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What's the Matter with Sound? - How Primary School Students Perceive the Nature of Sound

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Abstract
Sound is a very omnipresent physical phenomenon that plays a crucial role in our daily lives. It is essential for verbal communication and helps us orient ourselves. Children are especially affected by sound and its presence in their daily lives. This circumstance, and the subject-specific interesting facets of the topic of sound, make this particularly interesting for the classroom. In order to provide effective sound education, it's important to understand how children perceive sound. This research aims to explore the ways in which primary school children experience sound. The inquiry conducted of 24 interviews with primary school children, with a focus on the propagation of sound. Various experiments were integrated into these interviews in order to provide a child-friendly approach to this rather abstract topic. The interviews were analysed phenomenographically. The focus on sound propagation allowed the children to express their understanding of the nature of sound. The various experiments that addressed different levels of awareness (black box, Schlieren setup) were also beneficial in this regard. The results showed that primary school children already have a wide range of ways of experiencing the nature of sound.

Keywords Phenomenography · Perception · Sound · Primary school · Conception

Introduction

Physical phenomena are often difficult to grasp for students due to their abstract nature. In particular, phenomena that cannot be perceived through all of our senses, such as light and sound, cannot be perceived in the core of their physical nature. Sound can be heard, but not seen. Light can be seen, but not heard. Nevertheless, primary school students in particular bring a multitude of experiences with sound into the classroom. Acoustic impressions such as conversations, noises and emotionally moving experiences such as music have accompanied

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most of us since birth. It is a topic that is close to their lifeworld and therefore interesting for the students. This is an important component that constitutes a proficient teaching topic. For effective teaching, it is crucial to consider not only the subject perspective, but also the student and teacher perspectives in relation to the chosen topic, as emphasised by the Model of Educational Reconstruction (MER) (Duit et al., 2012). For the other (subject-related) component, it is necessary that the topic provides important basics that are essential for further education. And also in that regard sound is a very enriching topic for teaching. For example, there is the mathematical-physical description as a mechanical wave, but thermodynamics and the associated concepts such as pressure and density also play an important role and thus offer many starting points for further in-depth study (Linder, 1992).

Given that sound is of interest to primary and secondary education, studies dealing with the perception of sound would be incredibly valuable for educators and educational researchers. They offer insights into the perspective of students, which may not always be easily accessible from a professional viewpoint. However, there is relatively limited research on learners' ways of experiencing sound (Rico et al., 2021; Yerdelen & Sungur, 2020). The focus of this limited pool of studies is often on older pupils or students. In this context, the work of three teams of researchers should be highlighted: Linder and Erickson (Linder & Erickson, 1989; Linder, 1992, 1993), Hrepic (Hrepic et al., 2002; Hrepic, 2004; Hrepic et al., 2010; Hrepic, 2011) and Eshach (Eshach & Schwartz, 2006; Eshach, 2014; Eshach et al., 2016; Volfson et al., 2018). Studies examining the ways of experiencing sound of primary school children have only emerged since the 1990s (Watt & Russell, 1990). As the ways of experiencing sound can be very different across different age groups, it is sensible to consider them individually. However, studies conducted on older students still provide valuable insights and can serve as indicators of how primary school students may perceive sound.

Thus, investigating the ways in which primary school children experience the nature of sound appears to be worthwhile and meaningful. With this research interest in mind, the well-received phenomenography was chosen as the methodological approach (Han & Ellis, 2019). It allows the researcher to openly address the ways of experiencing. And the presentation of the results is intended to provide a possible approach for reframing the perspectives of the students didactically and how this can contribute to the development of a scientific understanding of sound (Han & Ellis, 2019).

Literature Review

In the description of learners' perceptions, various terms are used. Typically, the term 'conception' is employed, particularly in constructivist-oriented conceptual change research, it emphasises the focus on (more or less elaborate) concepts. The research approach of phenomenography consciously distinguishes itself from this perspective through the use of the English term "way of experiencing", thus including awareness to a greater extent (Marton & Booth, 1997). This study uses the term "way of experiencing" in this sense.

The awareness of sound as substance is easily understandable, which is why it is not surprising that the way of experiencing sound as a kind of entity has been a part of the results in all known research studies (Linder & Erickson, 1989; Hrepic et al., 2002; Eshach & Schwartz, 2006). Building on this focus, Eshach (2014) developed a Sound Concept Inventory Instrument (SCII) based on the substance scheme of Reiner et al. (2000) and an interview study (Eshach & Schwartz, 2006), which aims to assess to what extent students perceive sound as an entity.

In this context, the criteria for substance-based classification in the SCII are as follows (Eshach, 2014):

- Sound can propagate in a vacuum.
- The size and number of sound particles influences the hearing experience (volume and pitch).
- Sound is an invisible material.
- Sound has corpuscular properties (has a surface and a volume).
- Sound can be pushed at or away (by objects or by the medium of propagation).
- Sound can experience friction.
- Sound can be contained.
- Sound can be consumed.
- Sound is subject to gravity and falls down when dropped.

Both Hrepic et al. and Eshach describe the process-based interpretation as the desired way to experience sound. According to Hrepic et al. (2010), process-based means that sound can be described in general as a propagating wave. For Eshach (2014), process-based means that sound is associated with the movement of particles in a medium or that changes in pressure and density play a role (Eshach, 2014). Thus, Eshach et al. take into account the studies of Linder and Erickson who found that the awareness of sound as a wave does not necessarily mean that this wave corresponds to a mechanical longitudinal wave. In accordance with the mathematical representation often found in textbooks, for example, some students described the sound wave as a transverse wave (Linder, 1992). Alternatively, it was assumed that the particles of a medium collide with each other in a domino-like chain reaction during sound propagation (Linder & Erickson, 1989).

In all of these studies, the focus is on older students. Research on primary school children in particular dates back to the 1990s (Watt & Russell, 1990). The study did not focus on the nature of sound, but on the origin, propagation and reception of sound. This is understandable, because it is easier to link a phenomenon to concrete events, especially for younger students. In addition, conclusions about the properties of sound can also be drawn from the results. When comparing the results to the criteria from Eshach's SCII (Eshach, 2014), many tatements made by the children can be attributed to a substance-based way of experiencing. For example, the children described how sound can penetrate through holes in objects, or how sound can be captured using a funnel, or amplified by bouncing multiple times off the walls of the funnel. An important result of this study was that the children had difficulties describing the actual propagation of sound in more detail (Watt & Russell, 1990). To be able to describe the propagation of sound, it is important to have an understanding of the nature of sound and how it can propagate.

Based on these insights from previous studies, the following research question appeared to be enriching both for research and education:

- How do primary school students experience the nature of sound?
  - Can similarly differentiated ways of experiencing sound, as found in older students (sound as entity, wave or process), also be found in primary school students?

Methods

The methodological framework for this study is phenomenographic, which aims to systematically describe the different ways of experiencing a phenomenon[1] in what is called the outcome space (Marton & Booth, 1997; Åkerlind, 2005). The outcome space consists of categories of description, that hierarchically represent the different ways in which a phenomenon can be perceived (Åkerlind, 2005).

Data Collection

The data collection was carried out through semi-structured interviews, the most common phenomenographic data collection method. In selecting the survey group size, an attempt was made to interview enough individuals to obtain a sufficient variety of ways of experiencing. At the same time, it was important not to collect too much data to still allow for adequate management and analysis. Therefore, Marton and Trigwell (2000) recommends a sample size of 10-20 people. In this study, 24 German primary school students in the third (10 female (f), 8 male (m)) and fourth grade (3 f, 3 m) aged 8 to 10 years from two different primary schools were interviewed. Half of the students came from a school in the city center of Hannover (a German city with about 500 000 inhabitants), while the other half attended a school on the outskirts of Hannover. The students were selected at random by the teachers among those who had their parents' permission. Like all primary school children in Germany, the students have been attending general education (Sachunterricht) classes since the first grade, including science classes. However, the topic of sound itself has not yet been addressed in class. Six students had participated in a bat observation hike in the weeks leading up to the interview. The interviews lasted an average of 45 minutes.

Interviews with children are a special form of interview where the needs and abilities of children must be particularly taken into account. The children were actively encouraged with drawings to make the unspeakable explicit (Fuhs, 2012). In addition, the interview situation was recorded on video to capture both the audible and the visible aspects (Dinkelaker & Herrle, 2009, 15). In addition to question stimuli, various methods in the form of specially developed experiments were included to address the children with different impulses and to enable them to have various accesses to the topic. This resulted in three phases of the interview, with all three phases being conducted using an interview guide (the questions are listed in Appendix A). In addition to the pre-defined interview questions, follow-up questions were used to further explore interesting topics from the interviewees' responses in the interview situation (Han & Ellis, 2019).

In the first phase, the children were asked questions about sound propagation based on the interview guide. The questions were designed to raise awareness of sound propagation and related aspects to the children. The guide was created based on Helfferich's scheme (Helfferich, 2011), with questions from the aforementioned publications on ways of experiencing sound also taken into account. Various small experiments (paper funnel, knocking and speaking through a door) were integrated into this interview situation to provide practical and illustrative examples to the students.

[1] In the context of phenomenography, a phenomenon is the present scenario at hand (in didactic terms, this would be the subject matter or the learning environment) and should be distinguished from the scientific phenomenon. For example, the physical phenomenon of sound can contain various phenomenographic phenomena (such as hearing something being said or experiencing a thunderstorm).

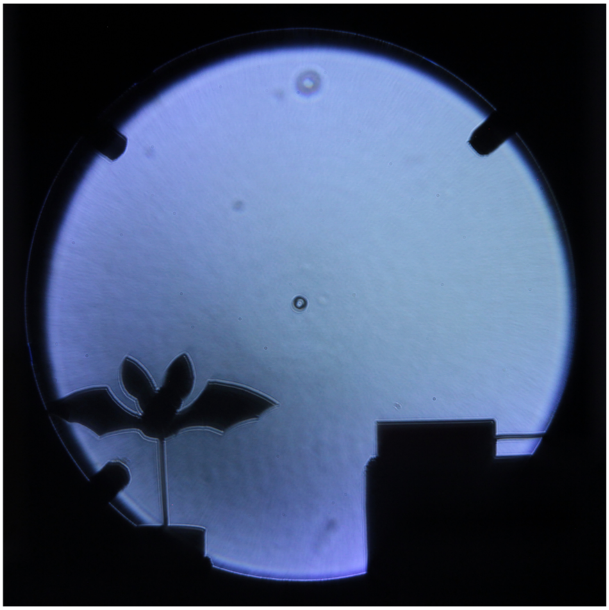

Fig. 1 Schlieren image of ultrasound emitted from the speaker at the bottom right and propagating to the left towards the bat model on the left side

In the second phase, a specially designed black-box experiment was the focus of the interview. A black box was deliberately chosen because it can encourage children to explore abstract processes in a model-like way (Glanville, 1982). The intention was to address the propagation of sound through the black box in a different way, where children can work concretely on a setup while leaving enough room for their own awareness. The children were given the task of using speech and listening at the openings of the box to deduce what might be inside the box, similar to the setup in Rode and Friege (2017) for optical black boxes. In the box, the sound was manipulated through pipes that connected different openings. As two children had to try this setup simultaneously, two children were interviewed at the same time. This also increased the spontaneity of the interview process as they could engage in a dialogue with each other.

In the third phase, the abstract topic of sound was approached from a completely different perspective: through sight instead of hearing. This allowed for a different awareness of sound propagation to see if visual perception could enable the children to experience sound differently. With the help of a Schlieren imaging setup (Author, 2021), it was possible to see the (ultra-)sound-induced density fluctuations of the sound. Before the children could observe the sound with the setup, they able to observe their hand movements in front of the mirror. This was meant to illustrate that the setup can make air visible. Then, the sound was introduced. For this purpose, an ultrasound speaker with a frequency of $40\,kHz$ was used, as sound with a lower frequency cannot be made visible with the setup. To establish a connection between the inaudible ultrasound and audible sound, a bat model was used (Fig. 1).

Table 1 Scheme of the phenomenographic analysis

	Step	Description
1	Familiarisation	Transcription of interviews with focus on semantics and content (Sin, 2010). Multiple readings of data (transcripts, drawings etc.) (Dahlgren & Fallsberg, 1991).
2	Acquisition[1]	(Temporary) assignment of text passages to a deductive-inductive formed description category (Marton & Booth, 1997, 133).
3	Condensation[1]	Screening of transcripts, each with focus on a mode of experience, structural aspects and referential aspects (Marton & Booth, 1997, 133).
4	Integration	Within the categories of description, statements are grouped based on their similarities (Marton & Booth, 1997, 134).
5	Structuring	The categories of description are hierarchised and form the outcome space (Åkerlind, 2005).
6	Revision	Revision of research findings based on respective quality criteria and presentation (Marton & Booth, 1997, 125).

[1] Iterative procedure (Åkerlind, 2005): step 2 and 3 have to be repeated several times

Data Analysis

When analysing the data, the evaluation steps of relevant publications were followed. The individual steps of the analysis procedure are made transparent in Table 1. For the analysis of the 12 interviews, computer-assisted qualitative data analysis software (CAQDAS) was used, which supported the deductive-inductive approach in open coding. This allowed for the visual breakdown of the data using the MindMap function in the subsequent analysis (step 3 condensation and step 4 integration in Table 1). Transparency is considered one of the most important quality assurance aspects in phenomenography. In addition to disclosing the analysis steps in this section, the results were regularly discussed in two evaluation rounds to ensure intersubjective comprehensibility (Åkerlind, 2005). These rounds mainly consisted of PhD students familiar with phenomenography and other qualitative analysis methods. Finally, all interview passages cited in this article were translated from German into English, with an attempt to present the statements as faithfully as possible.

Results

The phenomenographic results are presented as an outcome space, consisting of the categories of description, in the form of Table 2. It consists of three elements: a description of each category, a selection of illustrative statements for each category, and a heading for the entire category level (left column) (Han & Ellis, 2019). The structure is hierarchical, with the ways of experiencing arranged or evaluated in relation to the desired way of experiencing (usually the learning goal). The categorisation is based on the differentiation of experience, i.e. which aspects are experienced (as relevant), and on the integration, i.e. the extent to which these aspects are related to each other and to the phenomenon (Marton & Booth, 1997). The tables

Table 2 The nature of sound

Mechanical wave	**1: Sound as a pressure wave**	
	M: And the sound is made of air and then there are just small sound waves in front of the mirror. (I6, 585)	
	L: There are small pressure waves [describing the pattern of sound visible in the Schlieren imaging setup]. (I5, 486)	
Electric charge	**2: Sound as a kind of electric current**	
	H: I think the air conducts that [referring to the sound]. (I3, 105)	
	X: This [how sound propagates] is, so to speak, like water lightning, so then the water conducts it and only the air conducts the sound. (I11, 201)	
Wave	**3: Sound as (transverse) wave**	
	A: There are some waves from noise or something. (I12, 88)	
	X: And then there was also a sound wave [makes a sinusoidal movement with the finger] coming out, or whatever it is. (I11, 62)	
Entity	**4: Sound as entity**	
	D: The noise also needs space and then it pushes the air away anyway. (I1, 158)	
	A: Because the air cannot carry it [the sound] for so long. (I12, 203)	
	4.1: Sound as particle	**4.2: Sound as fluid**
	P: But at some point all these [sound] particles are used up. (I7, 443)	*S: Then it [the sound] eventually dissolves. (I8, 253)*
	S: Each point is equally loud and then, when you have more in your ear, it's louder. (I8, 260)	*V: There is air [when we speak underwater]. (I10, 165)*

are to be read such that the smaller the number or the higher up something is in the table, the more differentiated and integrated the way of experiencing is.

At first, the children described sound as something that can displace air or be carried by it (category 4). In some cases, particles were explicitly mentioned (category 4.1), which can also fly, as described by P in the following.

P: Yes, because a sound consists of millions and millions of particles and the sound flies, or yes, spreads out. (I7, 448)

However, sound does not necessarily have to be something solid to be considered an entity. It can also be a kind of liquid or gas that spreads (category 4.2). In these ways of experiencing sound, it is clearly separated from the air. Although air is seen as important for the propagation of sound, in this case it serves as a transport or carrier medium.

In conceptual terms, the awareness of sound as a wave is obvious, since primary school children also encounter the term “sound wave”. Especially in German, the term “Schall” (sound) is strongly associated with the term “Schallwelle” (sound wave). Therefore, the sole use of the term wave does not necessarily entail a detachment from the perception of sound as an entity. In some statements, it became apparent from the context that other characteristics were more prominent in the experience, as the following quotes show.

X: I am going to shoot you with sound waves now! (I11, 161)

Y: Yes, because the sound wave is released with more force, so to speak. (I11, 432)

Especially the last statement of Y shows that a wave can also be pushed around, which is a criterion for an entity according to Eshach (2014). The air can also carry the wave, as described by D, so that a separation of sound and medium is still present.

D: Because the wind then tends to carry the sound waves in the other direction. (I1, 244)

However, there were also many statements by the children in which the term wave was combined with wave movements, for example:

The child X describes and draws sound as lightning. X: And then you speak. That’s me [draws a person]. So, and then [what you spoke] comes to the other like a lightning. (I11, 234)

J: When it’s further away, then you hear it worse and worse [makes a sinusoidal movement with the hand]. (I4, 192)

In this case, these movements resembled transverse waves (category 3).

In more abstract terms, in category 2, sound is perceived as something that is conducted through the air. Here, too, air serves as a kind of transport medium, but the separation between medium and sound is not as clear with an electric current. However, if sound is described by X as a lightning (Fig. 2), a separation of sound and medium could still be perceived.

Category 1 is the way of experiencing sound as part of the air.

I: What do you think, where is the air?

O: The air is there. Or in the sound waves. (I7, 824)

Interestingly, this conversation with O and all other statements for this category were only made in the context of the Schlieren experiment.

Fig. 2 Sound drawn and described by child X: And then you speak. That's me [draws a person]. So, and then [what you spoke] comes to the other like a lightning

The Schlieren setup seemed to have a significant influence on the way of experiencing sound in this interview setting. In order to better assess and evaluate this influence, it was important to investigate how the children perceived sound exclusively with the Schlieren setup. The outcome space for the ways of experiencing sound exclusively in the Schlieren setup is presented in Table 3.

The children first perceive the shape of the visible density changes (category 5.2). The explanation with the bat is understandable for some children, but does not lead to the awareness that what they see is sound, but rather something abstract that only bats can perceive (category 5.1).

For some, sound remains an entity (category 4). The darker areas in the density changes are perceived as sound, which displaces the air.

G: With the darkness there, the air goes away because there are sound waves. (I3, 546)

Other children recognise waves in the pattern (category 3). Here, the way of experiencing the waves remains as transverse waves.

In the second category, the children link sounds such as tones and noises with the waves they see. Here, a peculiarity of the German language must be emphasised. Unlike in English, the word "sound" is rarely used in everyday German for tones and noises. The children therefore do not always associate this with the term.

The first category is also the mechanical wave. This is divided into the way of experiencing a pressure wave (Table 1.1), as in Table 2, and the way of experiencing sound as part of the air (category 1.2). The latter also goes hand in hand with the central role of air as a wave carrier for the mechanical wave sound.

Table 3 Sound perception in the Schlieren setup

Mechanical wave	**1.1: Sound as pressure wave**	**1.2: Sound is air**
	L: There are small pressure waves [describing the pattern of the sound visible in the Schlieren imaging setup]. (I5, 486)	*M: And the sound is made up of air. (I6, 585)*
Tones	**2: The waves are tones**	
	D: I can try it [the Schlieren setup] out by speaking and see if you can see any waves. (I1, 557)	
Wave	**3: Recognise waves**	
	D: You can see small waves like this [makes a waving hand gesture]. (I1, 531)	
Entity	**4: Sound as entity**	
	Z: [The air is] always in the spaces in between. [The dark area] is the sound or something. (I12, 442)	
Abstract	**5.1: Recognise the sound (as an abstract concept)**	**5.2: Describe the shape**
	N: Only bats can hear the sound. There is no sound coming out at all. (I6, 605)	*D: Such circles and they keep getting bigger. (I1, 546)*

Discussion

The children expressed a fascinating range of ways of experiencing sound: as an entity, a wave, an electric current and a mechanical wave. In particular, the awareness of sound as a kind of electric current presents an interesting way of experiencing sound that has not been documented in the literature before. This is especially interesting because it provides a description of sound propagation that is independent of the experience of sound as a (transverse) wave. Perception as a (transverse) wave seems to be strongly influenced by everyday language, at least in German, so particular attention must be paid to the way of experiencing the students are actually referring to. That it can be problematic to designate and describe sound as a wave has also been emphasised by other authors in the past, including Eshach and Schwartz (2006) and Linder (1992). At the same time, the focus here is more clearly on a possible propagation mechanism and thus differs significantly from the idea of sound as an entity or as a simple fluid. Unfortunately, the students' statements are not very specific, leaving the question of what exactly the students are imagine when they speak of an electrical current open.

An essential part of the interview design was to use various methods that were distributed across the three phases of the interview (see Methods section). In order to address the abstract topic of sound with the children, it was also important to incorporate experiments that encourage model thinking (black box experiment) and those that engage senses other than hearing (schlieren experiment). Especially with the latter, it became evident that this change of perspective opened up new possibilities for the children to experience the phenomenon of sound. The awareness of sound as a pressure wave (category 1 in Table 2) is a surprising result. As mentioned in the results (Results section), these statements only emerged in the context of the Schlieren setup (Author, 2021). The more detailed breakdown of the awareness of this particular setup in Table 3 shows even more clearly the range of the ways of experiencing this experiment allowed the children to have. This demonstrates the possibilities that this experiment offers not only to amaze children but to truly convey a new awareness of sound. Because the visual perception of sound in this experiment allows for a much more direct connection between air and sound than it is possible in other experiments. In comparison to the rest of the interview, the Schlieren experiment shows that variations in learning objects are important and enable to discern different aspects of a phenomenon. This finding confirms the conclusion of other publications that the choice of an experiment in the classroom should always be made with consideration of the learning goal and the aspects that the students can discern in this experiment (Bernhard, 2018; Tang et al., 2022). From a didactic perspective, there is therefore a great opportunity to use this setup to help children experience the scientifically correct concepts of sound. However, in what form this should exactly happen would have to be investigated separately.

The results of this study can be compared well with previous publications. The awareness of sound as an entity can be found in the results of Table 2, particularly in category 4. To name some aspects from the Literature review section, for example, the children expressed that the size and number of sound particles influence the listening experience (loudness) (category 4.1 in Table 2), or that sound is an invisible material that can be pushed around (category 4 in Table 2) (Eshach, 2014)). The results of this study show that entity is not only limited to solid materials. Some children also perceived sound as a fluid (category 4.2 in Table 2). The way of experiencing sound as an entity can also be found in category 3. The mere use of the word "wave" does not necessarily indicate that the children mean that the wave is part of the carrier medium. This was also impressively demonstrated in the Schlieren experiment. Here, what was seen was described as a wave, but at the same time as something that displaces the air (category 4 in Table 3).

The process-based way of experiencing sound, which can be divided into the awareness of sound as a wave (Eshach, 2014; Hrepic et al., 2010) or the more differentiated subcategories of Linder and Erickson (1989) (see Literature review section), is in contrast to the way of experiencing sound as an entity .

Primary school students can also perceive sound as a wave, as shown in category 3 of Table 2. In some cases, the way of experiencing sound as a wave also included the perception as a mechanical wave that is part of the propagation medium (category 1 in Table 2 and category 1.2 in Table 3). When the term “wave” was used, the children always understood it to mean a transverse wave, which they depicted with hand movements or in their drawings. Linder (1992) also found that students perceived sound waves as transverse waves. A more detailed description of the propagation process, such as the domino-like triggering in the study by Linder and Erickson (1989), could not be determined.

Conclusion

Sound is an abstract phenomenon, which is easily forgotten because it is so commonplace. The latter that makes it an exciting topic for primary school children. However, the abstract nature should be considered when planning teaching concepts. The present study aims to provide insight into what children perceive about sound, specifically about the nature of sound, by focusing on the propagation of sound. This knowledge can now be used to revise and design new and old lessons, exercises and tasks for teaching sound in the classroom. The results presented here (Tables 2 and 3) serve as a guide to what ways of experiencing sound can be expected from children in the classroom. This allows for tasks to be differentiated to meet the children where they stand in terms of their ways of experiencing. This enables a more individualised teaching approach, which can still be pre-planned to some extent.

Looking at the results of this study in the context of previous studies on the awareness of sound by different age groups, interesting ways of experiencing sound are revealed. It would be interesting to further examine the individual categories presented in Table 2, particularly category 2 in Table 2, which raises the question of what children specifically perceive as electric current in sound. Another exciting sub-result of this study was how helpful the Schlieren experiment was in providing students with a new perspective on sound. Furthermore, this study by no means covers the entire spectrum of phenomena associated with sound. Sound is not just a mechanical wave that propagates, but also a sensory impression that we humans can experience through our ears, among other things. Therefore, it seems appropriate to continue researching the field of experiencing sound.

Limitations of the Study

This study does not allow for unconditional generalisation of the results. First of all, there is the sample. With 24 children, many perspectives were included in the outcome space for the framework provided by this method. However, it is entirely possible that there are other ways of experiencing in primary school children that were not expressed in this sample, partly because the way of experiencing is directly dependent on the perceivable phenomena (such as the experiments offered).

In the problem-centered interview method, care was taken to incorporate the interviewer’s prior knowledge into the questions, but not to obscure the children’s original perspectives by consciously addressing the children's relevance structures to minimise the interviewer's influence (Sin, 2010). However, a certain degree of influence remains.

Finally, the analysis itself should be mentioned. To present the study transparently, the individual procedural and evaluation steps, as well as the resulting outcomes, are disclosed in the Method section. It is in the nature of the phenomenographic approach that even if the quality criteria are met, another person may not reproduce exactly the same results, but it should be comprehensible how the results presented were obtained (Åkerlind, 2005). These limitations were deliberately reflected upon and actively taken into account in the study's processing.

Declarations

Ethical approval and consent to participate The implementation of the study was previously approved by the Lower Saxony state school authority (reference H1Rb-81402-(03/2019)). The interviews with the children in this study were conducted in accordance with the ethics policy. And the consent for the data collection and publication of all legal guardians was obtained.

Conflicts of interest The authors declare that they have no conflict of interest.

Appendix A: Interview Questions

A.1 English interview questions

Part I: General Questions

1. Have you ever heard the word sound? When I talk to you, is that sound too?
2. How does sound get from me to you?
3. Can you describe what air is? Does anything happen to the air when sound spreads?
4. What would happen if there was no air here (e.g. like in space)?
5. What do you think? Can you hear underwater?
6. If someone is talking outside the room, can we hear them? What happens to the sound?
7. When someone knocks on the door, do you hear it better, worse or just as well?
8. When I talk to you now, you can hear me. Where can you hear me and where not? If I were hovering over you, could I hear you?
9. If you hear a group of musicians playing in the street and then you slowly move away from them. You go further and further away. What happens to the music?
10. If you shout something to someone who is standing far away, do they hear you immediately or later?
11. I can also make loud and soft sounds. What do you think makes a sound loud or soft? Is there a difference between loud and soft sounds?

12. If I play a high note with the xylophone and a low note with the xylophone, what do you think? Is there a difference between high and low tones?
13. When you whisper, the other person cannot hear you very well. I have a paper funnel here. Could it help you understand each other better?
14. Imagine someone is listening to music really loudly and you are trying to sleep. What can you do to make it quieter?
15. When there is thunder and lightning, you hear or see one before the other. Which one do you hear or see first? Why is that?
16. Are there sounds that we cannot hear?

Part II: Black Box

1. If you speak into the holes and listen at the other holes, maybe you find out what is happening inside the box.
2. (It sounds louder/muffled.) What do you think is the reason for this?
3. Look, here are some tubes. What do you think they do with the noise?
4. And here is some soft material on the walls of the box. Why do you think it's there?

Part III: Schlieren Imaging Setup

1. With this mirror, it is possible to see what is happening in the air. For example, if I hold my hand in front of the mirror, I can see how the warm air rises from my hand.
2. Now I'll show you something very special: I'll show you sound. For that, I brought a speaker that makes a very high-pitched sound. It's so high that only bats can hear it.
3. Can you describe what you see?
4. I had said that the setup makes air visible. What do you think happens to the air with the speaker now?

A.2 German interview questions

Part I: Allgemeine Fragen

1. Habt ihr das Wort Schall schon einmal gehört? Wenn ich mit euch rede, ist das auch Schall?
2. Wie kommt das Geräusch von mir zu Dir?
3. Beschreibt mir mal, was Luft ist? Passiert etwas mit der Luft, wenn sich ein Geräusch ausbreitet?
4. Was würde passieren, wenn hier keine Luft wäre (z. B. wie im Weltraum)?
5. Was meint ihr? Kann man unter Wasser hören?
6. Wenn jemand draußen vor dem Raum redet, können wir das hören? Was passiert da mit dem Geräusch?
7. Wenn jemand nun an die Tür klopft, hört ihr das besser, schlechter oder genauso gut?
8. Wenn ich mit euch rede, könnt ihr mich hören. Wo könnt ihr mich hören und wo nicht? Wenn ich über euch schweben würde, könnte ich euch hören?
9. Wenn ihr eine Gruppe Musiker auf der Straße spielen hört und ihr euch dann langsam von ihnen entfernt, ihr geht also immer weiter weg. Was passiert dann mit der Musik?
10. Wenn Du jemandem etwas zurufst, der ziemlich weit weg steht, hört er Dich dann sofort oder erst später?
11. Ich kann auch laute und leise Töne erzeugen. Was meint ihr, was macht einen Ton laut oder leise? Gibt es einen Unterschied zwischen lauten und leisen Tönen?
12. Wenn ich mit dem Xylophon einen hohen Ton erzeuge und einen tiefen. Gibt es einen Unterschied zwischen hohen und tiefen Tönen?

13. Also, wenn ihr flüstert, kann man den anderen ja nicht gut verstehen. Ich habe hier einen Papiertrichter. Könnte er euch helfen, einander besser zu verstehen?
14. Stellt euch mal vor, jemand hört richtig laut Musik und ihr versucht zu schlafen. Was könnt ihr machen, damit es leiser wird?
15. Bei Blitz und Donner hört oder sieht man das Eine vor dem Anderen. Was hört oder sieht man zuerst? Warum ist das so?
16. Gibt es Töne die wir nicht hören?

Part II: Black Box

1. Wenn ihr in die Löcher sprecht und an den anderen Löchern lauscht, könnt ihr vielleicht herausfinden, was in der Kiste passiert.
2. Es klingt lauter/dumpfer. Was meint ihr, woran liegt das?
3. Guckt hier sind Schläuche, was meint ihr was machen die mit den Geräuschen?
4. Und hier ist so weiches Material an den Wänden der Kiste, was meint ihr, warum das da ist?

Part II: Schlieren Imaging Aufbau

1. Mit diesem Spiegel ist es möglich zu sehen, was in der Luft passiert. Wenn ich zum Beispiel meine Hand vor den Spiegel halte, kann ich sehen, wie die warme Luft von meiner Hand aus aufsteigt.
2. Jetzt zeige ich euch etwas ganz Besonderes: Ich zeige euch Schall. Dafür habe ich einen Lautsprecher mitgebracht, der einen ganz hohen Ton macht. Der ist so hoch, dass ihn nur Fledermäuse hören können.
3. Beschreibt mal was ihr seht?
4. Ich hatte ja gesagt, dass der Aufbau Luft sichtbar macht. Was meint ihr, was bei dem Lautsprecher jetzt mit der Luft passiert?

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