Student Understanding Of Sound Propagation: Research And Curriculum Development

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Abstract. We describe recent results in an ongoing investigation of student understanding of sound, especially of sound propagation in solid media. We have recently administered written questions and conducted interviews to probe student reasoning about this topic, specifically the effect on the pitch or frequency of a sound that is propagated from one object to another. Our findings show that the concepts of propagation and resonance are not functionally distinguished by these students; many students seem to be distracted by the resonant properties of an object that is propagating sound. Furthermore, students have more difficulty when considering propagation of a sound through objects with sound generating properties than with objects not associated with sound generation. This work forms the basis for instructional materials to improve student learning, especially among preservice teachers. The curriculum developed to date is reasonably successful at addressing these student difficulties.

BACKGROUND AND CONTEXT

Overall, little research has been done on how well sound is understood by students at either the college or precollege level.[1-5] Sound is typically taught at the elementary level. Because elementary teachers need to have a thorough understanding of the topic in order to teach it, our efforts toward research and curriculum development are targeted primarily toward preservice teachers. We have been identifying student difficulties as part of the process of developing a guided-inquiry-based curriculum on sound; this curriculum is currently used for primary and secondary teacher preparation at the college level. In this paper we will describe some difficulties that K-12 teachers have with specific concepts within sound, as well as discuss some details of the curriculum.

The main population discussed in this paper is a class of primarily elementary and secondary education majors taking a hands-on, inquiry-based physics course at The University of Maine.

The questions discussed here were asked as a pretest for the second section of the curriculum. In the first section students associate sound with vibrations and the properties of sound with those of vibrations. We note that the students are led to understand that pitch is an indicator of frequency. Students listening to sounds that had identical frequencies in different materials reported hearing the same pitch.

Previous research included analysis of written responses to questions asked of several classes including both preservice and in-service teachers.[6] In this paper we discuss new results that build on our earlier work. We have asked pretest, homework, and examination questions as well as interview tasks that are variations on the previously asked questions. Our data come from 14 students in the class who took both pre- and post-tests. Additional data are provided by individual interviews of two students from a different semester of the same course.

THE STUDY

Previous examination of written pretest responses left us with several questions to explore in greater detail. We are particularly interested in student understanding of propagation of sound through various materials. In particular, we study student conflation of transmitted pitch with the resonant properties of the material propagating the sound. In the basic scenario, a tuning fork is struck and then placed on a wooden meter stick, at the other end of which is a second tuning fork, already in contact. The students are asked if a sound will be heard from the second tuning fork, and (if so) what frequency the sound will have. Variations on this question (illustrated in Figure 1) include changing the connector material or the size of the second tuning fork. One additional variation involves the use of a light bulb as the second object.

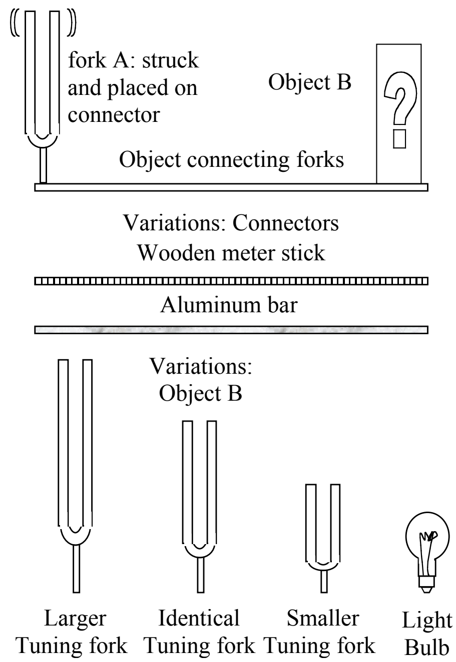

Figure 1. Format of question posed to students, including variations. The theme of this question is that fork A is struck and placed on the "connector"; students are asked to predict what sound will be heard from Object B. Variations concern the material of the connectors and the type of object at the end of the connector.

The responses students provide on written questions may lack sufficient detail to allow us to understand the students' thinking. Thus, an interview protocol was developed based on the written questions to clarify vague or ambiguous student explanations, rather than resorting to unwarranted interpretation of written responses. Interview subjects were encouraged to explain where their answers came from, and were not given any answers until the interview was completed. The subjects were probed to determine their understanding of (1) how the length of a tuning fork affects the pitch produced when the fork is struck, and (2) what causes the tuning fork to make a sound. Both subjects demonstrated adequate understanding of these two concepts. Subjects were then asked about the scenarios shown in Figure 1 that involve a second tuning fork as Object B. In addition, a variation was asked in which a string is used as the connector and Object B is a plastic cup.

RESULTS AND DISCUSSION

The data obtained from these questions point to three ideas that various students seem to hold about what characteristics of this system affect the frequency of the propagating sound: the material of the connector, the size of the second tuning fork, and whether or not the second object is typically associated with a specific frequency. We discuss these three ideas below, along with relevant information about the curriculum and post-test data.

Material of Connector

Earlier data suggested that students may think the material of the connecting bar alters the pitch of the sound heard at the far (right) end of the bar. In order to explore this issue, we asked a version of the pretest using identical forks, first with a wooden meter stick, and second with an aluminum bar of the same length. The students were aware that the tuning forks were also made from aluminum. Using identical forks allows us to filter out responses influenced by the size of the final tuning fork (discussed in the next section). Students were asked to compare the pitch heard at the second fork in the two situations. Responses to this pretest are summarized in columns 1 and 3 of Table 1. This question yielded an interesting result: the majority of students discussed the volume of the sound heard with the aluminum relative to the wood, rather than the pitch; the students who did mention frequency in this part of the question gave no reasoning for their response.

TABLE 1. Results for question varying connector but with an identical tuning fork as Object B. N = 14.

Connector	Wooden Meter Stick		Aluminum Bar	
Response	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
f_A	7	13	2	12
Lower than f_A	1	0	1	0
Higher than f_A	1	0	1	1
Frequency not specified	2	0	8	1
No sound	3	1	2	0

After working through the first section of the curriculum, students easily grasped that the size of a tuning fork affected the pitch it produces when struck. Some students seemed to be extending that effect to the connector. This interpretation is supported by Mark (pseudonym), who gave this response in an interview. Mark explained that the pitch heard in the meter stick "would be lower, because it's bigger than the tuning fork, … and it'll have a lower sound."

After taking the pretest, students explore a variety of different arrangements. Students listen as sound propagates from a tuning fork to each of the following: a short aluminum rod, a meter stick, and two meter sticks clamped together at a 90˚ angle. A "telephone" made of cups and string provides another means for exploring propagation; a tuning fork then replaces one of the cups (as in the interviews). Students are then asked to generalize from these experiments. Students do not set up the pretest scenarios until later in the curriculum.

The pretest question described above was later given as homework. As Table 1 shows, there was marked improvement among students: for the scenario using the wooden meter stick as a connector, the number of correct responses improved from 7 to 13; for the aluminum bar, the gains were more dramatic, with 2 correct responses on the pretest and 12 on the homework.

Size of Object B

In addition to altering the connector material, different versions of the pretest varied the size of the tuning fork at the far end of the wooden meter stick. For example, fork B was *larger* than fork A in pretests administered to 5 separate classes at three different universities (N = 69; Column 1 of Table 2). Twenty-six of these students responded that the pitch heard at fork B would be the pitch produced by fork B, f_B, which is lower than that produced by fork A, f_A. We also asked the question in which fork B was *smaller* than fork A. Responses stating that the pitch was raised could be attributed to the size of the second fork, while a lower pitch could be assumed to be caused by the longer connector.

As seen in Table 2, student performance on both versions of the pretest was similar: a far larger percentage stated that the sound would have the frequency f_B, whether fork B was larger or smaller, rather than f_A. In fact, for this group, none of the students gave a correct response on the pretest (this was also true of one class previously). It is worth noting that both interview subjects also chose f_B as their response to this question.

Students were given the same question as part of the same homework assignment described in the previous section. This was the only question on the set of four that did not show any pre/post improvement, indicating that the difficulty elicited by the presence of a different tuning fork, a distinct "sound-making" object with its own (resonant) frequency, is persistent. Three students changed their response to a correct one, while three others who gave a partially correct response on the pretest gave completely wrong responses on the post-test.

TABLE 2. Results for question varying the size of tuning fork B, with a wooden meter stick as the connector.

Size of Tuning Fork B	**Larger** ***N = 69***	**Smaller** ***N = 13***		
Response	***Pretest***	***Pretest***	***Post-test: HW***	***Post-test: Exam***
f_A	17	0	3	10
f_B	26	7	7	1
Frequency not specified	7	2	0	0
No sound	12	0	3	2
Other	7	4	0	0

A second post-test question of this type was given on the final exam. The scenario involved two students who each have a (different) tuning fork. The students in the scenario need to propagate the sound with the pitch of the first student's fork down a radiator pipe and, more importantly, across a gap between two radiator pipes; the second student's fork is used to fill the gap. On the exam, the students are asked what pitch will be heard *after* the gap if the first fork is struck and placed on the first pipe.

We have data for 13 students for all three questions (pretest, homework, exam). Of these "matched" students, 10 provided responses on the exam question similar to the following: "[the second] fork will produce the same frequency as [the first], even though they are different sizes. [The second] tuning fork is just acting as another surface to vibrate." Of the 3 students who answered incorrectly, one stated that the pitch of the second fork would be heard, since something can only vibrate at its own "unique frequency." The other two said that because the second fork is different, it cannot vibrate at the frequency of the first one, and so no sound will get through at all. Most students understood the dynamics of propagation by the end of the course, but this example demonstrates the persistence of the idea that things only vibrate at "their own" frequencies.

Classification of Object B

A final situation was presented to students on the pretest and later in homework. In this scenario, Object B was a light bulb, chosen as an object that is not associated with sound at all to see whether students would still expect the pitch to be altered by an object that has no obvious resonant sound properties.

On the pretest, only three students gave correct responses (see Table 3). Results on this question improved dramatically after instruction, when 11 students were correct. All of the incorrect responses referred to a *higher* frequency being heard at the light bulb. Furthermore, the reasoning behind these responses deals with the size of the bulb, which was drawn as smaller than the tuning fork. Clearly these students are associating the size of the object with a specific pitch, despite the lack of an obvious association with sound.

TABLE 3. Results from question using a wooden meter stick as a connector and a light bulb as Object B. N = 14.

Response	Pretest	Post-test
f_A	3	11
Higher than f_A	0	3
Frequency not specified	5	0
No sound	2	0
Other	4	0

In interviews, students were asked similar questions, again starting with the tuning-fork–meter-stick–tuning-fork (tf-ms-tf) scenario, and comparing that to a tuning fork tied with a string to a plastic cup.

When considering the string and cup situation, Melissa (pseudonym) stated correctly that the pitch heard from the cup would be the same as that from the tuning fork, and that the sound vibrations "travel" through the string. When comparing this situation to the tf-ms-tf scenario, Melissa said that the string and meter stick had similar roles – "sound travels through" each one. However, when it came to the receiving tuning fork and the cup she said, "I think the pitch through the cup is going to be same as [the tuning fork]. I thought that the pitch would be different… [in] the meter stick [situation]." Melissa restated and confirmed that she had two distinctly different ideas about how the pitch from the tf-ms-tf system compared to the tuning-fork–string–cup system. When asked if a bigger or smaller cup affects the pitch (again, in an analogy to the larger or smaller tuning fork in the tf-ms-tf system), she said that the pitch would still be the same.

Like Melissa, Mark originally stated that he would hear the pitch produced by the tuning fork coming from the cup. However, in contrast to Melissa, upon comparison with his earlier reasoning about the tf-ms-tf situation, Mark stated that a bigger cup *would* change the pitch heard from the cup somehow. Mark chose incorrectly to be consistent between these objects, whereas Melissa chose to distinguish between the properties of the two systems.

We see in the interviews a difference in students' ideas about how sound works with a sound related object, compared to a non-sound related object. This is consistent with the data from the light bulb question: associating an object with sound *generation* causes confusion when considering sound *propagation.*

CONCLUSIONS

Our findings show that the concepts of propagation and resonance are not functionally distinguished by these students; many students seem to be distracted by the resonant properties of an object that is propagating a sound. This distraction is not alleviated when considering objects not associated with sound generation.

Simple experiments that provide students with empirical observations seem to be effective at addressing some of these difficulties; however, the tendency to associate the size of an object with any sound, regardless of origin, is persistent.

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