Start With Phenomena

How Does Sound Travel in a String?

Facilitating a change in sound conception with fourth graders
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In Chinese science curriculum, the sound unit generally starts with observing various sound making phenomena and finding out that they all involve vibration. (In China, the elementary science curriculum standards assign all sound-related content to the 3–4 grade band, including the idea that vibrating matter makes sound, which was assigned to the K–2 grade band in the Next Generation Science Standards [NGSS].) In previous teaching, we noticed that although our fourth graders could relate sound with vibrating matter after such learning, they would keep applying properties of matter when explaining sound-related phenomena, such as describing echo as “very small sound beads that hit the wall and bounce back.” Such observations motivated us to pursue a conceptual change, helping students conceptualize sound as energy rather than matter. Understanding sound as a form of energy and that energy can travel from place to place through sound falls under the fourth-grade expectations in NGSS (4-PS3-2; 4-PS3-3; NGSS Lead States 2013). It requires treating sound as a process of vibrating motion, so that vibration strength can be associated with the amount of energy, and the propagation of vibration can be seen as energy transfer.

Chi and colleagues (Chi, Slotta, and Leeuw 1994; Chi and Roscoe 2002) studied the nature and roots of misconceptions. They divided all the entities in the world, that is, everything in independent existence, into three major categories (or in their language, ontological trees): matters, processes, and mental states. Many misconceptions, they suggested, are caused by assigning attributes belonging to one category to entities of another. Treating sound, a process of vibration propagation, as having attributes of regular matter, such as occupying space or having weight, is a case in point. The conceptual change we pursue is for students to frame sound as a course of action rather than a regular thing. Such “tree switching” from “matter” to “process” would be much more difficult than “branch jumping,” that is, subcategorical change within the same major category. Therefore, I designed with my mentee teacher, Ms. Chen, an opening lesson to the sound unit, targeting at revealing and challenging students’ matter-based sound conception. She successfully implemented it in a few classes with average academic standing.

FACILITATING CONCEPTUAL CHANGE

A string phone consists of two paper or plastic cups and a string connecting the two (see Supplemental Resources for the procedure). When a person speaks into one cup, another person can hear it with the other cup. This can only work well with the string tightened up. We used this phenomenon to organize our lesson. The phenomenon was first presented to trigger students’ initial explanations, which are mostly matter-based. After a first round of sharing, we encouraged students to explore the phenomenon in detail, collecting evidence that can speak to their initial explanations. Many of their close-up observations would draw attention to the propagation of vibration and form challenges to the matter-based explanations. The original experimental setting can also be modified to afford further exploration and generate further evidence in support of treating sound as process and energy. As students engage in this continuous process of evaluating their explanations against new evidence, they find it makes more sense to treat sound as process and energy rather than as matter. We provided a detailed timeline table for this lesson in the Supplemental Resources. In the following pages, we focus on the roles the phenomena play in the lesson.

TRIGGER INITIAL EXPLANATIONS

At the beginning of the lesson, Ms. Chen presented the students with a string phone made of cotton string and two plastic cups (see Figure 1a). She randomly invited two students up to demonstrate the string phone, trying it out with the string in stretched state and slack state, respectively. After that, she asked the receptor to report the phenomena: one can hear clearly when the string is stretched but can barely hear anything with a slack string. Ms. Chen then raised the question, “Why does the same string phone work differently in these two conditions?” Based on the observed relationship between string state and sound transfer effect, the students actively constructed their initial explanations. They typically treat sound as an entity of matter rather than of energy. Some assumed weight, suggesting, “Like things on the slide, sound can go down but cannot climb up.” Some emphasized space occupation, conjecturing that, “Sound would leak into the air from the tiny gaps that formed when the string is curved.” Some drew

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analogy to their personal experience, such as, “Sound travels like how we run, reducing the speed when getting to a curve.” There were also students who referred to vibration, claiming that “the vibration cannot happen when the string is curved.”

As this discussion went on, students’ matter-based preconceptions were fully exposed and recorded on the board. The diversity of and conflicts among ideas motivated students to further explore the phenomenon.

ARGUE WITH EVIDENCE FROM DETAILED OBSERVATIONS

Ms. Chen divided the students into groups of four, instructing the members of each group to take turns being the speaker, the receptor, and observers, experiencing the phenomenon and carefully observing each part of the string phone, looking for evidence that can support or challenge the ideas on the board. To save time, each group was provided a premade string phone. Teachers with more flexible time schedules can surely have students make their own string phones. Supplemental Resources provides the list of supplies, procedures, and safety recommendations for doing that.

After experiencing and observing the phenomenon, the students came back together and had a heated discussion, in which they constructed evidence-based arguments for or against the initial explanations. For instance, after touching the string and feeling its vibration in different conditions, one group reported that “the whole string is vibrating when it is stretched” and “when it is curved, the vibration is strong on the speaker’s side, but on the receptor’s side it is very weak.” With such observations, they held on to the explanation that “sound travels in vibrations,” highlighting its attribute as a process. A few students further explored the mechanism of sound transfer by focusing on phenomena associated with the curved part of the slack string. One student noticed that the vibration strength “was not reduced much in the straight part of the string above the curve” but “reduced a lot after the curve,” claiming that it would support the matter-based theory that sound leaks out from the curved part. Another student jumped right on this idea, declaring that he “put his ear near the curved part and heard nothing.” He further claimed that “sound is vibration” and “it [the vibration] does not go anywhere but simply gets weaker in transfer.” Embedded in this argument is the understanding that sound transfers from one place to another in the form of vibrating motion. It treats sound as a process of motion, and its propagation as the transfer of kinetic energy.

In this part, variations among initial explanations promoted detailed and diverse observations of the phenomena. Evidence gained that way informed students’ arguments. Through sharing, these arguments triggered dissatisfaction toward matter-based preconceptions and provided rationales for taking sound as process and energy.

DRAW ON PHENOMENA FROM MODIFIED EXPERIMENTAL SETTINGS

The discussion after the first round of exploration usually cannot solve all the conflicts but motivates further exploration and investigation.
investigation and explanation construction. Ms. Chen asked students what could be done to further test their ideas. Sometimes the students come up with modifications on their own. For instance, to test their idea that sound, as regular matter, “can go down but cannot climb up,” some students came up with the idea of placing the speaker’s cup at a lower location and the receptor’s cup at a higher location. If the sound “cannot climb up,” they predicted, the string phone would fail to work in this new setting “even with the string tightened up.” The finding that sound transfer in this modified setting does not differ from that in the original setting led the students to spontaneously discard their initial matter-based idea.

To further students’ explanation construction, teachers can also suggest modifications to the experimental setting. For instance, many students stated that sound, even in the form of vibration, would “require empty space to travel,” which is a typical attribute of matter. To put this idea to the test, Ms. Chen asked, “If we replace the cotton string with metal one, what would be the effect?” Students who emphasized the need of space quickly predicted “that would definitely fail (to transfer sound)” since “metal string does not have empty space inside.” Students who take vibration strength as the key factor, in contrast, predicted the same or even better sound transfer, since “metal string can keep the vibrations going, that is why we use it for musical instruments.” After trying out string phones connected by fine iron string (see Figure 1b), many shifted toward treating sound as a process of motion: “Unlike the cotton string, inside the metal string there is no empty space, so I’m convinced sound vibration does not need empty space to travel. It just travels by vibrating the string.”

The modifications introduced should follow the logic of students’ matter-based explanations and lead to phenomena that can serve as counter evidence. For instance, when students stuck to the idea that sound “goes in a straight line only and cannot make a turn,” Ms. Chen suggested that they set up the string phone in a “V” shape, with one student pulling down the middle of string tightly with another string (Figure 2). The fact that sound can be successfully transferred

![FIGURE 2](image-url)

Students in argument.

Their ideas have been summarized on the board. The right column described the phenomenon: sound can be transferred (“✓”) with stretched string; sound cannot be transferred (“✗”) with slack string. Students added on the second drawing information about vibration in different parts of the string. The left column briefly recorded their ideas: (1) transfers into the air; (2) goes fast in straight line and goes slow in curved part; (3) transfer in the empty space in the string; (4) vibration→sound
within that setting and that the vibration can also be felt on the added string became evidence in support of the process-based idea of “sound as vibration.” In another instance, to challenge the idea that sound would “leak out” from curved cotton string, we provided string phones made with silicone capillary tubes. Since students would not expect any matter to be able to leak from such tube, yet sound transfer would still get greatly reduced when the tube is in slack state, students are more convinced that “leaking is not the cause.” By the end of the lesson, when Ms. Chen asked the students to review their ideas and decided on what explanation they would support, almost the whole class dropped their matter-based initial explanations and turned to the process-based ideas of “sound is vibration” and “sound travels by making things vibrate.” Although the term energy was not explicitly used, students’ sound conceptualization well resembled the definition of sound energy: the movement of vibrations through matter.

As Ms. Chen recalled in her teaching journal, a few students came to her after the lesson, wanting to know if sound is “a type of air” or something “straight and thin.” After the lesson, most shifted to process-based views, treating sound as “vibration of the air” or “wave motion” that “transfers through vibration.” We also assessed the extended learning effect in one class three months later with open-ended questions. Q1 asks for a description of what sound is. Q2 comes from their learning contexts: whether a string phone with stretched V-shaped string can transfer sound. Q3 asks whether a stethoscope can transfer heartbeats better without the front membrane (see Supplemental Resources for the questions and scoring rubric). Out of the 43 students in that class, only one gave a matter-based response to Q1, and the majority (28, 65.1%) treated sound as a process of motion. Similarly, the majority (26, 60.5%) provided an energy-based explanation to Q2 (e.g., “because the string is tightened and the vibration can pass by”), with only a few (3, 7.0 %) still reasoning in a matter-based way, suggesting that sound would “stop” or “be blocked” at the turning point. For Q3, while all suggested that the membrane would not block sound, only 18 (41.9%) explicitly mentioned the vibration nature of sound. Put together, there is evidence that most students did shift toward conceptualizing sound as process and energy, but it would take more effort for them to reason with that conception in other contexts.

POSSIBLE EXTENSIONS

The inquiry activity design presented above can be extended in many ways. If time permits, students can make their own string phones with different string lengths, and the idea of energy dissipation can be introduced and explored. They can also apply the conceptions built up in this lesson to predict and explain other sound-related phenomena, such as how a loudspeaker can make small Styrofoam balls move in plastic tubes. Visualizing sound with this new phenomenon

### FIGURE 3

String phone in the “V” shape setup.
FIGURE 4

What students think sound is before and after the lesson: (a) typical answers prior to the lesson and (b) typical answers after the lesson.

CONCLUSION

To summarize, engaging students in the pursuit of coherent explanations for a series of phenomena associated with the string phone can be productive in many ways. In terms of disciplinary core ideas, it can challenge students’ matter-based conception of sound and promote the understanding of sound as process and energy. In terms of scientific practices, it allows students to construct explanations and identify evidence from observation to support or challenge different explanations. In terms of crosscutting concepts, it can provide great opportunities for students to differentiate patterns (observed relationship from single phenomenon) from mechanisms (underlying stories that can keep different phenomenon in coherence), understanding that causality may or may not be inferred from events happening together.

Supplemental Resources

Timeline and instructions can be found at https://tinyurl.com/39fczwzs.

REFERENCE

