Journal of Science Education and Technology, Vol. 16, No. 3, June 2007 (© 2007)
DOI: 10.1007/s10956-007-9048-4

Comparing Students' and Experts' Understanding of the Content of a Lecture

Zdeslav Hrepic,[1,2,3] Dean A. Zollman,[2] and N. Sanjay Rebello[2]

In spite of advances in physics pedagogy, the lecture is by far the most widely used format of instruction. We investigated students' understanding and perceptions of the content delivered during a physics lecture. A group of experts (physics instructors) also participated in the study as a reference for the comparison. During the study, all participants responded to a written conceptual survey on sound propagation. Next, they looked for answers to the survey questions in a videotaped lecture by a nationally known teacher. As they viewed the lecture, they indicated instances, if any, in which the survey questions were answered during the lecture. They also wrote down (and if needed, later explained) the answer, which they perceived was given by the instructor in the video lecture. Students who participated in the study were enrolled in a conceptual physics course and had already covered the topic in class before the study. We discuss and compare students' and experts' responses to the survey questions before and after the lecture.

KEY WORDS: instruction; lecture; perception; physics; physics education; sound; understanding.

INTRODUCTION

Besides one-on-one teaching, the lecture is probably the oldest instructional format and today it is still the most common form of instruction. Therefore, it is not surprising that educators have been paying close attention to issues related to this teaching method (e.g. Cazden, 1988; Exley, 2004). This attention has resulted in variety of findings significant for improvements of classroom practice (Cooper and Simonds, 2003). However, the situation is far from satisfactory. Science education researchers are still concerned with questions that sound somewhat frustrating such as "Do they just sit there?" (Zollman, 1996) and "Why don't they understand us?" (Kvasz, 1997). Due to its advantages (primarily instructor-student ratio) the lecture is not likely to be replaced soon as a teaching method, although novel instructional formats have been developed, many of which have been proven to be more effective than traditional lecture (Hake, 2002). Therefore, the topic deserves our attention.

MOTIVATION

This study was motivated by an observation that the authors made during earlier research on students' mental models of sound propagation (Hrepic *et al.*, 2002). During that study students enrolled in a concept-based physics class were interviewed before and after the instruction. Interviewees knew that essentially the same interview questions would be asked after instruction. They also knew that they would receive identical extra credit for participation regardless of their performance.

[1]Physics Department, Fort Hays State University, Hays, KS, 67601, USA
[2]Physics Department, Kansas State University, 116 Cardwell Hall, Manhattan, KS, USA
[3]To whom correspondence should be addressed; e-mail: zhrepic@fhsu.edu

1059-0145/07/0600-0213/0 © 2007 Springer Science+Business Media, LLC

During the post-instruction interviews students reported that they sincerely attempted to learn the answers to pre-instruction interview questions during the lecture. Some of these students directly asked the instructor some of the interview questions both during and after the lecture. One student, anxious to give the right answers, even asked for permission to keep her class notes at hand during the interview so she would not confuse the terminology. Yet, in spite of the motivation that many of them had, what they learned from the lecture was far from satisfactory. Above all, some students were seriously wondering if the lecture they saw had anything to do with the interview questions. During the post-instruction interview, students were asked basic questions about the nature of sound propagation and whether sound propagates in a vacuum. Rather than providing an answer, one student, for example asked the interviewer with an apparent dose of frustration: "Did we learn all this stuff in class? Like, should I know all of these answers?" She repeated the same question again near the end of the interview.

The simplest possible explanation for this situation is that the instructor did not do a good job, but that does not appear to be the case. One of the authors (Dean Zollman) was the Head of the Department during the interview process. As part of his duties he observed a lecture that was coincidentally the one during which the instructor explained sound propagation. After seeing the lecture, Dean Zollman believed the instructor simply gave the answers to the interview questions "on a silver platter." He was therefore concerned that post-instruction interviews might be useless because most of the students would uniformly know the answers. However, this was not the case. So, a clear discrepancy existed between the expert observer's and the students' perceptions about the informativeness and clarity of the same lecture. The expert believed that the lecturer clearly articulated answers to the interview questions, yet some students did not even realize that the lecture was relevant to the questions for which they were actively seeking answers. In this situation we were faced with the same questions mentioned above: "Do they just sit there?" and "Why don't they understand us?"

GOALS

Based on the anecdote described above, we decided to conduct a study that would address the following questions:

- What kind of questions do students perceive as being answered in a lecture?
- How are students' perceptions related to their knowledge prior to the lecture?
- How do students' perceptions of the content of a lecture compare with those of experts?

CONTEXT OF THE STUDY

The study was conducted at Kansas State University, a Midwestern public university. We accomplished our research goal through individual interviews of students enrolled in "The Physical World," (referred to from now on as P-World) a concept-based introductory physics course at KSU. The class used *Conceptual Physics* (Hewitt, 1998) as a textbook. Interview questions addressed aspects of sound propagation. All interviews were held after the instruction in which students covered the following topics:

1. Vibrations and Waves: Speed, Transverse and Longitudinal Waves
2. Interference, Standing Waves, Doppler Effect
3. Sound: Origin, Nature, Transmission, Speed
4. Reflection and Refraction of Sound, Resonance, Interference

Participants completed their class exams related to these topics before the interviews.

METHODOLOGY

We interviewed 18 P-World students. Half of these students had taken two semesters of physics in high school. Eight of them had no physics in high school and one student had it for one semester. Thirteen students were female and five were male. The student participants volunteered to take part in the study for an extra credit worth 2% of the total course grade. It should be noted however, that our interviewees scored marginally higher on the class exam related to this topic (vibrations, waves and sound) than the class as a whole. Also, there was less variability in test scores of our interviewees than overall. This indicates that we did not get our sample from the low performing segment of the class population.

During the experiment all participants saw the videotaped lecture in what we considered an idealized format. Our intention was to set up an experiment in which factors that normally inhibit learning during the lecture (e.g. poor teacher quality, lack of concentration toward the end of the class period, classroom noise, etc.) were eliminated as much as possible. Besides elimination of these inhibitors, our idealized lecture also had several important advantages that are not normally present in a lecture. These will be discussed below.

Before the experimental video lecture all participants were asked to answer six questions related to sound propagation. These questions were deliberately chosen so that they were addressed in different ways and to different extents (depths) during the lecture that followed. They ranged from a question addressed explicitly and multiple times to one not addressed even indirectly. These questions (Q) are listed below

1. Describe how sound propagates when a speaker talks and a listener hears her voice?
Answer: The speaker sets the air particles around her mouth into longitudinal vibrations. These vibrations or disturbances are transferred to adjacent air particles. In this way the disturbance travels to the listener, who perceives it as her voice.
2. Does the speed of propagation of sound in the air depend on the temperature of the air? If not, why not? If yes, how does it depend on the temperature of the air?
Answer: Yes. Sound propagates faster if the temperature is higher.
3. Does the speed of propagation of sound depend on the motion of the source? If not, why not? If yes, how does it depend on the motion?
Answer: No. While the observed frequency of sound will depend on the motion of the source relative to the receiver, the speed of that sound is affected only by the properties of the medium in which the sound propagates.
4. Does the speed of propagation of the sound depend on the medium through which it propagates? If not, why not? If yes, how do the speeds of sound in solids, liquids and gases generally compare with each other?
Answer: Yes. Generally it is faster in solids than in liquids and faster in liquids than in gases.
5. Would anything be different for sound propagation in the space without air (vacuum) and in the space with air? If not, why not? If yes, what would be different?
Answer: Yes. Sound does not propagate in vacuum.
6. We have a dust particle floating motionlessly in front of a silent loudspeaker. There is no wind in the room. In one moment we turn the loudspeaker on. If the loudspeaker is playing a single constant tone do you expect that this sound will affect the dust particle? If not, why not? If yes, how? (Describe its motion.)
Answer: Yes. It will vibrate longitudinally.

After students completed the initial written survey the researcher discussed the given answers to make sure the student understood the questions and to seek further clarifications of the answer if necessary. The initial survey had three purposes: (1) to mentally warm up students for the topic, i.e. to put the students in a mental mode in which they were thinking about sound; (2) to present the students with questions for which they should be seeking answers in the video lecture; and (3) to provide a pretest on the topics to be discussed in the lecture (i.e. to determine if they knew the correct answers before this lecture).

After the initial survey, students watched the experimental videotaped lecture. To ensure we had a high quality teacher, we chose a segment of the videotaped lecture of an internationally known teacher and author, Paul Hewitt. Hewitt is also the author of the textbook that the students used in their physics class so the video lecture and the textbook that students were using were reasonably coordinated to the same extent at which they are typically coordinated in a regular course. The segment was chosen as part of the lecture that specifically deals with the nature of sound propagation and it was taken from a commercially available tape "Vibrations and Sound II" (Hewitt, 1991). The segment starts with instructor's statement about the speed of sound in air and finishes with his definition of refraction.

We considered this video lecture format idealized because:

1. The instructor whose lecture was shown to participants is a nationally and internationally recognized teacher and the author of one of most popular textbooks for a conceptual physics course.
2. Before the study the students had already heard classroom lectures on the topic of the video lecture.
3. Before the study students had already taken the class exam related to this topic. For this reason we can assume that many of them did study the topic (at least to some extent) in addition to the class lecture. Students who participated in the study performed on average slightly better on this test than the class as a whole.
4. By taking the survey just prior to the video lecture students became familiar with the questions for which they were supposed to find answers during the lecture. This way they could be more focused on these specific questions, rather than on everything that the lecturer said. The question reminder list was available to them while they viewed the tape.
5. After participants finished with the survey, the researcher went through all of the questions and answers to make sure they understood the questions (and that he understood their answers).
6. By taking the survey right before the lecture, students were alerted to and mentally warmed up for the lecture topic.

7. The "lecture time" was approximately 14 min, which is less than 1/3 of the normal class time, so students could keep their concentration at a higher level than during the typical 50 min lecture.
8. Students were allowed to pause/stop and rewind the tape at any time during the lecture. This way we eliminated possible misunderstandings due to the speed of the talk, terminology that was used, pace of delivery, etc.
9. There were no typical classroom distracters such as noise, conversations and other interruptions.
10. Both the lecturer and participants were native English speakers, which is a kind of compatibility that is not always present in US physics classrooms.

All of these advantages are significant when we compare this situation to a real classroom lecture. We contend that if problems are found here, we can conclude that in a real lecture, the situation can only be equal or worse.

After completing the survey and before seeing the video lecture, participants were given the following instruction: "In this part, you are looking for the lecturer's answers, which may or may not be same as ones you have given initially. Note: The questions may not be answered in the same order as they are posed. They also may be answered more than once or not answered at all. If you see the question answered more than once, please record the given answer each time."

While watching the lecture participants were asked to indicate the question that was answered and the time on the tape at which it was addressed. They also recorded the answer as (they perceived) it was given by the instructor. Finally they indicated the extent to which the question was (in their opinion) addressed by the lecturer on a scale ranging from 1 (hint of the answer) to 5 (answered completely).

At the end of the video lecture the participants were asked if answers to any of the questions could be inferred from what they had heard in the video lecture. This follow-up question ensured that students recorded answers that they perceived to be implicit in the video lecture even though the answers might not have been stated explicitly by the lecturer.

Besides investigating students' perceptions of the lecture, we probed the responses of a panel of experts following the same protocol. For the purpose of this study experts were defined as M.S. or Ph.D. degree holders in physics or Ph.D. students in physics who had completed their coursework. In addition, we required that the expert's mental model of sound propagation before the video lecture was definitely the wave model. Two of the 11 potential experts were disqualified as they did not satisfy the latter criterion. Some of the data we collected with disqualified experts will be mentioned separately from the rest of the experts.

Finally, we asked the videotaped instructor, Paul Hewitt, to answer the same set of questions in the same way as our interviewees. His input was an invaluable point of reference for this study.

DATA ANALYSIS

For the data analysis, participants were grouped as students and experts. Input from Dr. Hewitt was analyzed separately from the other experts and is denoted in the results section of this paper as the lecturer's answer. Experts' results were also analyzed without including the two disqualified participants.

Classifying participants' answers and ratings was relatively straightforward for all of the questions except the first one that dealt with the nature/mechanism of the sound propagation. Due to the complexity of answers related to this question, we classified them in terms of the mental models of sound propagation that they depicted. Models were identified through the procedure described earlier for identifying mental models of sound propagation (Hrepic *et al.*, 2002, 2005). Models found in this study were a subset of those described earlier. They include:

1. Wave model: This is the scientifically accepted model. This model was described earlier as an answer to question 1.
2. Entity model: According to the entity model, sound is an autonomous, self-standing unit different from the medium through which it propagates. We refer to this unit as an "entity." Two major kinds of entity models are:
   a. Independent Entity model—according to which the sound entity does not need a medium to propagate.
   b. Dependent Entity model—according to which the sound entity needs motion of medium particles to propagate.
3. Ether model of sound: Sound is propagation of the disturbance created by longitudinal vibration of sound particles or sound molecules that are different from the particles of the physical

medium. The following example that a student wrote should clarify this model: ‘‘Sound particles vibrate back and forth and send the sound forward. The disturbance of the sound particles moves horizontally to the listener's ear.’’ The name for this model was chosen by the authors in the previous studies (Hrepic, 2002; Hrepic *et al.*, 2002) because it is reminiscent of the propagation of light in Ether.

RESULTS

We will first present data that show questions that were perceived by participants as being addressed in the video lecture, i.e. questions to which they recorded an answer during or after the video lecture. As a reference point we start with responses from Hewitt and the researchers' initial rating (Table I).

Table I shows that researchers and the lecturer perceived that Q1, Q2 and Q4 were answered. A common judgment was also that Q3 was not answered and Q6, although not answered, can be inferred. The slight disagreement between the instructor and researchers existed only with respect to question 5 for which experts, unlike the instructor, believed it could be inferred from the lecture.

Table II shows results obtained from students and experts who participated in the study.

As the data in Table II show, similarly to the lecturer and the researchers, other experts as well as a large majority of students perceived Q1, Q2 and Q4 as answered in the lecture. However, unlike the experts, students did not perceive Q5 and Q6 as answered. All but one expert believed that either one or both Q5 and Q6 were either addressed directly or could be inferred from the lecture.

Conversely, Q3 was perceived as addressed by five students although not by a single expert. Of these five students, three decided that the answer can be inferred after watching the video and not while watching it. This result is not easy to explain. One possibility is that students as well as many other people comply with the social norm that Heritage (1984) calls ‘‘morality of cognition’’ and according to which we are supposed to try to give ‘‘reasonable answers to reasonable questions.’’ Also, it is possible that since the question was asked, some students believed that there should be something about it in the video. However, the fact that fewer students attempted to answer Q5 and Q6 than Q3 diminishes the plausibility of these explanations. According to experts' and researchers' opinions there was an actual hint given in the video lecture for answering Q6. Experts, researchers and the lecturer thought the same for Q5 too. However, without exception they believed Q3 was not addressed at all. Another possibility that we considered is that students might have misunderstood the Doppler Effect as changing wave speed rather than frequency. However, the Doppler Effect was not addressed in this video segment and none of these students mentioned the Doppler Effect either by name or by alluding to it conceptually during the interview. Thus, this hypothesis is also unlikely.

Table II further shows that experts perceived all questions as being answered more frequently than students did (except Q3 that no expert saw as answered). Similarly, experts rated the answers as being more thorough than the students did. The

Table I. Lecturer's and researcher's estimates on which questions were addressed and to what extent

	Lecturer		Researcher	
Question	Question answered?	Complete-ness rated	Question answered?	Complete-ness rated
1. Nature of sound propagation	Yes	4	Yes	4
2. Dependence of speed of sound on temperature	Yes	5	Yes. Fully	5
3. Dependence of speed of sound on movement of the source	No	0	No. No possibility to infer the answer	0
4. Dependence of speed of sound on the medium	Yes	4	Yes. Fully	5
5. Sound propagation in a vacuum	No	0	No. But with the possibility to infer the answer	2
6. Effect of sound propagation on the dust particle	Hint given	2	No. But with the possibility to infer the answer	1

Table II. Results from students and experts

		How *frequently* were questions addressed in the video lecture?			How *completely* were questions addressed in the video lecture?			How many *correct* (and relevant) answers were recorded by participants?			
Question	Viewers group	# participants who thought the question was addressed	Average number of times addressed	Mode of times addressed	# participants who rated completeness	Completeness rated (Average)	Completeness rated (Mode)	During and after the video lecture	Already before the video lecture	Only as an inference	Total number of inferences
1	Students ($N = 18$)	15 (83%)	1.2	1	13	3.8	5	2	1	0	3
	Experts ($N = 9$)	9 (100%)	2.1	1	8	4.5	5	9	9	0	0
2	Students ($N = 18$)	18 (100%)	1.3	1	17	4.8	5	17	8	0	0
	Experts ($N = 9$)	9 (100%)	2.4	2	8	4.7	5	9	8	0	0
3	Students ($N = 18$)	5 (27.8%)	1	1	3	2	N/A	1	1	1	3
	Experts ($N = 9$)	0 (0%)	0	0	0	0	0	0	0	0	0
4	Students ($N = 18$)	18 (100%)	1.4	1	16	4.1	5	17	12	0	0
	Experts ($N = 9$)	9 (100%)	3	3	8	4.8	5	9	8	0	0
5	Students ($N = 18$)	3 (16.7%)	1	1	2	2.6	N/A	2	2	2	3
	Experts ($N = 9$)	7 (77.8%)	1	1	1	3	N/A	7	7	7	7
6	Students ($N = 18$)	3 (16.7%)	1	1	4	2	2	2	1	1	2
	Experts ($N = 9$)	7 (77.8%)	1	1	5	2.2	1	6	6	3	4

Table III. Students mental models after the lecture

No. of students	Students' understanding of sound propagation after the lecture
4	Did not address the nature of sound propagation
3	Addressed sound propagation. Used model is inconclusive but inconsistent with a wave model
5	Retained initial Independent Entity model
1	Retained initial Dependent Entity model
1	Retained initial Ether model
1	Retained initial Wave model
1	Improved model from Independent Entity to Dependent Entity
1	Improved model from Dependent Entity to Ether
1	Improved model from Independent Entity to Wave

exceptions were again question 3 (not rated by experts) and question 2 for which the average rating by students was scarcely higher than that of the experts.

Correctness of the answers to the addressed questions

As shown in Table II, for most of the questions the number of correct answers that participants gave during and after the lecture is the same or close to the number of correct answers before the lecture. The exceptions are the students' answers to Q2 and Q4. In these cases the number of students who correctly answered these questions during the lecture significantly increased. These questions were different from others in that they had *all* of the following features: (a) they required a simple answer, (b) they were explicitly addressed and (c) they were addressed more than once in the lecture.

Similarly to Q2 and Q4, Q1 was also perceived as addressed by the majority of students (83%). But, unlike Q2 and Q4, only one student who did not have the wave model before the lecture finished with the correct answer (wave model) in Q1. Question 1 was different from questions 2 and 4 in that it required a relatively complex answer. This apparently was a significant problem for understanding in the lecture setting. Table III shows the pre-post instruction dynamics of students' mental models of sound propagation that Q1 dealt with.

Although the entire lecture segment was related to sound propagation, three students did not perceive Q1 as addressed at all. One student superficially recorded the answer to Q1, so he too did not address the nature of sound propagation. Only three students "upgraded" their models: two of them from an incorrect to a less incorrect model and one from an incorrect model to the correct model. For another three students we could not determine with certainty the mental model that they used, but their responses were clearly inconsistent with the correct (i.e. wave) model. The remaining students retained their initial (incorrect) model after the lecture.

Answers to Q3 and Q5 were recorded correctly during (or after) the lecture only by students who knew the correct answer before the lecture too. In the case of Q6, only one student answered it correctly and did not know the answer earlier. This is very much consistent with the opinion of the lecturer that Q3 and Q5 were not addressed and that a hint was given for Q6.

Making inferences

For a total of 22 instances the participants decided after viewing the complete video, that an answer to a question could be inferred from the video. Eleven inferences were made by students and another 11 by experts. Therefore, although the number of experts who participated in the study was half the number of the students, they made the same number of inferences as the students (11). This indicates that experts more frequently believe that an answer to the question can be inferred on the basis of the video lecture than students do. This is not surprising but it is important for a teacher to have this result in mind so s/he can more realistically set the expectations for student learning.

Another important insight into inference making comes from the analysis of correctness of answers that were given as inferences after the video lecture. Out of all 22 inferences that were made, 14 were correct answers on respective questions. Four of the correct inferences were given by students and 10 by experts (experts made 11 inferences but one of those was incomplete although the stated part was correct and thus not all inferences made by experts were considered correct). In all instances when correct inferences were made, this was done only by participants (students and experts) who also answered the question correctly before viewing the video. In another words, participants who did not know the correct answer to begin with, never made a correct inference. This calls for caution with respect to students' ability and comfort to make accurate inferences on the basis of the lecture content.

The incomplete inference that an expert made was related to a question that he answered partially correctly in a survey. The inference that he made supported the correct part of his initial answer, but he said nothing about the incorrect part. This further exemplifies the tendency of both students and experts to find confirmations of what they already know in the lecture and their hesitation to make inferences they are not sure about.

We saw earlier that students rated the completeness of answers much higher if items were explicitly addressed. However, a variety of conceptual misunderstandings can occur even with respect to those questions. When the nature of students' answers was examined, the following undesirable traits were observed. Students may...

1. *concentrate on particularities and details* in the instructor's statements at the expense of the more general concept.

   Example: "Sound travels faster through the steel than through the lead," or "Sound travels four times faster in water than in air and 15 times faster in steel than in air."

2. *record details incorrectly*.

   Example: "Air is a poor conductor of sound. Sound travels four times faster in steel and about two times faster in water [than in air]."

3. hear/understand exactly the *opposite* of what the instructor said.

   Example: A student who said before the video that temperature does not affect the speed of sound recorded during the lecture: "Sound propagates faster in cold air. Slower in a warm air.")

4. hear what was *not said.*

   Example: Two students who did not mention sound molecules before the video lecture used this term while making an inference from the lecture e.g. "The *molecules of the sound* will hit each other *and travel toward the listener*." Three students mentioned "sound molecules" or "sound particles" while describing propagation of sound both before the lecture and while writing the answer *during* the lecture. One student used the term "sound particles" before the lecture and after the lecture stated, "He [the instructor] described it [the sound] more as rays than as particles."

5. make *inappropriate generalizations*.

   Example: "In a liquid ... sound would move four times faster than when it is not in a liquid."

6. create *false positive* answers (a correct answer given for a wrong reason).

   Example: A student who correctly answered that a dust particle vibrates in the direction of sound propagation (Q6) also wrote as the answer on Q1, "Sound travels in waves. *The sound molecules vibrate* back and forth. It follows one another." And additionally on Q6, "*Sound bounces back and forth* and keeps going back and forth so the dust particle will move back and forth with the wave (moving around the same place)." Note: On the researcher's follow-up, this student explicated that he distinguishes "sound molecules" from air molecules which makes this answer necessarily incorrect. In the student's words: "They're both molecules but it's a different type. The sound molecules move right through air molecules." The notion of a medium of vibrating "sound molecules" through which sound propagates has been referred to as the "Ether" model of sound propagation.

7. perceive the *incorrect answer when no answer* is given to the question.

   Example: "If the source is moving fast ... you'll hear it faster."

8. correctly repeat the instructor's statement but not make sense of it.

   Example: A student recorded as an answer to Q1, "Molecules start moving. Vibrate back and forth," and there is nothing incorrect with that. However, during the follow-up question the student explained that, "He [the instructor] was just talking about the way the sound moves. When molecules start moving, they're vibrating back and forth and they hit the next one and the next one ... [Sound is] just traveling with those, I guess. I don't know. It's just traveling with that. Like being carried with each vibrating molecule. ... I'm just in the dark with this whole sound thing."

9. *correctly repeat the instructor's statement but not make sense of it without even realizing that it does not make sense to them.*

   Example: "Molecules hit one another until they reach the person."
   Interviewer: "How is sound related to these molecules hitting each other?"
   Student: "What do you mean? ...I don't know. I mean I don't think every molecule just kind of transfers...I don't know. I didn't think about that."

10. *correctly repeat the instructor's statement but interpret it differently than intended.*

    Example: Before the video lecture, one of the participants thought of sound as an entity that would move through the vacuum faster than through the air. During the video lecture the student noticed the lecturer's statements about vibration of molecules and the analogy of a room full of vibrating ping pong balls that he used for air molecules. However, the student just incorporated this information into the previous notion of the Entity model of propagation. Her model just evolved from an Independent Entity model to a Dependent Entity model. According to the latter model, sound is still an autonomous entity, different from the medium. However, it uses the vibration of the molecules of the medium in order to propagate.

11. *...hear "what makes sense" and overlook what was actually stated.*

    Example: While watching the video lecture a student recorded that "[The dust] particle vibrates up and down

[transversely]." This was the same answer that he gave before the interview. The following conversation took place during the follow-up:
Interviewer: "So, what did he [instructor] say about the direction of vibration? Do you remember?"
Student: (Pause) "What do you mean?"
Interviewer: "How did you conclude that they will vibrate up and down?"
Student: (Pause) "Just...it wouldn't...it wouldn't make sense to vibrate...They couldn't vibrate sideways."

12. *use the same terminology as experts with a very different meaning attached to it* (both before and after the lecture).

Example: Before the lecture a student wrote the answer to Q1 as, "The sound propagates as a wave (transverse)."
Follow up: Interviewer: "If you could tell me, what does that mean?"
Student: "I don't know. It moves as a wave (laughs). That's all I really know. ..."
Interviewer: "Now, when you say "it" I would like if you could tell me what "it" is and when you say it propagates as a wave ... if you could tell me what does that mean?"
Student: "The sound particles themselves move as a transverse wave. Take the path of like...[Draws the picture below]"

The next section of examples is related to the effect of the student's initial understanding on comprehending the lecture content. With respect to their earlier answers students (may):

1. *retain their previous "background" ideas although they change the answer.*

Example: A student had as the written answer on Q2, before the video: "Yes [speed of sound propagation depends on the air temperature] because the warmer the air, it's more dense and it takes longer for the sound to get somewhere. [i.e. Warmer the air—higher the density. Therefore *lower* the speed.]"
The same student wrote the following answer to the same question (Q2) during the video: "The air molecules are closer in warmer air and they hit each other faster and so sound is faster in warmer air. In cold air the molecules are further apart and they don't hit each other as fast as warm molecules. [i.e. Warmer the air—higher the density. Therefore *higher* the speed.]"

2. *retain their initial (incorrect) model in identical form.* In the following example it is the Ether model.

Example: One written answer to Q1 before the video was: "The disturbance of the sound particles move horizontally to the listener's ear."
Additionally, the same student added in her answer to Q2 before the video lecture: "No, [speed of sound does not depend on temperature] because the temperature has nothing to do with how fast or slow the sound particles vibrate sending forth the disturbance."
The written answer to Q1 after the video was: "Sound particles vibrate back and forth and send the sound forward."
Follow up: Interviewer: "That's basically what you told me before, is that right?" Student: "Uh huh (Yes)."

3. *incorporate new (correct) information into existing (incorrect) concepts.*

Example: A written answer to Q1 before the video: "The disturbance of the sound particles move horizontally to the listener's ear."
The written answer to Q2, after the video: "Warmer air makes the sound particles move even faster. Sending sound faster."
Follow up: Interviewer: "So, you expect together with air particles, sound particles will also move faster..."
Student: "Yeah."
Interviewer: "In warmer air?"
Student: "Yeah."

4. *be more confused (less sure about correct answer) after the lecture* than before it.

Example: A written answer to Q1 before the video: "The sound particles leave the speaker's mouth and travel to the listener's ear and bounce back to the speaker." Follow up (before watching the video): Interviewer: "Does air plays a role in propagation of sound through the air?"
Student: "I think so."
Interviewer: "So, what is the role of air?"
Student: "It helps it travel, it helps it move."
The written answer to Q1 after the video: "The direction of sound will always be at right angle to the waves. [Sound] travels at equal speed in equal directions when it is at the same temperature."
Follow up (after watching the video): Interviewer: "Do you think that sound can propagate through a vacuum now, a space without air?"
Student: (Pause) "I don't know."
Interviewer: "Is your model the same—sound particles carried by air?"
Student: "Actually, I don't know anything about the sound. Air doesn't have much to do with it I'm guessing."
Interviewer: "OK."
Student: "And then the vacuum thing doesn't matter anymore. I don't know (laughs)."
Interviewer: "So you think it could propagate through vacuum exactly as well?"
Student: "Probably."

When interviews with experts are examined we find that unlike students, experts (may)

1. have plentiful resources to correctly figure out things they never thought about before by engaging in deductive reasoning and testing their models.
2. talk about sound waves in terms of pressure variations more than dynamic behavior of particles of the medium.
3. consider a variety of reasons that would both support or disprove each of the possible answers when they are not sure about the answer.

Unexpectedly, in the same manner as students, experts may

1. subscribe to answers that are commonly considered students' naive responses.

   Example: Due to the sound propagation, particles in the medium vibrate transversely.

2. not have the wave model of sound propagation (in this study those were disqualified).
3. stick to their earlier (incorrect) models and answers regardless of instruction content.

   Example: One of the disqualified experts gave the following answer to Q6 before the video lecture:

   Interviewer: "How would it [the dust particle] move?"

   Participant: "In this direction, towards the listener."

   Interviewer: "OK. So if sound is long enough would it eventually reach the listener?"

   Participant: "Yeah."

   Interviewer: "OK."

   During the video lecture the same participant gave the following written answer to this question: "The sound waves travel like when air molecules are pushed by the wave and sound travels from one molecule to another (so if there is a dust particle in the room in front of some sound waves, the particle will move with the waves)."

CONCLUSIONS AND DISCUSSION

In this study we investigated how students make sense of a physics lecture. Many investigations in the learning of physics have shown that students who have completed a traditional lecture-based physics course do not have a good conceptual understanding of the material that they have studied (Hake, 2002). However, none of the previous studies have directly investigated the transfer of knowledge in a lecture environment. In the present study, in some ways the lecture that was presented to the students was "as good as it gets." The lecturer is well known for his ability to present physics in a clear and entertaining way. His lecture related to sound propagation was presented on a videotape which the students controlled by stopping, rewinding and reviewing as they wished. Participants also learned about sound in their on-campus course and were tested on the topic several weeks prior to the study. Further, students took a six-question pre-test as a part of the study and were prompted in advance that the same questions *could* be addressed in the video lecture. Their task was to determine if and when that happens during a short, 14-min video clip, which they watched at their own pace and without disruption. Thus, if a lecture can transmit knowledge from the lecturer to the student, this situation was exceptionally favorably set to accomplish that task.

The questions that the video lecture addressed ranged from those with simple, straightforward answers to those which required a model of sound propagation. In order to evaluate what students took away from the lecture we combined their pre-test answers, their answers recorded during the video lecture and the answers they gave during one-on-one interviews before and after the video lecture. We found that during a lecture, students are most likely to correctly identify and understand sought answers on the pre-determined questions when the answers are simple, have been stated explicitly and have been stated multiple times.

This result is consistent with a variety of constructivist-based models of teaching and learning. The advocates of these learning approaches insist that the students must be actively involved in their learning. In our videotaped lecture few questions were posed by students in the videotaped classroom but the learning environment for our students-participants was rather passive. They had control of the videotape but could only stop it or replay section of it. Thus, the active engagement in the teaching–learning process was very limited. Similar to a large lecture class they could not ask questions of the lecturer or become involved in hands-on or minds-on activities. As a result the amount of knowledge transferred from the lecturer to the student was relatively small. Further, the students learned best those concepts, which could be explained in a relatively simple way. The concepts which involved using scientific models seemed to have escaped transfer to the students.

This study also confirmed that students' prior knowledge can have a substantial effect on how they understand a lecture. Prior knowledge affects what students perceive to be addressed in the lecture. It may distort their understanding of the learning content to the extent they may believe they heard what was not stated in the lecture at all. Again this conclusion is consistent with a constructive approach to learning. The students' prior conceptions were not directly challenged during the lecture as they would be in an active engagement mode of instruction. Thus, the students had no reason to modify their prior conceptions. Instead, they used their prior conceptions as a basis for interpreting what they heard.

A second part of this investigation compared how experts and students perceived the information presented in the videotaped lecture. Experts tend to believe that questions are addressed more frequently and more thoroughly than the students do. This finding indicates once again the importance of prior knowledge on the interpretation of a presentation. Experts have been dealing with the topic for number of years and in a variety of ways both as students and teachers. They are familiar not only with the concepts but also with the jargon and vocabulary. They have read many texts and taught from them. Thus, the experts have a rich context from which to draw inferences about what is covered in a lecture. Students, on the other hand, are encountering the topic typically for the first time and are not familiar with the scientific notions of the commonly used words. In the best case they read one text and therefore may interpret words and statements differently from the experts.

This result has implications for teachers at all levels. We must be constantly aware of what our students hear and see in our presentations. We can easily conclude that we have "covered" a topic well. However, students with a much more limited background may not be able to understand the content as desired. An active learning environment in which the teacher sees directly what the students know and helps them build new knowledge would help avoid this problem.

A related finding is that experts tend to believe that generalizations are possible more frequently than students do. An unexpected finding in the study was related to the correctness of the inferences: correct ones were made in this study only by students (as well as experts) who also knew the correct answer before the experimental lecture. As teachers we attempt to bring students to the level of understanding from which they can make further generalizations on their own. We do not want to suggest we should abandon this goal. However, based on this finding, we should be cognizant of the fact that the gap between presented information and a "logical" conclusion that we as experts perceive as optimal may be too wide for students.

This study has shown that a variety of misunderstandings can occur during the lecture even if the conditions for learning are far better than in a typical classroom. From this perspective, the answer to the question, "Do they just sit there?" is—no, they don't! Instead they go through intensive cognitive processes, which, unfortunately, may be very different from the instructor's intentions and expectations. We see evidence that in a traditional lecture setting, with one-way instruction, these cognitive processes have to be extremely carefully guided and monitored. If possible, feedback from students should be sought along the way either directly or through interactive technologies (e.g. classroom response systems). In this respect we suggest, at a minimum, inclusion of interactive lecture methods such as Peer Instruction (Mazur, 1997) to facilitate learning through students' engagement even in the largest auditoriums.

Findings of this study are important for a lecturer to keep in mind because the aforementioned problems with students' understanding were observed in a situation that had significant advantages to a typical classroom lecture.

LIMITATIONS OF THE STUDY

1. The study was held at Kansas State University, a large Midwestern public university with essentially open admissions. The site was chosen because of its accessibility for researchers.
2. Using only students that were taking a concept-based introductory physics course limits our ability to generalize the findings to all students who take introductory college physics.
3. Extra credit offered to participants is a possible source of sample biasing.
4. This study was concerned with only one topical area—sound.
5. Although the experimental lecture was idealized in many ways, when compared to a real lecture it had some disadvantages too. In a real lecture, students can stop and ask questions. The instructor as well, may notice students' confusion and respond to it effectively. An instructor can also request students' participation. So, it is possible that these advantages of a real lecture may counterbalance some of the negative aspects that were observed in this study.

ACKNOWLEDGEMENTS

This work was supported, in part, by the National Science Foundation under grant REC-0087788. We extend many thanks to Dr. Paul Hewitt for his kind participation in this research. His input was invaluable to the analysis of our data.

REFERENCES

Cazden, C. B. (1988). *Clasroom Discourse: The Language of Teaching and Learning*, Hainemann, Portsmouth, NH.

Cooper, P. J, and Simonds, C. J. (2003). *Communication for the Classroom Teacher*, Allyn and Bacon, Boston, MA.

Exley, K. (2004). *Giving a Lecture; From Presenting to Teaching* (1 ed.): Routledge Falmer.

Hake, R. R. (2002). Lessons from the physics education reform effort. *Conservation Ecology* 5(2):28; online at <http://www.consecol.org/vol25/iss22/art28>.

Heritage, J. (1984). *Garfinkel and Ethnomethodology*, Polity Press, Cambridge, UK.

Hewitt, P. G. (1991). Vibrations and sound II. On *Conceptual Physics Alive*! [Video tape]: Addison-Wesley.

Hewitt, P. G. (1998). *Conceptual Physics* (8th ed.). Addison-Wesley, Reading, MA.

Hrepic, Z. (2002). *Identifying Students' Mental Models of Sound Propagation*. Unpublished Master's thesis, Kansas State University, Manhattan, KS.

Hrepic, Z., Zollman, D., and Rebello, S. (2002). *Identifying Students' Models of Sound Propagation*. Paper presented at the 2002 Physics Education Research Conference, Boise ID. Published in conference proceedings.

Hrepic, Z., Zollman, D., and Rebello, S. (2005). *Eliciting and Representing Hybrid Mental Models*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, April 4–7, Dallas, TX. Published in conference proceedings.

Kvasz, L. (1997). Why don't they understand us?. *Science and Education* 6: 263–272.

Mazur, E. (1997). *Peer Instruction: A User's Manual*, Prentice Hall, Upper Saddle River, NJ.

Zollman, D. (1996). Millikan lecture 1995: Do they just sit there? Reflections on helping students learn physics. *American Journal of Physics* 64: 114–119.