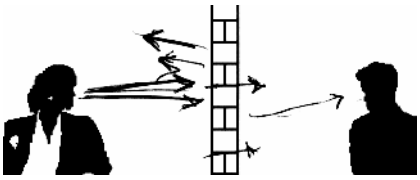
I: Without air. OK. And does air play any role in this process? As we speak there is air between two of us. Does it play any role in this process?
ASHLEY: Umm…I don't think so. I'm not sure. (laughs).
I: Good or bad role…
ASHLEY: Umm…I don't…I don't know. It doesn't seem like it would interfere at all with the sound waves going and it seems like they can go through the air freely.
I: How do you perceive them? Those sound waves going through the air?
ASHLEY: Umm…I don't really know. Um…I…Um, I really don't know. I guess…like moving forward from the direction where they come from and moving out in all directions from where they come.
I: And would you say they are made of some…They are kind of…err…same kind of entity?
ASHLEY: Umm… Nooo…no. I, like I don't think there is any substance to them at all.
I: OK. OK. Would they…would propagation of sound influence the movement of air particles? I think you've already answered that one.

ASHLEY: Am…I'm not…really sure…would it interfere with the air is that…?
I: Would it influence the movement of air particles as it propagates through the air?
ASHLEY: Oh…No. No, I don't think so.
I: OK. OK. Let's go further.

MODEL: Entity: Independent – Strong form

CONTEXT 4.

I: What would you say about the possibility for those two people to hear each other's voice if they talk loudly?
…
ASHLEY: OK. Um. Like the sound…she would talk, but many of the particles would bounce back off the wall, so a lot of them would go through, but I guess some of them might escape like through the bricks…
I: What particles?
ASHLEY: Um. Some of the sound waves might, like go through the wall, but most of them would bounce back in another direction maybe…once when they come in contact with the stuff.



I: So sound waves or sound…you said particles…?
ASHLEY: Yea. I, …I meant the sound waves.
I: OK, so sound will bounce back and sound will go through?
ASHLEY: Yea.
I: And so how is sound wave different from some kind of particles that would be moving?
ASHLEY: Um…
I: How is it different?
ASHLEY: I…because the waves are, like, made up of energy not made up of substances.
I: OK. So they are kind of entity but not made up of mat…substance but of energy?
ASHLEY: Right.
I: OK. And now this portion that goes through….
ASHLEY: Uh huh (Yes).
I: How it manages it?
ASHLEY: Um…(pause). I don't know because they are small enough that there's, like…they can…I don't know…some of the energy like can travel…through the wall… maybe. Or through like if there's any like little cracks or holes there, anything in the wall then the energy can go through those spaces.
I: So if there are no cracks?

MODEL: Entity: Seeping

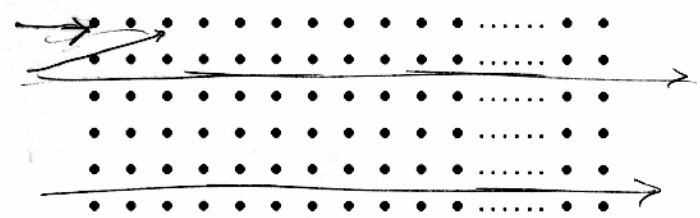
ASHLEY: Umm…I don't know (laughs).
I: Just homogeneous material?

ASHLEY: Um…(pause). I'm not sure how they trav…I don't know how they would go through it if there aren't any holes at all, but I would say that some of them would, like get…the listener will still be able to hear some things…So I'm not…quite sure why.

MODEL: Entity: Seeping – Strong form

CONTEXT 4a.

I: OK. Now, this is sub-situation…
ASHLEY: Uh huh (Yes).
I: …so what happens on this microscopic level as the sound riches the wall?
ASHLEY: Um. Probably as it reaches the wall there will be some that would like go through there…maybe. As sound can travel through the different places, and get through.



MODEL: Entity: Seeping

I: OK. Would this sound… would this propagation of sound through the wall influence the movement of the particles of the wall?
ASHLEY: No.
…

MODEL: Entity: Seeping – Strong form

Related to entity model we can mention here also several sound properties that could be considered as indicators of the entity model, but which we discarded in this study as not good enough to be uniquely associated with the entity model. These are:

- Separable (Countable) – Sound can become disunited or disjointed. One sound can be removed from others. A number of sounds can be determined.
- Corpuscular – Sound has a spatial volume, a structure. It can be dissolved/broken into pieces.
- Inertial – Sound tends not to change direction of propagation. Loosed string looses some of the sound because of the curvature.
- Gravity sensitive – Sound curves downward while propagating.
- Buoyancy sensitive – Sound is supported upward by air. Sound falls down without air to support it.
- Sine curving – Sound travels along the sine curve in a homogeneous medium
- Zigzagging – Sound zigzags in a homogeneous medium as bounces off its particles while keeping the main direction.
- Meandering – Sound continuously changes direction in a homogeneous medium as affected by particles of the medium and other on its way.

- Affectable: bounces off – Sound bounces off the medium particles.
- Affectable: disperses – Sound spreads out in a various directions when it encounters the particles in/of the medium.
- Intrusive: disperses – Sound disperses the particles of/in the medium. It kicks off the different particles in random directions away from the path of movement.
- Non-intrusive (for medium particles and particles in medium - air particles, dust particle, wall particles) – Sound does not affect the movement of the particles it encounters.

Example of wave model:

Informant's (Mr.T.'s) demographic info: Interviewed post-instruction only; had 2 semesters of high school physics.

CONTEXT 1.

I: …try to describe, as fully as you can, how the sound propagates in this situation? So what's going on between these two people as this sound propagates?
MR.T: So what allows her to hear what you're saying?
I: Exactly.
MR.T: Um, as we learned in class that um…sound waves are coming out of his mouth. It's vibrating against the air particles. They create back and forth waves, longitudinal waves, and they eventually reach over to her ears, which she's going to hear and vibrate her eardrum.
I: OK, so what is sound wave?
MR.T: Sound wave is um…nothing more than a motion, disturbance in the air, moving in one direction.

MODEL: Wave – by definition

I: OK. So what is disturbed?
MR.T: The position of the particles. They don't move up and down just this way back and forth.
I: OK. So does air plays a role in this propagation
MR.T: Yes.
I: So what's the role of the air?
MR.T: The particles of the air, little molecules that make up the air make the…Through the motion they create the wave.

MODEL: Wave – Strong form

Example for shaking hybrid model:

Informant's (Jordan's) demographic info: main population student; had 2 semesters of high school physics; section taken from post-instruction interview transcript

CONTEXT 1a.

I: It moves through the air, so in the space without air would anything be different for sound?

JORDAN: (Pause) Probably it'll, it wouldn't a…it wouldn't slow down, it'd just keep traveling.

MODEL: Entity: Independent

I: OK. Does propagation of sound affects the air?
JORDAN: Um, yes.
I: How?
JORDAN: It sort of shakes up all the molecules in the air. So it shakes them up so they are moving as it passes through.

PROPERTY: Intrusive – (air particles) vibrate

I: OK. So this is impact of sound on air and impact of air on sound would be?
JORDAN: It will be to change it and to weaken the disturbance eventually as it moves along.
I: OK, so without air…?
JORDAN: It'd just keep moving, without any change.
I: OK, so would it go basically infinitely in that situation, totally without air?
JORDAN: Uh huh (Yes).

PROPERTY: Independent

I: OK.

MODEL: Shaking model – hybrid (SH) – Strong form Through combination of sound properties: Intrusive – (air particles) vibrate Independent

Example of Longitudinally shaking model:

Informant's (Virginia's) demographic info: main population student; had no high school physics; section taken from post-instruction interview transcript.

CONTEXT 1.

"I: What's going on between two of them and the listeners hears the sound?
VIRGINIA: OK. The sound comes out of speaker's voice and moves the particles back and forth just the little bit. Then it goes on to the next one till it moves to the listener's ear.
I: Particles of what?
VIRGINIA: Particles of air.

PROPERTY: Intrusive – (air particles) vibrate longitudinally
PROPERTY: Domino effect (in longitudinal vibration of air particles)

…

I: Yeah.

VIRGINIA: And the sound comes out of the speakers voice and it causes that first particle to move back and forth, which, I guess, might trigger a vibration which moves it to the next one and it does the same thing and keeps going till it hits the listener's ear.

PROPERTY: Domino effect (in longitudinal vibration of air particles)

I: OK. Now I understand this part.
VIRGINIA: OK.
I: So, how is sound related to movement of air particles?
VIRGINIA: …I don't know (laughs). I really don't.
I: OK. That's fair enough.
(Irr.)

CONTEXT 1a.

I: And in space without air, would anything be different for the sound than in space with air?
VIRGINIA: Well as far as I can understand from the lecture that…it would be more difficult because it doesn't have those particles to travel against or with, or however we want to say that.
I: So it will be more difficult in space without air?
VIRGINIA: Right. Yeah, I think it would maybe take longer for the listener to hear the speaker.
I: OK, because there would be no air particles at all?
VIRGINIA: Right.

PROPERTY: Independent

I: OK, so how would sound get to the listener in that situation?
VIRGINIA: …Good question…(pause)…I have no explanation for that, I don't know (laughs). We didn't study as much on sound as I thought we are going to for this.
I: OK.
VIRGINIA: So…
I: OK. But I mean you're saying it will propagate but not as well…
VIRGINIA: Clearly or…as quickly.
I: Yeah, as in air?
I: So the question was, as the sound propagates does it affect the air in any way, so did you already answered this question or…?
VIRGINIA: Um…it affects the air particles that…it just moves back and forth but the air particle, like the first air particle doesn't travel all the way through to the listener's ear, like I thought before. It just moves back and forth and then that causes it to go to next one, which does the same thing.

I: OK. This is how sound influences the motion of air particles [referring to the drawing]?
VIRGINIA: Right.
I: OK. Good.

PROPERTY: Intrusive – (air particles) vibrate longitudinally
MODEL: Longitudinally Shaking model – hybrid (LSH) - Through combination of

sound properties: Intrusive – (air particles) vibrate longitudinally, Independent - Strong form

Example of propagating air model:

Informant's (Hope's) demographic info: main population student; had no high school physics; section taken from pre-instruction interview transcript.

CONTEXT 4a

I: So what happens on this microscopic level as the sound reaches the wall? Now these are brick molecules?
HOPE: Right.
I: And sound comes from speaker's side.
HOPE: OK.
I: What happens?
HOPE: Is there that much space in between the molecules?
I: Yeah, and now this is microscopic structure.
HOPE: OK. Right.
I: So we just enlarged it really a lot.
HOPE: OK. I think I've changed my answer [that brick molecules vibrate in the wall].
I: OK.
HOPE: I think that air molecules vibrate among the brick molecules, but…do you want me to draw all this for you?
I: Yes sure, please.

HOPE: I think they kind of go in and through all of this, bouncing off of the brick molecules and come out on the other side.
I: OK.
HOPE: So they can listen and hear it.
I: OK. That was clear. Would this propagation influence the movement of wall particles?
HOPE: Um (pause) a little bit but not very much.
I: OK. I see. Why, because…?
HOPE: Because I think that air molecules kind of use the wall molecules just to bounce of them, or so.
I: OK, and that causes these wall particles to…?
HOPE: Just to move a little bit but not very much.
I: OK. Move a little bit. So they will move and stay where they left?
HOPE: Yeah.
I: OK. This is air molecule on your drawing?
HOPE: Right.
I: OK.

MODEL: Propagating air model – hybrid (PAH) – By definition - Strong form