SUBJECT MATTER EDUCATION
IN PRACTICE –
NEW WAYS FOR TEACHING SCIENCE
NR 8, SEPTEMBER 2008

TEACHING ABOUT SOUND, HEARING AND HEALTH

KNOWLEDGE BASE, SUGGESTIONS FOR TEACHING AND COPYING MATERIAL

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ISSN 1651-9531, Editors: Anita Wallin and Björn Andersson

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PREFACE

This material is based on research and it is designed for teachers who work in the compulsory school.

The first version was developed at the Department of Education in Gothenburg as material for in-service training courses that were financed by the Swedish National Agency for Education. Since then it has been financed by the Department of Education and the ISSUE project (Integrating Subject Science Understanding in Europe). The aim of the ISSUE project was to design and validate teaching learning sequences within different areas. The manual Sound, Hearing and Health is the Swedish contribution. The manual exists in two partly different versions; the first one, developed in 2006, was intended for pupils aged up to 13 years. That version is available in three languages: English, Swedish and Spanish. This extended version is aimed to cover the whole compulsory school (with pupils up to 16 years of age). The Agency for School Improvement has contributed to the development of the extended version, which is available in two languages: English and Swedish.

The idea of producing material for teachers within the area of sound and hearing was first broached by Professor Björn Andersson. Eva West wrote the first draft in 2001. Under her guidance, the material has been used by and tested on teachers in both in-service training and undergraduate studies. It has been revised several times.

Some of the teachers have tested part or all of the material in their classes. They have given us the opportunity to follow their work in the classroom and have recorded their impressions in diaries, expressing their views on the contents and the set-up.

We especially wish to thank those teachers and pupils at Lerlyckeskolan in Gothenburg who have done extra work when testing the material. They are Eva Carlsson-Landström, Linda Stråhle and Anna Andersson and their pupils in form four, 2005-2006, and Tommy Hagen, Gunilla Trapp, Lotten Svensson and Sara Jansson and their pupils in form six.

We are also very grateful for the work teachers and their pupils from secondary schools in Kungälv have done in developing this extended version. These teachers are Cristine Lysell, Ytterbyskolan, Ulrika Hanse and Susanne Westin, Thorildskolan and Lise-Lott Stiig from Munkegärdeskolan.

Gothenburg August 2008

Eva West

ACKNOWLEDGMENTS

Figure 4.1 on page 36 is from AMMOT (2002).
The pictures on page 81 and 91 are from Jardine (1964).
The picture at the top of page 89 and the two upper pictures on page 90 are from the LMN project (1975), section 8, chapter 1.
The model in the picture on page 86 was developed and built by Anna Anderssson, Linda Stråhle and Eva Carlsson-Landström.

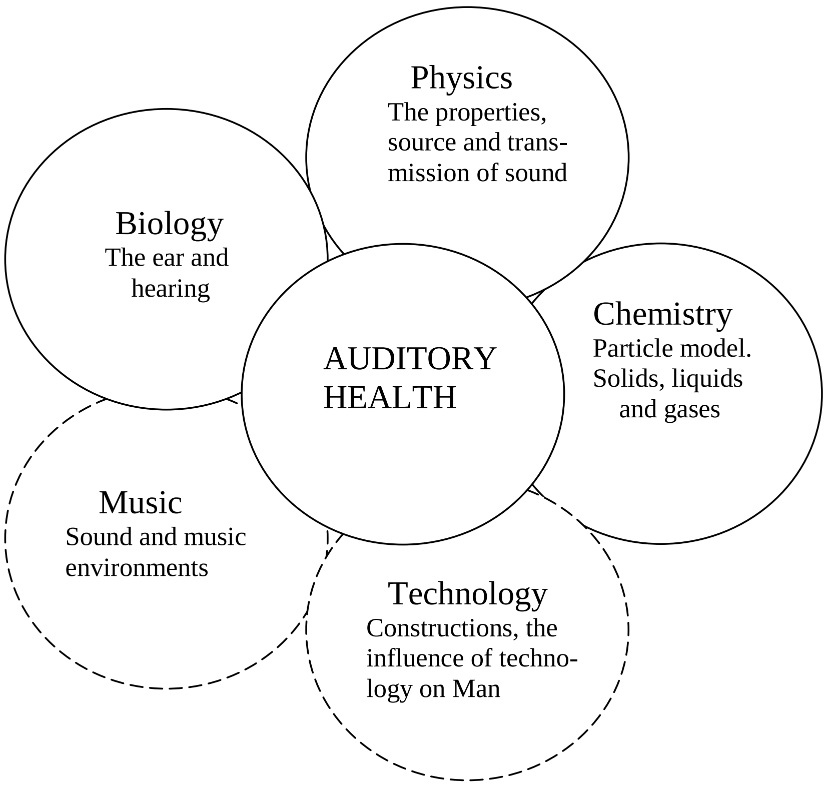
In the supplement there are questions that are formulated by other persons than the author, or inspired by their ideas:

The containers and *The trumpeters parts 1-4* were developed by Björn Andersson
The lightning is from the TIMSS study 2003, Skolverket (2004).
The cymbals and *Under the water* were developed by Linda Stråhle, Eva Carlsson-Landström and Tommy Hagen.
Animals and Hearing – materials for copying were developed by Cristin Lysell.
The clock in the silent room, The barking dog, Liza and the dog, The flute note and *The resounding mountain parts 1 and 2* were developed from ideas of Björn Andersson.
The wire. The idea and the pictures come from Assessment of Performance Unit, APU (1989).
The swimming baths was formulated by Ulrika Hanse and the picture was drawn by Cristine Lysell.
What have I learned? was developed by Cristin Lysell and Susanne Westin.
Why do you call it sound waves? and *Explanation – Do you hear the car traffic better certain days?* The pictures are taken from Jardine (1964).
Can you hear on the moon? The idea to the question is from Viennot (2001).

INTRODUCTION

The main idea behind this manual is that integration of knowledge from different school subjects will contribute to a holistic picture of sound, hearing and health, which may increase children's and pupils' understanding of the area. This includes taking care of both their own and others' auditory health. The subjects primarily dealt with in this manual are biology, physics and chemistry, but they also include music and technology. Many other subjects can also be integrated into this field.

Acoustics means the scientific study of sound and includes the origin and transmission of sound and how it can be detected and perceived. The concept "sound" is sometimes defined in different ways and is generally used to describe two things: a perception of sound and/or the disturbance in a medium that gives rise to this. Strictly speaking, then, this material should be entitled "Teaching about acoustics and hearing health", but since the terms sound and hearing are probably closer to pupils' everyday usage than the meaning of the concept acoustics, the latter is not used. The meaning of the term sound in this manual corresponds to the origin and transmission of sound.



The manual about Sound, Hearing and Health deals with the following aspects:

- knowledge about sound and hearing in historic times
- how children, pupils and students reason about sound
- a survey of current subject didactic knowledge in chemistry, physics and biology that supports teachers in the planning of their courses
- the content of syllabuses, followed by a number of suggestions for lessons
- ideas and questions for discussion and evaluation intended for pupils
- pupils' attitudes towards the sound environment characteristic of present-day youth culture, together with other health aspects.

The manual does not contain any uniform recipe for how teaching should be done; rather it is a tool to assist the teacher to further develop his/her own knowledge. The teaching – learning process will be followed by continuous formative assessment, which means that the teacher continuously assesses the development of the pupils' knowledge and conceptual understanding, and uses the results to revise the content or form of subsequent lessons. This will in turn have on impact on how the pupils learn and understand the content.

The numbers in the text refer to the references used. The list of foot notes may be found on pages 118-120.

1. HEALTH AND ATTITUDES

There are many research reports that deal with the sound environment and health issues. In this chapter we refer to numerous studies that motivate and support the teaching of sound, hearing and health.

1.1 The sound environment – a growing societal health concern

Working and leisure-time environments with high sound levels[*] have become more and more common, which has resulted in many people having some form of hearing impairment. Furthermore, during the last ten years, impaired hearing among young people has rapidly increased, which will probably result in an even greater increase in the number of people with impaired hearing in the future. A new risk factor is the massive increase in the use of MP3-players. This will not only cause great suffering for those affected but will also mean higher societal costs.[1]

Studies show that 12 % of 7-year-old children have experienced tinnitus, i.e. they hear sounds in the ear or in the head that are not real sounds.[2] More than one in three 12-year-olds sometimes listen to music in headsets. After listening to loud music or other loud sounds one in five 12-year-olds in Sweden, is troubled by ringing, squeaking, hooting or buzzing in the ears. Just over one in ten reports that their hearing is worse afterwards. About 3 % children in this age class report that they often or always have tinnitus.[3]

Among young people aged 13-19, more than one fifth have had longish periods of temporary tinnitus, and six of ten have felt pain in their ears in connection with high sound levels, mainly related to concerts and discotheques. Almost half of them report they have felt momentary peeps or buzzing sounds. A tenth report permanent tinnitus, and barely one fifth are becoming sensitive to sounds. Those who report on permanent tinnitus and other hearing impairments are the ones who protect their hearing to a higher degree. They are also more worried, while few of those without problems are worried. Twice as many girls as boys are worried about impairing their hearing.[4]

The opinion of many researchers within the area is that precautions at an early age should be taken in order to maintain children's auditory health. Children should

[*] In a scientific context, the terms sound level and sound volume are synonymous. The adjectives used with these are high and low. In everyday language, we talk about loud music and soft music. Another property of sound is its frequency or pitch. The adjectives used for this phenomenon are high and low.

be taught about sound, hearing and health as early as possible to develop an awareness of how to handle loud sounds and noise.[5] The problem is that we ourselves can not determine which sound level the ear can stand. Therefore knowledge is the most important protection.

At work and in school

According to the WHO, the white sound in rooms where teaching is pursued should not exceed 35 decibels, dB(A)[**]. An employee exposed to sound levels of 80 dB(A) during an eight-hour working day should be informed about the noise risk and be offered hearing protection. The same directives apply for the entire EU.[6]

The risk of suffering from hearing impairment from classroom noise is not so great, except in music, physical education and woodwork lessons, where sound levels are considerably higher. Furthermore, the sound level is so high even in dining-rooms and recreation rooms in schools that it could cause hearing impairment such as tinnitus.[7]

In leisure hours

Many young people expose themselves to loud sounds in their leisure hours. They listen to loud music mostly in their own MP3 players, but also at discotheques, at music festivals and concerts, at parties, at the cinema, during training activities, at sports events and so on.

Young people aged 14-20 on average listen to music 3 hours a day, and much of this listening occurs via MP3 players. With improved technique, the MP3 players allow them to listen to loud music without reducing its quality even at high sound levels.[8] Studies show that young people gladly raise the sound volume even more in the bus or car, or in other environments where other sounds disturb them, when they wish to live in peace, when their favourite music comes or just to relax. The technical design of the MP3 earphones also allows them to listen to loud music among other people without disturbing them. Many young people that practice sports and think they live a healthy life fail to realise that, if they are wearing their MP3 earphones, they are exposed to high sound levels even when they are out jogging, biking or riding a horse.

The MP3 players have turned listening to music into an individual activity where it is only the individual him/herself who controls the duration and sound level of the music. His/her own knowledge and attitudes to loud sounds are of decisive importance. Several research reports show the importance of knowing that high

[**] The sound level is measured in a unit that is called decibel (dB). When you measure sound, you use a special filter (an A filter) that makes a sound level meter (= decibel meter) perceive the sound in approximately the same way as the human ear does. The sound level is therefore said to be measured in decibel A, dB (A).

sound levels can damage hearing not only temporarily but even permanently, but this it not enough. Most young people know that loud sounds might damage their hearing but nevertheless think that their own listening is not at risk. Thus, one of the most important issues to work on actively is to make young people conscious of their own vulnerability.[9] According to WHO music that is listened to through ear-phones for one hour should not exceed 85 dB(A).[10]

There are walkmans and other similar gadgets that, judging by their design, are specially intended for children and therefore comply with the EU’s safety directives for toys. These directives stipulate that the sound levels in portable walkmans etc., intended for children, should not exceed 90 dB(A). Tests show that even after just a few minutes, a child is exposed to the same risk as a person who works a whole day in a noisy environment. The ”baddies” among the MP3s had such high sound levels that they could cause hearing impairment after one single occasion.[11]

Young people also risk contracting hearing disorders and tinnitus at discos, for instance, where music is played at sound levels that are far too high. The sound level at an evening disco is often gradually raised during the course of the evening, reaching a peak towards the end. Most people know that high sound levels can cause damage, but they have superficial knowledge of how this damage arises and at which sound levels damage occurs. In certain cases, there are myths that must be broken before the right information can be conveyed. One such example is that music cannot be harmful because ”I like it”.[12]

Children younger than 13 years are affected more than young people between the ages of 18 and 20. The younger the child, the more sensitive s/he is to high sound levels. The WHO’s recommendation is that the average sound level should not exceed 90 dB(A) for children up to the age of 12 and the maximum level should be below 110 dB(A). Junior discos or the like are examples of such activities. The recommendation for ordinary concerts is that the average sound level should not exceed 100 dB(A) and the maximum level should not exceed 115 dB(A).[13]

Several studies show that half of the pupils think that sound levels at discos are “just right”, whilst nearly 40 % are of the opinion that sound levels are too high. There are far more girls than boys that think the music is played too loud, and also more girls than boys use hearing aids. There is even an age difference when it comes to the pupils’ attitudes. Half of the older pupils want to have a lower sound level, while the younger pupils are less critical. When younger pupils go to discos, only a tenth of them protect their ears, whereas they protect their ears to a greater extent in other places, particularly at open air concerts (more than a third). They mostly protect themselves by using ear-plugs. A large number of them avoid going close to the loud-speakers and/or they go outside to rest their ears. Only a very few try to get sound technicians or disc jockeys to lower the sound.[14]

Even those who play music can be affected. Three out of four musicians, both younger ones and older ones, have trouble with tinnitus, and this is often combined with other hearing disorders. Practically all of them carry on with their music, using hearing protection, in most cases.[15] If both musicians and young people have hearing disorders as a result of high sound levels, then the question is: Why do they play so loud?

1.2 What are pupils' arguments on the issue of noisy environments?

In The National Evaluation of the Swedish Compulsory School 2003[16], more than nine-hundred 12-year-old pupils were given the following problem to solve. They were supposed to take their stand in a question concerning sound levels in a class disco and to put forward arguments for his/her choice. The result has shown that two thirds of the pupils only use supportive arguments to motivate their standpoints. Just over a tenth of them give both supportive and counterarguments, which they use to reason in a more detailed and problem-focused way. Naturally, it is very important that pupils learn to bring up both arguments for and arguments against the issue in question when working with this type of assignment in school.

Raise or reduce?

Those who choose to raise the volume argue that it is the high sound level that makes a disco, and that loud music gives you your own “cool” experience. The counterargument to this is the risk of damaging people’s health, but this does not seem to matter for those who choose to raise the volume of the music.

Those who choose to reduce the volume argue that they care about the health of those who do not want to or cannot be in an environment with high sound levels. One counterargument here is that it will not be a proper disco if the volume is reduced, but this is not sufficient reason for those who want to lower the volume.

Some of the pupils are sheer egocentrics, i.e. they are quite unconscious of other people’s health. Others show that they are simply considering others, thereby showing that they do not include themselves in the problem under discussion. One quarter of them clearly associated the ego with ”all the others”. They had allegedly shown signs of having understood that too high a sound level is, in fact, not only dangerous for others but also for themselves.

How the pupils solve a conflict of sound levels

Many pupils give suggestions as to how a conflict about the sound levels in the class disco could be solved. Most of the suggestions include solutions that can be put into practice directly, for example:

- dividing the pupils into two groups, placing some in a room where loud music is played and the others in a room where soft music is played

- technical solutions such as pupils who are sensitive to loud music having to have ear-plugs
- solutions such as alternating the sound volume between loud and soft, for example, by having a loud song and then a soft song.

All of these types of direct solutions indicate the pupils' naive attitude towards their own health. There are other indirect suggestions relied on methods based on chance such as voting or tossing coins about the sound levels. Among the various suggestions for solving the problem, it was possible to differentiate some that allow some sort of democratic aspect or fairness aspect to take precedence over the health aspect.

The number of pupils who accept that those who like loud music can have loud music is overwhelmingly high. They seldom question the aspect of health on a deeper level. It seems easy for pupils to understand that other people can get tinnitus, but it is difficult for them to realise that the same thing can, in fact, happen to them as well. The problem-solving is not based on actual knowledge of the matter at issue. Pupils do not value scientific knowledge as being particularly important when they have to make decisions about sound levels in the classroom. If pupils understand how the ear works and know about the sensitivity of the ear and the effects of sound levels, they might have suggested other solutions. In order for pupils to be able to tell the difference between facts and their own sets of values, they need continuous practice in differentiating between scientific knowledge and their standpoints.

Girls and boys

Girls show that they care for others to a somewhat higher extent than boys, and this attitude is in harmony with the choices they make. There are twice as many girls as boys that show consideration for others or for other people's health. Nine-tenths of these pupils choose to reduce the volume of the music at the disco. There are twice as many boys as girls among those pupils that do not care about others i.e. they lack the ability to show empathy for others. The majority of these pupils choose to raise the sound level at the disco.

1.3 Teaching about hearing health

Hearing impairment has now become a societal health issue, and the research reported here shows that teaching about hearing health is an important part of the work for good health. A sound knowledge is a prerequisite for pupils making healthy choices in surroundings with high sound levels. Nevertheless the question is complicated, and there are several elements besides real knowledge that influence the pupils' choices. The individual's idea of him/herself as vulnerable or invulnerable is an important issue when it is about taking risks like exposure to loud music. Defence mechanisms come into play when one is maintaining the idea of ones' own invulnerability. Either you claim that you are not affected by those negative consequences that might follow your behaviour (e.g. hearing impairment) or you start taking precautions (e.g. start using ear protection) without actually changing your behaviour. The social norms accepted in the peer group are another element to consider. For example, professional musicians are dependent on keeping their hearing. and it is in the social norm to use hearing protection. Therefore, the reasons for using hearing protection are stronger than those preventing the use of hearing protection. A further element is the question of where responsibility should lie, that is, does he/she accept responsibility for him/herself or does he/she consider other people to be responsible. If I am responsible for my future hearing, then it is also my responsibility to take action (by using hearing protection, avoiding places with loud music, reducing the sound volume, and so on), but if I don't feel responsible, then I do not need to act. Then it is someone else's responsibility, for example the producers of the MP3 players, the disc jockey or "society".[17]

Of course, the teaching can be planned and designed in different ways but, irrespective of this, the research indicates that the following components are important when the aim is to improve the pupils' chances of keeping their hearing health:

- The pupils should learn that they risk getting permanent tinnitus if they are exposed to high sound levels.
- Pupils should realise that they themselves as individuals might be affected, that is, the question of vulnerability/invulnerability.
- To make the students aware of risk considerations by working on, when possible, whom they think should bear the responsibility for or control their hearing health.
- How to use MP3 players in a healthy way.

2. CURRICULA AND SYLLABUSES

In the first chapter a number of arguments for teaching about sound, hearing and health were presented. In the following chapter, the Swedish steering documents are used as an example to illustrate the link between different school subjects and the area sound, hearing and health. Depending on how the school's steering document looks for different school years in the different countries, it is left to each teacher to analyse it in a similar manner in his/her own country.

2.1 Content of Swedish Curricula/Syllabuses 2000

The stated goals give the minimum level of knowledge that all pupils should reach in the fifth and ninth school years (pupils aged 13 and 16, respectively). The goals thus express a fundamental level of knowledge of the subject at both these points in time. Goals to reach for the ninth school year form the basis of assessing whether a pupil should be given the mark "Pass".

The list provides an overview and shows how the teaching areas link up with goals in different syllabuses, while forming a basis for concretising teaching goals and formulating marking criteria that the pupils understand. It is also evident from the list that a number of goals in the different scientific subjects, for example those under the scientific activity and the use of the knowledge, are similar to each other.

Goals in the 5th school year

The goals in the fifth school year should form a check-point. The idea is that the goals should be evaluated, and that any pupil that does not achieve this goal in the 5th school year should be given the opportunity to acquire the knowledge that is lacking.

In the school subjects biology, physics, chemistry and technology for school year 5, there are a number of goals to reach that affect the area of work. In music, there are no such goals at this age.

Science studies

Pupils should

concerning nature and Man

- develop their knowledge of the structure of the human body and its functions (biology)
- have an insight into the fundamentals of dispersion of sound, hearing (physics)
- have a knowledge of the concepts of solids, liquids, gases (chemistry).

concerning scientific activity

- have an insight into experimental work, as well as recurring field observations in their immediate environment (biology)
  have their own experiences of systematic observations, measurements and experiments (physics)
- be able to make observations about different materials (chemistry).

concerning use of knowledge

- have an insight into and be able to discuss the importance of habits which promote good health (biology).

Technology

Pupils should

- be able with assistance to plan and build simple constructions.

Goals in the 9th school year

The goals for biology, physics, chemistry, technology and music for school year 9 contain clearer goals concerning sound-hearing-health.

Science studies

Pupils should

concerning nature and Man

– have a familiarity with the organs of their own bodies, their systems and how they function together (biology)
– have a knowledge of different forms of energy and energy conversion (physics)
– have a knowledge of pressure, heat and temperature in relation to different forms of matter (physics)
– have an insight into how sound is created, dispersed and recorded (physics)
– have a knowledge of the properties of air and water (chemistry).

concerning scientific activity

– be able to make observations in the field and carry out experiments, as well as have an insight into how they can be designed (biology)
– be able to carry out and interpret simple measurements of environmental factors (biology)
– be able to make measurements, observations and experiments, as well as have an insight into how these can be designed (physics, chemistry)
– be able to carry out experiments based on a hypothesis and formulate the results (chemistry).

concerning use of knowledge

– be able to take part in discussions on the importance of regular exercise and good health habits (biology)
– be able to use not only a knowledge of science, but also aesthetic and ethical arguments in issues concerning the applications of physics in society and technical constructions which exist in pupils' daily life (physics)
– have an insight into how experiments are designed and analysed through theories and models (physics)

– be able to use results from measurements and experiments in discussions about environmental issues (chemistry).

Music

Pupils should

– be aware of the effect of different sounds and musical environments on people as well as the importance of audiology.

Technology

Pupils should

– be able to build a technical construction using their own sketches, drawings or similar support, and describe how the construction is built up and operates.

One might not in the first instance associate teaching about sound, hearing and health with the subject of chemistry, but since sound transmission occurs in different substances, which in their turn exist in different states (solid, liquid and gaseous), there are natural links.

FOR DISCUSSION

What effect does the wording of the curriculum in your country have on teaching about sound, hearing and health?

To what extent do you think the goals of the syllabuses in your country are linked to and influence the planning of the area sound, hearing and health?

How do you think the goals of the syllabuses in your country could be realised so that all pupils achieve fundamental knowledge in the area sound, hearing and health?

3. SOUND AND HEARING THROUGHOUT HISTORY[1]

The earliest historical signs that humans have struggled with speculations about sound goes back to ancient Greece. Writings are preserved in which well-known philosophers recorded their ideas about sound and hearing. By and by more scientific studies appeared, particularly during the Renaissance, and the mid-1700s saw the founding of the first scientific journal, in which scientists could publish their results in the form of articles. So started the open, critical, scientific debate, that we are familiar with today.

Throughout history, well-known philosophers and scientists have struggled with the same problems that pupils face today when attempting to understand the nature of sound and hearing. This provides a fascinating backcloth to the teaching-learning process. For instance, an eleven-year-old may, like Plato, wonder whether loud sounds are transmitted faster than soft or weak sounds. An historical outlook may thus give the pupils new perspectives on their own learning; imagine knowing more than Plato or Aristotle!

The historical resumé more or less follows the same structure as in Chapter 7, which concerns how children, pupils and students perceive sound and hearing. The same structure reappears in the chapter on suggestions for teaching, Chapter 11. The intention is to make it easy for the teacher to take up and make use of historical comparisons in their lessons.

3.1 The origin of sound

Pythagoras (580-500 B.C.) was interested in vibrations and did experiments with strings of different lengths. He found that there was a connection between pitch and the length of the vibrating strings. A longer string gave a lower tone than a shorter string of the same thickness. His experiments laid the foundation of the harmonic scale that we use today. At the end of the 1500s Galileo resumed Pythagoras' experiments, and in doing so was able to refine the theory by showing that in actual fact it was the number of oscillations per time unit of the string that gave rise to the different pitches. True enough, a string of the same thickness does oscillate faster the shorter it is, but the number of vibrations is a more exact measure of the pitch than the length of the string.

3.2 The transmission of sound

The theory that sound requires a medium in order to be transmitted already originated in classical antiquity. Learned men perceived sound as something that spread out from sources, but had different ideas about the nature of this something. The idea that sound is material was clearly expressed. Demokritos (430-371 B.C.) imagined that the voice was air that had a certain form and was transported. However, the Greeks did not have access to the modern concept of gas, and it is not so easy to know what they meant by “air” and how they conceived of its different processes. Aristotle (384-322 B.C.) thought that air had to be pressed together/compressed to enable sound to be transmitted, and that it was some kind of small air packet, a little wind, that moved forwards. Aristotle seems to have been the very first to write about waves, which he compared with water waves, when describing sound transmission. Sound, air and hearing were linked together by Chrysippus (280-207 AD). He assumed that sound spreads like a sphere from a sound source, and that you can hear because the air is set in motion between what is sounding and what is being heard. The Roman Lucretius (97-55 B.C.) thought that when a person screams loudly “the voice’s atoms” pass the narrow gullet in such large amounts that they cause pain.

At the beginning of the 1600s there were still some scientists who clearly expressed the idea that sound involves a transfer of matter from one place to another. Pierre Gassendi (1592-1655) imagined that sound transmission meant that a flow of atoms was emitted from a sound source and, further, that the speed of sound is the speed of the atoms, and that the frequency is the same as the number of atoms emitted per time unit. A similar idea is expressed by Isaac Beeckman (1588-1637), who thought that each vibrating object splits up the surrounding air into small, round, air-filled bodies, which are sent off in all directions and which are perceived as sound when they reach the ear. The idea that sound is the same as a net transmission of matter has thus existed for a long time, so that it is hardly surprise that we often find similar ideas among today’s youngsters.

An evidence that sound transmission has to do with matter, without necessarily being the same as a net transfer of matter, was put forward by Boyle and Hooke (1600s). They succeeded in constructing a functioning vacuum pump in which they hung a ticking watch and then pumped out all the air. The sound of the watch ticking then stopped even though the hands moved. When the air was let in again, the ticking sound returned. At the beginning of the 1700’s, scientists were in complete agreement that sound could only be transmitted through a medium.

In the middle of the 1800’s, a German school teacher, Philip Reis, succeeded in converting sound vibrations to electrical current. This was the first embryo of the telephone of our day. Alexander Graham Bell, teacher for the deaf during the latter part of the 1800’s, used his good knowledge of sound, speech and hearing to get his pupils to experience sound. He used different membranes and other cunning devices to get them to “feel” sound. This inspired him to work further, and by 1876 he had developed the first telephone. In 1877, Thomas Alva Edison succeeded in constructing a simple gramophone. He fixed a small needle to a membrane, placed this over a newly waxed sheet of paper and then shouted ”Hello!” against the membrane while pulling the paper under the needle. Grooves were etched in the soft wax when the membrane vibrated. Then he drew the paper through the apparatus once more when the wax had congealed, and the little needle followed the grooves in the wax. The membrane vibrated and the audience round about perceived a sound that, with a little bit of good will, could be interpreted as "Hello". Edison called his little apparatus a phonograph.

3.3 The speed of sound

The speed of sound puzzled mankind for a long time. About 400 B.C. the Greek philosopher Plato formulated the hypothesis that the speed of sound is dependent on the sound volume, i.e. the louder the sound, the higher the speed. Aristotle (ca. 350 B.C.) expressed a similar idea, i.e. that the speed of sound from one and the same note would vary according to its volume. It would take more than a thousand years to solve this problem, and today we know that the speed of sound in air is independent of the volume. Viewed from this historical perspective, it is not strange that present-day pupils sometimes think like Plato.

Another aspect of the speed of sound is its relation to pitch, i.e. the frequency. The earliest known theory was also formulated by a Greek philosopher by the name of Archytas (ca. 370 B.C.). He thought that high tones are transmitted more rapidly than low tones. This theory was quite soon criticised by a disciple of Aristotle, Theophrastus (ca. 370-285 B.C.), who claimed the opposite – that different tones may be perceived at the same time, i.e. that all tones must consequently have the same speed. That theory still holds today.

Aristotle observed thunder and rolls of thunder and explained, quite contrary to what we know today, that the latter give rise to lightening. It was not until 400 years later that Pliny the Elder (ca. 50 AD) understood that lightening and rolls of thunder do occur simultaneously, but that the light moves more rapidly and reaches an observer before the sound.

During the Renaissance, methods were developed to investigate the surrounding world with the help of systematically planned and controlled experiments. Similar observations were already being made in ancient times, but they were not carried out in the systematic way that evolved during the Renaissance. Leonardo da Vinci (1452-1519) did experiments with resonance effects and found that a ringing bell emitted a sound that made another bell in the vicinity hum softly and, further, that the string of a lute made a string on another lute sound with the same tone. He also did experiments with echoes and discovered the phenomenon underlying modern sonar technology (echo sounder). Leonardo da Vinci was of the opinion that all sound has an absolute transmission speed.

The speed of sound continued to puzzle many scientists. What was the transmission velocity of sound then? Pierre Gassendi (1592-1655) questioned Aristotele's theory that the speed of sound is dependent on the volume and designed experiments to test this theory. Weapons that could give off different volumes of sound were chosen, a large cannon and a small musket. The experiment was carried on a calm day. One person fired the weapons, one observed the muzzle flame in connection with the firing, and another listened for the sound about five kilometres away. The time it took for the sound to reach a listener was measured both with the help of heart beats and with the oscillations of a pendulum. Irrespective of the choice of firearm, it was found that the transmission of sound took the same length of time. The conclusion was that different sounds move at the same speed in air. The velocity of sound was calculated to be 478 m/s.

Marin Mersenne (1588-1648) measured the time it took before an echo from a sound source could be perceived. Since the distance was known, it was possible to calculate the speed of the sound in air, and a value of 448 m/s was obtained. Mersenne concluded from this that it should be possible to hear a trumpet blast anywhere on earth within 10 hours! He was not aware that sound spreads in every direction and that sound transmission also includes a transformation of kinetic energy to thermal energy. The sound “is snuffed”. Mersenne is sometimes called the “the father of acoustics”, perhaps because he was the first to determine the frequency of an audible sound. Somewhat later (1650), Borelli and Viviani measured a value of 350 m/s for sound speed, which came even closer to the value that we calculate with today.

During the 1600s people also started to use theoretical, mathematical models to formulate hypotheses and theories about different phenomena. A familiar example is Newton (1642-1727), who presented a calculation of the speed of sound in his famous work *Principia*, which stimulated other researchers to devise experiments to test Newton’s theory. Cassini and a group of French scientists (1738) carried out a careful experiment with the help of two cannons. They placed the cannons just over 30 km apart from each other and fired them alternately – a cunning arrangement, because they wanted to eliminate the effect of the wind on the experiment by calculating first the time it took for the sound to move in each direction and then the mean value. Furthermore, they noted at what temperature the experiment was carried out, although at that time they had no idea that the temperature does in fact affect the speed of sound. Thanks to the careful notes that were made during the experiment, it has since been possible to calculate the speed of sound they actually measured. As 0 % this means 332 m/s, which is in accordance with what we know today.

The question whether or not the speed of sound is affected by the air temperature was solved a few years later. The Italian Bianconi measured the speed of sound in Bologna in the summer and winter of 1740, and found that the speed of sound increases with the temperature. The results were confirmed in the years to follow by the Frenchman Condamine, who compared the measurements from a cold Quito, the capital of Ecuador, with measurements of the speed of sound in a much warmer Cayenne, in French Guyana.

As knowledge of the speed of sound started to spread during the 1700s, it was possible to begin using it in other calculations. This enabled Derham to calculate how far away thunder was by measuring the time between the lightening and the peal.

The first measurements in other media than air were reported in the beginning of the 1800s. It was found that the speed of sound in metals was much higher than its speed in air. The first serious experiment to measure the speed of sound in water was probably made in the waters of Lake Geneva by a Swiss.

It is evident from the above resumé that the speed of sound was a hard nut to crack!

3.4 The ear and hearing throughout history

Documents from ancient times also show that people also wondered about the mechanism underlying hearing. Around 500 BC Anaxagoras realised that hearing depends on sound penetrating into the brain. He believed that an animal's hearing depends on its size. His theory was that large animals with large ears should be able to hear distant, loud noises, while small animals with small ears are only able to perceive nearby sounds of short duration. Plato (427–347 BC) maintained the following[2]:

> ”We may in general assume sound to be a blow which passes through the ears, and is transmitted by means of the air, the brains and the blood, to the soul; and that hearing is the vibration of this blow, which begins in the head and ends in the region of the liver.”

Theophrastus (372-288 BC), who was mentioned in connection with the speed of sound, connected sound transmission with what happens inside the ear. His thesis was that, since the organ of hearing has contact with the surrounding air, the air inside the ear should also move in the same way.

It was not until the 1500's, when corpses began to be used for anatomical studies that knowledge about the ear's function began to expand rapidly. Earlier, knowledge about the ear was confined to the outer, visible parts. The knowledge of the anatomy and function of the ear is derived from a number of Italian physicians. At the beginning of the 1500's, de Capri found two small ear bones (auditory ossicles) in the middle ear, one of which was attached to the eardrum (tympanum). These small bones were later named the hammer and the anvil. His discovery led him to formulate a theory about how the ear functions, to the effect that the movements of air in the outer ear canal (auditory canal or meatus) cause the eardrum to vibrate and that the movement is transmitted to the ear bones so that they knock against each other. The third little ear bone, the stirrup, was discovered in the same century by Ingrassia. Yet another Italian, Eustachius, discovered a fine little tube, shaped like a trumpet, which links the middle ear to the throat (pharynx), and described it so well that it was allowed to bear the name of the discoverer, the Eustachian tube.

At the end of the 1500s it was possible to start differentiating impaired hearing caused by faulty sound transmission in different parts of the ear. The Italian physician Caprivaccio was the first to diagnose impaired hearing and deafness. He examined in what part of the ear hearing was impaired by getting the patient to hold a small iron rod between his front teeth. A vibrating string from a musical instrument was attached to the rod. If the patient heard a sound when the string was plucked, it was concluded that the hearing impairment was located in eardrum. The sound vibrations were further transmitted via the iron rod through the skull bone to the ossicles without needing to pass the eardrum, and could therefore be perceived by the patient. If no tone was heard, it was concluded that the hearing impairment was located in the ossicles or further inside the ear.

At the end of the 1700s Cortugno reports in his dissertation that the inner ear contains a fluid and concludes that sound transmission in this part of the ear must take plaice via fluid.

A first measurement of the highest frequency that the human ear can detect was made at the beginning of the 1800s, when a value of 24 000 vibrations per second was recorded, a value close to that we reckon with today, i.e. 20 0000 vibrations per second. Somewhat later, Hermann von Helmholtz wrote that individual nerve fibres function as vibrating strings, each and every one with its own resonance frequency.

3.5 The last 100 years

During the 1900's, the knowledge and use of sound has developed rapidly. We have been confronted with new techniques, one after the other, in the form of the gramophone, radio, TV, tape-recorder, computer, CD-player and MP3-player. Advanced detailed biological and medical knowledge has also evolved.

It was not until the 1940's that Von Beksey was able to show how the ear can distinguish different sounds due to the fact that the basilar membrane in the cochlea of the inner ear vibrates. We now know infinitely more about the ear's function and the transmission of the nerve impulses to the acoustic centre in the brain, and surgeons can perform advanced operations in the hearing organ.

Various assistive devices have been constructed for people with impaired hearing, and specially designed hearing protection against noise and high sound volumes has been developed. The sound levels in many working environments have been markedly improved. However, in the wake of this technological development come certain drawbacks that need to be dealt with. More noise and rising sound levels are becoming an ever-increasing problem with the growth of air and car traffic. Droning motorboats roar past in sea inlets, rivers and lakes that were once so peaceful. How are we to manage the noise environment in the future? We naturally want to be able to enjoy both sound and silence - and stay healthy.

4. MATTER AND SOUND

4.1 A particle theory for teaching

When testing the teaching-learning sequence about Sound, Hearing and Health, the teachers concerned pointed out the value of using a particle theory for matter to explain the transmission of sound. When the concept of particle theory is mentioned in this material, it refers to a particle theory for teaching.*

The particle theory

All matter is built up of smaller parts. During the testing of this material, we chose to think of all matter as consisting of ”particles”, without distinguishing between atoms, molecules, ions or even lesser parts. In some science teaching materials the term molecule is preferred to particle but it used in a similar way. In the present material, this could be problematic because the pupils might meet substances that are not built up of molecules, for example iron. Therefore we have chosen the concept of “particles”. It is up to the individual teacher to conclude which concept/concepts are the best bearing in mind the pupils’ age and preconceptions. Irrespective of the concept chosen, it should be used consistently.

In this material we thus imagine that air consists of “air particles”. Air consists of approximately 78 % molecules of nitrogen and 21 % molecules of oxygen, but there are also other sorts of molecules and atoms. Therefore, there is no uniform “air particle” in existence. This means that the concept of “air particle” includes all elements in the air. If the pupils are going to be able to separate the concepts of gaseous, air and oxygen, the meaning of the concept “air particle” needs to be discussed. Furthermore, we say that water consists of “water particles”, iron of “iron particles”, wood of “wood particles”, and so on. Thus all matter consists of small, invisible particles. If there aren’t any particles, there is a vacuum, i.e. nothing at all. The particle theory may be illustrated with the help of different models such as plastic balls, drawings, ping-pong balls, etc. Models always have their limitations but are nevertheless useful for visualising matter. It is essential to discuss the model concept continuously in science teaching and let the pupils reflect on the advantages and disadvantages of different models.

* However, physicists use the particle concept in most cases with reference to subatomic particles, i.e. particles that are smaller than atoms, known as elementary particles.

In our everyday language, we use the term particle in another meaning, e.g. soot particles. It is true that this is also a question of small units, but these particles are very large compared with those in the particle model. According to the particle theory, one soot particle (macroscopic) consists of millions of tiny “carbon particles” (sub-microscopic). In this case, the “carbon particles” correspond to carbon atoms.

Many children/pupils do not think that air is “anything”. You can’t see air, can you? All the same, air is something. Air is matter that consists of air particles, and one litre (1 dm^3) has a mass of one gram. Thus, the air in a box with all sides measuring 1 metre has a mass of about 1 kilogram. It is possible to demonstrate that air is something by quite simple means. If you hold a large sheet of hardboard or plywood in front of you and try to run with it, you notice that there is something in the way. It is the air that stops your progress. Another way is to stick your hand out through a side window when you are out in a car. Then you can also feel that the air is in the way (that it resists), or when you are out cycling with your jacket undone on a day without any wind.

The air around us is in the form of a gas, and this is one of the states of matter. A substance can be in a gaseous state, in a solid state or a liquid state. Imagine an ice cube that you take out of the freezer. At first, it has the same temperature as the freezer, e.g. -18 °C. If the ice cube is allowed to lie in a room, its temperature will gradually rise to 0 °C. Then the ice will begin to melt and turn into ordinary water. If we pour the water into a saucepan and place the saucepan on a hot plate, the water will gradually start to boil (at 100 °C). The water will evaporate into water vapour. The three states of matter differ from each other by the distance between their particles.[1]

Let us summarise the particle theory for solid, liquid and gaseous states with the help of models of very, very small round balls (Table 4.1). The particles are atoms, ions or molecules.

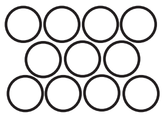
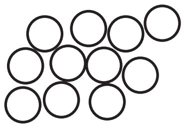
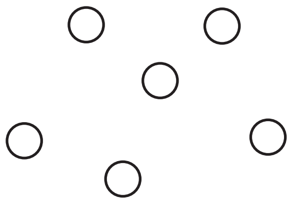
SOLID 	The particles … • sit closely together and in fixed places • move around *in their place*; the higher the temperature, the faster they move. • are drawn to each other by rather strong forces.
LIQUID 	The particles … • are quite close together but move *around each other*. • move faster when the temperature rises. • are drawn to each other, but not as strongly as in a solid state.
GASEOUS 	The particles … • are rather *far apart*. • move at high speed till they collide with other particles of the same substance or adjacent substance. Then they change their direction and speed. The higher the temperature, the higher the speed. • move in all possible directions.
ALL THREE STATES	The particles … • have a given size and shape, which do not change. • *are* matter; there is no matter between them, only a vacuum. • are very, very small (one millionth of a millimetre in diameter).

Table 4.1. A particle theory for solid, liquid and gaseous states (Andersson, 2005).

A vacuum means that particles are completely lacking; in other words, it is entirely empty.

4.2 Understanding sound with the help of the particle model

Sound arises when something vibrates, e.g. a guitar string or our vocal chords. When an object vibrates, it hits the surrounding particles, which in their turn hit particles close by, and so on. Accordingly it is the motion in the vibrating object that is transferred to the surrounding particles, which in their turn transfer the motion to adjacent particles, and so on. In scientific language, we say that kinetic energy is transmitted. So sound transmission only has to do with the transfer of energy via the particles that build up the substance through which the sound is transmitted. The concept ”medium” is often used for that substance, and this simply means that it contains matter, i.e. particles of some kind.

The closer the particles are to each other, the faster the vibration, the motion (the kinetic energy) is transmitted. Somewhat more simply, this means that, at the same temperature, sound is transmitted fastest in solid substances, more slowly in liquid substances, even more slowly in gases, and not at all in a vacuum. However, in one and the same medium, e.g. air (=gas), at different temperatures, the air particles have a higher kinetic energy in warm than in cold air. Thus the air particles in the warm air already move faster at the start, and when further kinetic energy is added in connection with a sound vibration, then it follows that this vibration will be transmitted more rapidly in warm air. Thus the sound speed is somewhat higher in warm air than in cold air. The speed of sound is therefore somewhat higher in warm air than in cold. Analogously, the speed of sound is higher in warm water than in cold, and it is higher in a heated piece of iron than in a cold one. An example of a common everyday conception that hinders us from fully understanding sound transmission is that sound is transmitted by specific “sound units” or “sound particle”, which have their own mass or take the form of small air packets, a little wind that moves. We recognise this idea from Aristotle, among others in our history of sound. This would mean that if there is no matter at all, i.e. no other particles at all, then the “sound units” or “the wind” would be transmitted without hindrance. Consequently, it would be logical to assume that sound would be transmitted fastest in a vacuum, more slowly in gases, even more slowly in liquid substances, and most slowly in solid substances. In reality, the exact opposite occurs, since sound cannot exist without material particles.

The speed of sound in air (20 ºC) is about 340 metres per second (the speed of light is 300 000 000 m/s). In water sound moves at a speed of 1 500 m/s, in wood 4 000 m/s and in iron 5 100 m/s.

4.3 How sound occurs and how it is transmitted

We now know that sound is transmitted by particles transferring a motion from a vibrating object. It is commonly stated that when sound moves forward, it is achieved by vibrations, i.e. condensations and rarefactions moving away from the sound source at a constant speed. This means that a vibration knocks a large number of particles at the same time (=kinetic energy is transmitted), giving rise to condensation and rarefaction of particles. It is these condensations and rarefactions that move away from the sound source, and not the particles in themselves. The concept of sound wave means just this, but the word is very confusing for both pupils, students and university students in physics. Some pupils have met the concept previously and attach various meanings to it, but extremely few have any idea of what a sound wave really means. If we are to promote a deeper understanding of sound transmission among the pupils, they need to be given the opportunity to discuss and work out the connection between vibration, particles and sound waves. Otherwise, there is a risk that the sound wave will be understood, for example, as something material that moves in the air and collides with the air’s particles, with the result that it will be quite impossible for the pupils to build up any conceptual understanding of the transmission of sound.

4.4 Sound can be transmitted, absorbed and reflected

When sound hits a surface, the movement can continue (be transmitted) in the new substance, absorbed or reflected. The properties of the material determine what happens to the sound. Knowledge about the sound properties (acoustics) is used when constructing houses, cars, trains, etc.

Reflection and echo

Earlier we have mentioned the fact that sound vibrations can be transmitted in matter and between different types of matter. Sound vibrations may, however, also be reflected and absorbed. A hard surface, such as a steep rock face or a concrete wall, reflects sound vibrations and can, in this way, give rise to an echo. This occurs only if the sound source, e.g. a person who shouts “Hi”, is standing at a distance of at least 17-18 metres from the hard wall. In this case, there is a time lag of 0.1 s before the sound returns to its source. At that moment the person can hear both his own shout and the reflected sound. If he stands closer to the wall, the reflected sound will return so rapidly that his brain will not be able to distinguish the short time lag between the sounds. No echo is heard. Thus an echo is one and the same sound that is perceived two or more times. A sound can, for example, be perceived many times in a large cave when it is reflected back and forth between the roof and walls. The same phenomenon occurs in a small room where the walls have a hard surface, i.e. in a bathroom. There a sound might be reflected so many times that the above-mentioned time lag will occur and an echo will be heard.

Nearly all the sound is reflected in connection with the echo, but a small part is transmitted further through the wall, though to a negligible extent. Rooms that are built of hard materials are noisy and full of echo effects. Since the sound remains for a while when the vibrations are transmitted back and forth, the vibrations will affect each other so that the sound can seem blurred, making it difficult to hear what people are saying.

Echoes are used to measure distance. Boats use an instrument called an echo sounder to measure the depth of water or to search for large shoals of fish. The echo sounder sends out a sound called ultrasound (see section 4.5) through the water, which is reflected by the sea bottom or the fish shoal and then registered by the instrument on the surface. The time lag between the transmitted and registered sound is used to calculate the distance with the help of the speed of sound in water.

Sound is absorbed

No echo occurs in a furnished room because the sound is reflected and spread in different directions and absorbed by the furnishings. Soft surfaces such as in furniture, curtains, carpets and suchlike can thus be used to dampen sound or reduce noise. A soft surface may, however, absorb far too much sound in a room when it covers large areas, and it is important to strike a balance between different types of surfaces according to what the room is to be used for.

Resonance

Resonance simply means “re-sounding”. This implies that something that is vibrating can set something else in motion, make it vibrate. One example that pupils may come across in lessons is when a humming tuning fork or a musical box is placed on a table, making the table vibrate so that the sound becomes louder. Other examples are stringed instruments such as acoustic guitars or violins. A vibrating string can not in itself set a sufficiently large volume of air in motion to produce the required sound. On the other hand, the vibrations from a string on an instrument can, in their turn, cause the air inside the instrument and the case to vibrate, which helps to magnify the sound.

4.5 The properties of sound

A sound has three different properties – pitch, sound volume and quality (timbre). It is easy to confuse these concepts. In everyday language, when we refer to the intensity of the sound, we use the adjective “loud”. When explaining this phenomenon more scientifically, we use the term “high sound level/volume”. When we talk about a “high sound”, however, we are referring to its pitch (frequency). It is therefore important that teachers make a clear distinction between these concepts.

Pitch (frequency) is determined by the number of vibrations emitted from a sound source every second that swings back and forth (oscillates). Frequency is measured in units hertz (Hz). A sound of high frequency (descant tones, ”squeaky” sounds) is caused by many vibrations per second, i.e. how rapidly the sound source moves backwards and forwards, while a sound of lower frequency (bass tones, muffled or hollow sounds) is caused by fewer vibrations per second. In the standard pitch used for tuning (musical note A), the sound source vibrates 440 times back and forth in one second. The frequency is said to be 440 Hz. A pure C-tone has a frequency of 262 Hz, and is consequently lower than the A-tone. To sum up: a low pitch has a low frequency and a high pitch has a high frequency.

Humans perceive sounds with frequencies ranging between 20 and 20 000 Hz. The frequencies that are higher than 20 000 Hz are called ultrasound, and those lower than 20 Hz are called infrasound. It may be of interest to note here that the tones that are used in music lie between about 30 Hz and 4 000 Hz, which roughly corresponds to the range of the piano.

The speed of sound in air is the same for all frequencies at one and the same temperature. On the other hand, there are certain differences in liquid and solid substances depending on the frequency of the sound. This accounts for the singing sound that sometimes occurs in ice when you go skating.

The sound volume (sound level) is affected by the vibrations created by a sound source. The distance that, e.g. a guitar string is moved from the "middle position" is called the amplitude of the vibration. The greater the amplitude of vibration, the higher the sound level (the louder the sound). The sound volume is measured in a unit that is called a decibel (dB). Sound can be measured with different filters (A, B and C filters) depending on what and how one wants to measure. A normal filter for measuring sound in human environments is the A filter, which allows the sound level meter (decibel meter) to measure the sound, especially weak sounds, in a way similar to how the human ear detects different sound levels. The sound level is therefore said to be measured in decibel A, dB (A). In some sport halls, school dining rooms and gyms, there is an instrument called a Sound Ear that monitors the sound level. It can be set so that small green lamps light up when the sound level is suitable, orange ones indicate that risk levels are close, and red ones indicate when the level is much too high. Figure 4.1 shows some examples of sound levels.[2]

Type of sound	dB(A)
Cannon fire	180
Jet aircraft	140
Rock concert	120
Disco	110
City traffic	88
School dining-room	80
Normal conversation	60
Whispering	20
Rustle of leaves	10

Figure 4.1. Examples of sound volumes (levels). The scale is logarithmic, which means that an increase of approx. 3 dB(A) is equivalent to double the sound volume. An increase of 10 dB(A) means a 10-fold increase in the sound volume.

To sum up: a *loud* sound has a *high* sound volume or level and a *soft* sound has a *low* sound volume or level. Strong and weak sounds also refer to sound volume.
The speed of sound in air is independent of the sound volume. A loud sound (e.g. cannon-fire) is transmitted at the same speed as a soft sound (e.g. the rustle of leaves). All sound from a rock concert, irrespective of whether the music is loud or soft, is consequently transmitted at the same speed.

Tone quality is the difference in sound between two musical instruments. One and the same musical instrument gives at one time sounds of different frequencies. The sound with the lowest frequency is called the fundamental tone (lowest pitch). The other sounds of higher frequencies (higher pitches) have double, threefold, fourfold etc. the frequency of the fundamental tone and are called overtones. The tone quality is defined by the number of overtones and their mutual intensity.

5. HEARING

The sense of hearing is of great significance even when the foetus is only a few months old. The foetus hears its mother's voice via the amniotic fluid. Of course, her voice sounds somewhat different, but nevertheless. When the baby is born it still has some fluid in its outer ear canal and hears everything as though it were under water. The growing foetus learns to recognise sounds from its surroundings more and more. These can be the voices of its mother, father, brothers and sisters or music that is often played at home. It is said that children who listen to music when they are in the womb are more musical. The most important part of a human's life as far as stimulating speech is concerned is during the first three years. Sounds that we have not had the opportunity to hear as infants can be very difficult for us to make out as grown-ups. This may result in the child having difficulty in making out speech if a hearing impairment is discovered too late.[1]

The human being has five senses: hearing, sight, touch, taste and smell, with sensors (receptors) that can register what is happening in the surrounding world. Hearing is important from a number of different aspects[2]:

- *Hearing as a communication system*
  Hearing probably is the sense that is undoubtedly the most important for our relations with other people. Speech and hearing are important prerequisites for our being able to function as social beings.

- *Hearing as orientation and warning systems*
  With the help of our sense of hearing we can make out what is happening in our surroundings and this also functions as an effective warning system that is at work even when we are asleep. But why do we have two ears? As regards our ability to hear different sounds, it does not really matter if we have one or two ears. However, two ears are necessary to determine the direction of a sound, so that we can receive information and judge whether it comes from behind, from the side or from the front. This depends on a small time difference between a sound reaching both your ears, which can be registered and perceived. Compared with sight, hearing works as well at night as it does in the day.

- *Hearing for relaxation and enjoyment*
  Hearing is also an important source of relaxation and enjoyment, and we enjoy listening to sounds we like, such as music, birdsong and the lapping of waves.

- *Hearing and rest*
  After a day or evening spent in environments full of different sounds, our hearing needs to recover in quiet environments, which is also an important requisite for our rest and sleep.

5.1 The anatomy and physiology of the ear

The human ear, whose parts function with amazing precision, is a small miracle in itself. We can tell the difference between all the sounds in our speech together with about another half a million other sounds. Our sound sensitivity enables us to discover a sound so soft that our eardrum only moves a tenth of a molecule's diameter.[3] Furthermore, our ears can also stand sounds that are ten million million, i.e. 10^{13}, times stronger – but we should not do this for too long a time if we care about our hearing. The auditory system consists of an outer, peripheral part and an inner, central part. The outer auditory system consists, in turn, of three parts: 1) the outer ear and the outer ear canal 2) the middle ear with its three small ossicles and 3) the inner ear with the cochlea and the auditory nerve (Fig. 5.1).

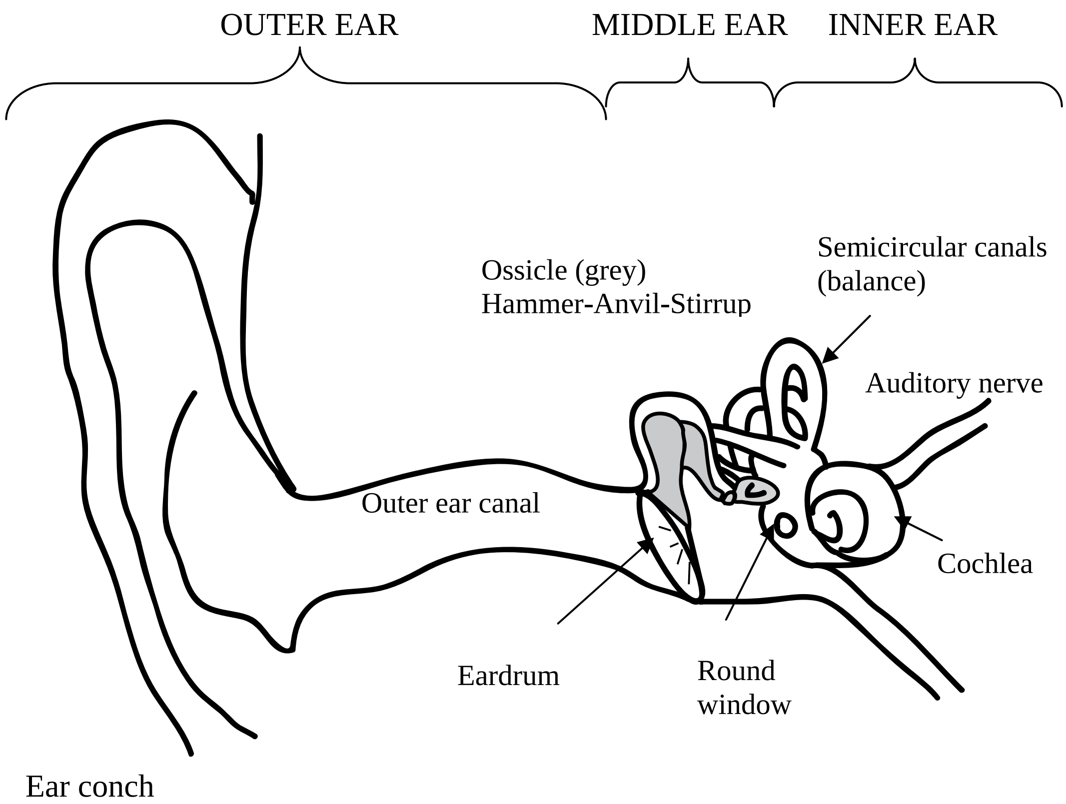


Figure 5.1. The outer auditory system. The human ear is usually divided into the outer ear, the middle ear and the inner ear.

The auditory nerve goes to the brainstem, where the inner auditory system takes over. In the brain, the auditory route runs from the brainstem via the central parts of the cerebrum to the auditory centre in the cortex in the temporal lobe of the cerebrum (Fig. 5.2).

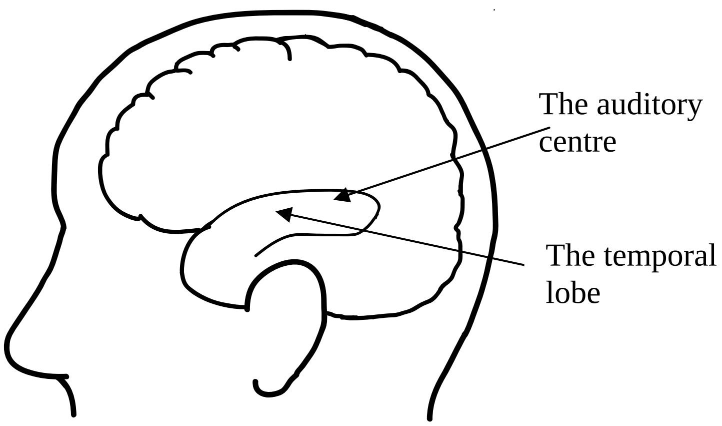


Figure 5.2. The auditory centre. The auditory centre is situated in the temporal lobe of the brain.

It is not until the impulses are registered here that the impulses are interpreted and we ”hear”. Round the auditory centre there is also an auditory memory centre that enables us to recognise sounds that we have heard previously. And this is maybe a good thing, because otherwise we would not understand if it is a dog barking or our best friend talking! Information is also exchanged with other centres in the brain, which enables us to associate the sound from a person we know well with a particular face, or with a perfume, or maybe with the expectation of getting a hug.

The parts of the middle and inner ear are very small, and together they would all fit into a little box the size of a sugar lump. Hence, diagrams often show the different parts of the ear in their wrong proportions.

The outer ear and the outer ear canal

The outer ear (Fig. 5.1) consists of the ear conch and the outer ear canal. The outer ear canal transmits sound vibrations to the eardrum, and thus it is important for hearing. This canal is approximately 3 cm long in an adult, and the skin there contains glands that produce ear wax so that it does not dry out. There are even small hairs that filter dust and the like. Many people have had “water in their ears”, and this is due to water being left in the outer ear canal after a shower or bath. The canal works like an amplifier of sound within the frequency range in which speech is produced, and this means that speech sounds are amplified by means of resonance two to four times.

The middle ear

The middle ear (Fig. 5.3) is a cavity filled with air situated in the hardest bone of the body. The eardrum consists of a thin, tightly stretched, cone-shaped membrane similar to a membrane in a loud-speaker, and this transmits vibrations from the air to the three ossicles in turn. In an adult, the eardrum is nearly one centimetre in diameter and just under a millimetre thick. The tension in the eardrum can be adjusted with the help of two small muscles, one attached to the first ossicle (the hammer) and the second attached to the third ossicle (the stirrup). In order for the eardrum to be able to vibrate properly the air on both sides of the eardrum, i.e. in the outer ear canal and in the middle ear, must have the same pressure. There is a small tube, approximately 4 cm long in adults, which connects the middle ear to the throat (pharynx), where air can go in and out depending on the pressure of the surrounding air. This is called the Eustachian tube (see History, section 3.2). The Eustachian tube is normally closed, which is a good thing because otherwise all the sounds coming from breathing and speaking would be transmitted directly to the middle ear. However, the Eustachian tube can be opened in order to adjust air pressure. This is done with the help of a small muscle that is used when we move our jaws in order to swallow or yawn. When our ears pop during an air flight this is a sign that the pressure balance in the middle ear is working. When you have got a cold, the mucous membrane of your Eustachian tube often gets irritated, making it more difficult for air to pass through. This results in there being varying degrees of pressure around the inside and outside of the eardrum. We usually say that “our ears are blocked”. The same often happens when we fly and then we can, as a rule, alleviate the problem by chewing. When diving we have to learn to equalise the pressure so as not to burst our eardrums.

A chain of three connected ossicles, the hammer, the anvil and the stirrup, transmit sound vibrations from the eardrum to the inner ear via the oval window (a small hole in the bone to the inner ear which is covered with a fine, thin membrane). The hammer is connected to the eardrum and is jointed to the anvil as well, which, in turn, is attached to the stirrup. When the eardrum and, consequently, the ossicles vibrate, the foot plate of the stirrup presses on the oval window, allowing the vibrations to be passed on to the fluid in the inner ear. The middle ear has an amplifying effect of 25-30 decibels (dB), because the area of the stirrup’s foot plate is much smaller than the area of the eardrum. Moreover, the three bones in the middle ear are attached to each other in a way that further augments the amplitude, the so-called leverage. To sum up, we can say that spoken sounds are amplified both in the outer ear canal and in the passage through the middle ear. It is owing to these amplitudes that we can hear sounds with the frequencies of the speech area, which would otherwise be 1000 times weaker than the sounds that we normally hear.

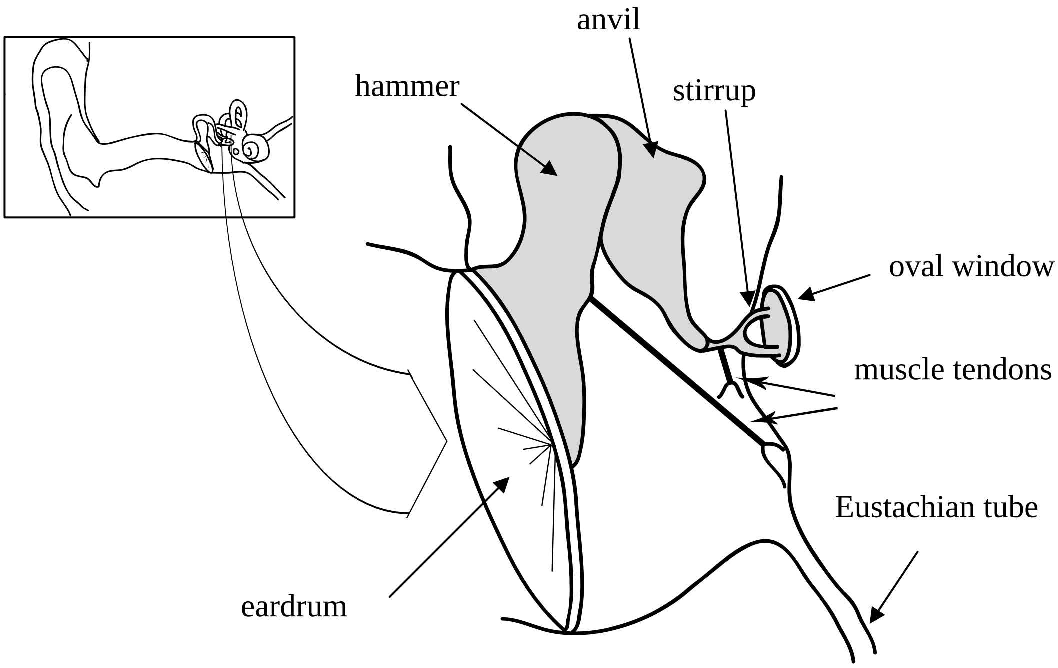


Figure 5.3. Magnification of the middle ear. The figure shows how the tendons of the ear muscles are attached to both the ossicles, the hammer and the stirrup.

Many children have recurrent infections in the middle ear. If they are serious and very frequent, a child's hearing can become impaired and this affects the child's language development in a negative way. A child that cannot make out the words that are spoken in his/her surroundings cannot learn to pronounce those words in the right way either, which, in turn, gives rise to other difficulties. One of the reasons why children get ear infections more often than adults is that their Eustachian tubes are short and almost horizontal compared with those of adults. Thus, throat infections can easily spread to the middle ear. Literally speaking, we can say that the cold runs out into the middle ear. Moreover, the walls of the Eustachian tube swell up more easily when children have infections and the cold remains confined to the middle ear. Recurrent or chronic ear inflammations are the most common cause of impaired hearing in children.

The inner ear

The inner ear (Fig. 5.4) lies protected in a cavity in the temporal bone and really consists of two parts, the balance organ and the cochlea where the sensory cells that register vibrations are situated. The entrance to the cochlea is the oval window (mentioned above). The cochlea is really only a 3,5 cm long canal at the end of which a round membrane, the round window, is situated. This canal is "folded in two" and shaped like a spiral. Inside the cochlea there is a fluid that is somewhat thicker than water, the composition of which is similar to sea water.

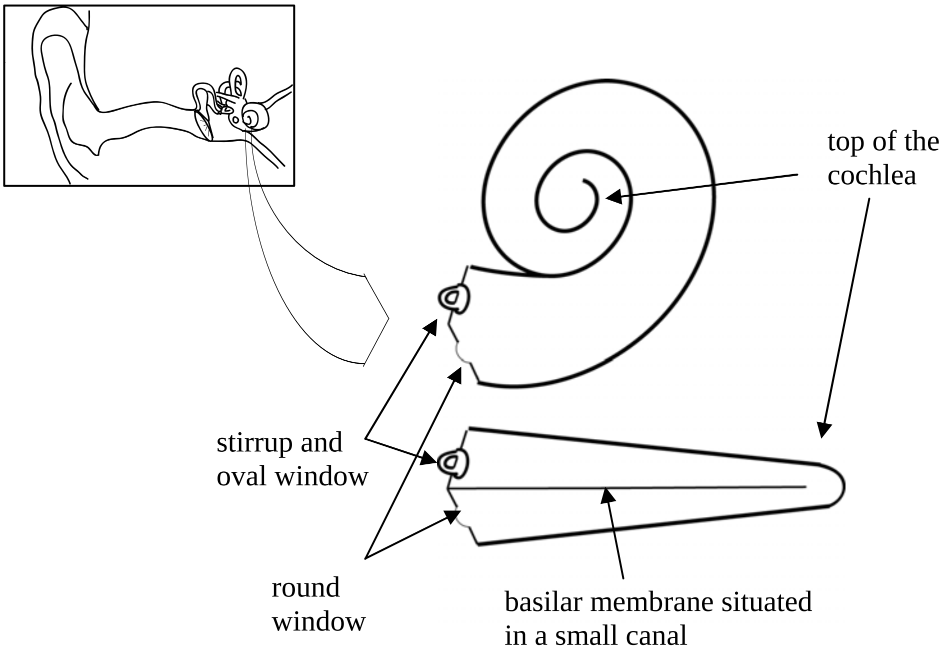


Figure 5.4. Model of the cochlea. The upper diagram shows the cochlea in the inner ear and the lower diagram what the cochlea would look like if it was opened out.

Between the upper and the lower parts of the canal there is one more very small canal. In the bottom there is a membrane, which is called the basilar membrane, where all the sensory cells that register vibrations are situated and they are usually called hair cells. This part of the inner ear is usually called the Cortis organ.

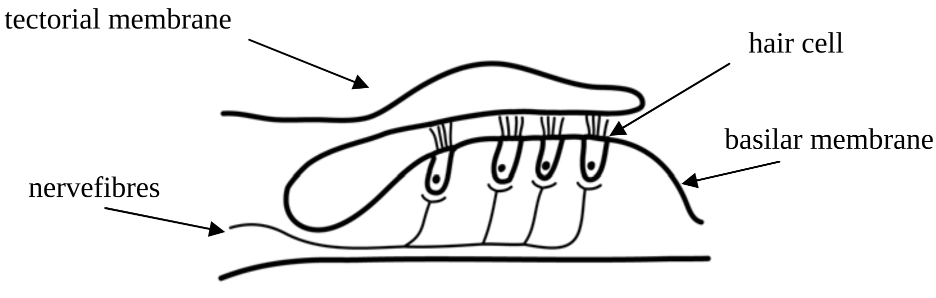


Figure 5.5. A cross-section of the basilar membrane inside the cochlea, the so called Cortis organ. A little gelatinous membrane, the tectorial membrane, is situated above the hair cells.

There are normally 15 000 – 20 000 hair cells arranged in rows. Certain hair cells can even take up impulses from the brain so that their ability to select and perceive sounds increases. We are born with a complete set of hair cells which are already fully-developed in the 24th week of pregnancy. Hair cells do not reproduce if they are destroyed, and we have to live without the ones we lose.

When the oval window vibrates (Fig. 5.6), the vibrations are conducted through the cochlea via the fluid. Depending on the frequency of the sound, a certain proportion of the membranes will start to vibrate. This will, in turn, stimulate the small hairs on the hair cells to emit electrical* impulses when they are bent against the tectorial membrane. These impulses are sent through the auditory nerve via the brainstem to the auditory centre of the brain, where they are interpreted as sounds. This is when we “hear”. So it is not until the vibrations, i.e. the kinetic energy that was transferred by air particles, ear drum, ossicles and fluid, reach the hair cells of the inner ear that they are transformed into electrical impulses, i.e. electrical** energy.

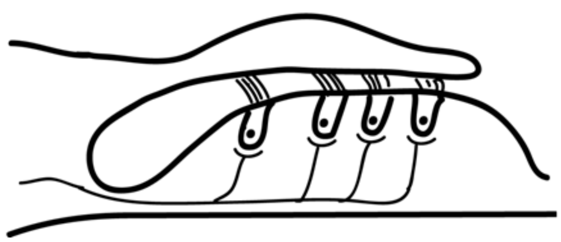


Figure 5.6. A cross-section of the Cortis organ inside the cochlea. The diagram shows how the small hairs of the hair cells are bent against the tectorial membrane when the membranes vibrate. Electrical impulses are then generated in the hair cells and the impulses are transmitted via the auditory nerve.

How can different tones be registered? Well, the membranes in the inner ear near the oval window move very easily and are very sensitive to high tones (= descant tones, high frequencies), while low tones (bass tones, low frequencies) are registered further inside the canal. High tones are therefore registered just inside the cochlea when the membranes in the basal convolution of the cochlea vibrate (Fig. 5.7). Sounds within the frequency range of speech can reach the middle convolution of the cochlea, and the lowest tones are not registered until they reach a point near the top of the cochlea. The basilar membrane therefore functions like a frequency analyser, which basically means that each tone has its particular place

* What is meant by electrical impulses in this connection is really the electromagnetic impulses, i.e. the ion streams that give rise to action potentials in the membranes of the nerve cells. Consequently, the electrical impulses in this connection cannot be equated with the current in an electric circuit.

** Electrochemical energy would really be a more correct term here.

in the cochlea. The brain will interpret the impulses as different tones depending on which sensory cells send these impulses to the auditory sense centre.

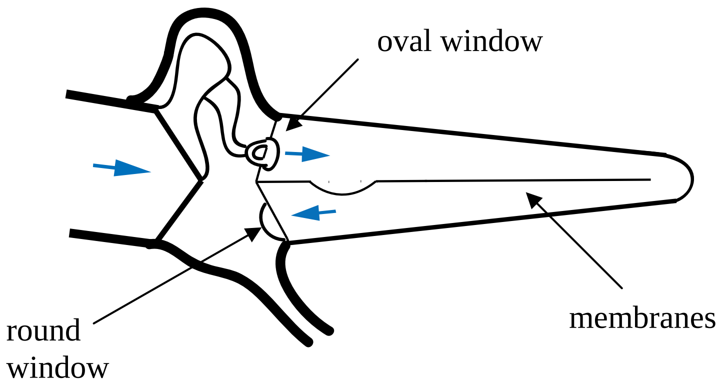


Figure 5.7. The mechanism of sound transmission. The sound is transmitted via the eardrum and the ossicles to the oval window in the cochlea and then through the cochlea. The figure shows how high tones affect the membranes (the basilar and the tectorial membrane) in the cochlea near the oval window.

A young person's ear can hear sounds within the frequency range of 20 – 20 000 Hz. However, an older person's ability to hear sounds slowly deteriorates, especially when it comes to sounds of higher frequency. This is why older people can seldom hear grasshoppers or the bird's highest notes. Our ears are best able to hear sounds i.e. are most sensitive to frequencies between 500 and 8 000 Hz. Speech, which is usually about 500 – 4 000 Hz, also lies within this range of frequency.

The auditory nerve from each of our ears consists of more than 30 000 nerve fibres from the Cortis organ. The auditory nerves from our two ears can exchange information with each other at three different ”stations” on their way from the inner ear to the cerebral cortex. The auditory nerve is, in normal cases, only perceived as an inward-going nerve i.e. that impulses go from the ear to the brain. This is almost true, since 98 % of the information that goes through the auditory nerve goes to the brain However, a number of nerve fibres send impulses from the brain to the ear. A considerable amount of this information is sent to the hair cells in the cochlea (as mentioned above) resulting, among other things, in a decrease in their sensitivity. This regulation results in unimportant sounds not being registered as effectively, which helps us to exclude unimportant background sounds and pay more attention to sounds that are more significant. Impulses in other nerves go to those muscles in the middle ear that help to protect our ears against loud sounds, but impulses can even affect the three ossicles so that they become sensitive to soft sounds.

Impaired hearing

There is a centre for auditory memory around the auditory centre in the cerebral cortex. This centre stores our hearing experiences and connects them with a context. Anyone who has previously heard a guitar, seen a guitar and learnt that it is called a guitar can recognise the sound of a guitar and know that it is a guitar. During the course of our lives we learn ”new” sounds in this way. So even if all the parts in our ears work perfectly, we cannot hear without our brains. Some people (and animals) have impaired hearing for other reasons, such as vibrations not being caught up by the ear, vibrations not passing through the outer ear canal (e.g. because of ear wax, or the eardrum e.g. because of inflammation of the ear) or via the ossicles or the fluid in the inner ear, or vibrations not being registered by the small hairs, or because the auditory nerve is damaged.

5.2 Hearing health

Health instruction has changed during the last few years with the introduction of a health-promoting or so-called salutogenic approach. This means moving our focus from looking for the causes of difficulties, problems and illnesses to increasing our knowledge of what promotes self-confidence, resistance and health. Of course, we can maintain good hearing quite simply by avoiding high sound levels. Children and adolescents who know a lot about sound, hearing and health have the basic requisites to choose a suitable sound level in their MP3s, in their stereos or at school discos themselves. If you cannot do anything about changing a high sound level at a concert or at a gym then there are various kinds of hearing protection on the market. The most basic hearing protection protects against high sound levels in general. If you want to have good sound quality when you listen to or play music, then there is hearing protection specially designed for music (ER-hearing protection), which tones down the music but maintains sound quality. You should preferably avoid using objects that make loud impulse sounds, such as fireworks and cap pistols, but if you choose or have to use them anyway, then you should, of course, use hearing protection. Lawn-mowers, hammers and sanders are other everyday examples of objects that produce loud sounds. You should also be aware of the fact that there are toys that emit such loud sounds that they are a danger to small children.

The working environment in school is another important factor that is possible to influence in different ways. Naturally, the design of the rooms is important. Examples of fittings that tone down sound and contribute to a better sound environment are sound absorbents in the ceiling and in the walls, curtains, carpets, plants and felt pads on tables and chairs. All of the people who work in these rooms, staff and pupils alike, also need to be aware of the fact that everybody should contribute to a good sound environment, for their own sake and for the sake of others.

If we all make a concerted effort to create a good sound environment and try to take our responsibility by reacting to people who, in their ignorance, play music too loud we can reach good results. We can use our influence at school discos and at the gym, or by talking to sound technicians at concerts. Parents are also an important group in this work, particularly when they are responsible for class discos or school discos. They must take their adult responsibility and make sure that the sound level is kept within reasonable limits, which is of particular importance if the children at the disco are under the age of 12.

People that expose themselves to high sound levels, whether this is at work or in their leisure time, need to rest their ears in order to recover. Among other things, the muscles in the ear need to rest. Therefore, the levels that people should expose themselves to during the course of a day are usually specified. If you have been in an environment with high sound levels during a working-day, you should avoid going to a loud concert the same evening. Pregnant women should be careful regarding high sound levels since the hearing of the foetus is fully developed by the 24^{th} week of pregnancy.

In chapter 1 you also will find what research has indicated about young people, sound environments and hearing problems.

Tinnitus

> ”The name tinnitus comes from the Latin *tinnere* which means to ring./…/Having tinnitus means that you hear sounds (that are not real sounds) in your ears or in your head. We do not know exactly where the sound comes from, but there are guesses that it is the auditory cells that, as a result of being damaged, emit false impulses to the brain that we interpret as sounds.”[4]

Tinnitus can have a variety of symptoms and be caused in different ways. It can sound like a weak buzzing, humming, whistling, or hooting sound, or combinations of sounds. Some people have tinnitus in only one ear, in both ears or somewhere in the middle of their heads. Both temporary and permanent tinnitus can be caused by a single overloud sound on one single occasion at a rock concert, by a banger, during a disco or by loud sounds spread over a longer period of time from e.g. a walkman, an MP3 or a noisy working environment. There can also be other possible causes, such as depressions or other medical conditions, medicines, illnesses, stress, old age and even an unhappy love affair. However there is no cure for permanent tinnitus caused by loud sounds, but there are several kinds of treatment that can bring relief. One of these is cognitive therapy where the patient can learn to become aware of his/her thoughts. This insight is then used to change negative thinking patterns. The patient is trained in focusing on other things besides the disturbing sounds in his/her head. Extravagant fear of tinnitus can also cause tinnitus or make it worse. The stress caused by worrying whether a high sound level will give you tinnitus can in itself give rise to tinnitus. Therefore, fear propaganda is not to be recommended. Information about tinnitus must be based on facts alone. Research shows that it is important for young people to know that they risk getting not only temporary but also permanent tinnitus from listening to loud sounds. Just as important is the insight that I myself might be affected. Young people often believe that the vulnerability applies to others not themselves. Having and living with tinnitus can be irritating for some people, particularly when it is quiet round about, whilst for other people it is considered a very severe handicap.

Being oversensitive to sound (Hyperacusis)

Even being oversensitive to sound is common in connection with tinnitus, which means that ordinary everyday sounds sound insufferably loud e.g. the screeching of chairs, the clinking of crockery, the buzzing of an overhead apparatus, children screaming etc. One consequence of being oversensitive to sound is that it can be difficult to localise where a sound comes from, which can be problematic in traffic. Being oversensitive to sound can be temporary, but can also be a permanent condition.

6. ANIMALS, SOUND AND HEARING[1]

6.1 How important are sound and hearing to animals?

Sound and hearing are important to all animals, especially to many aquatic species. In the depths of the oceans, where perpetual darkness reigns, hearing is more important than sight to the animals living down there. There are species of blind batrachians, reptiles, fish and mammals, but so far no vertebrate has been discovered that has no sense of hearing. Animals are dependent on hearing to be able to communicate, defend their territories, frighten their foes, keep the group together, navigate or look for food.

The sound environment in water is different because sound transmission is much more rapid, about five times faster than in air, and the sound reaches much further. There are many other sounds in the ocean besides those made by animals, not only natural ones such as the patter of raindrops on the surface, breaking waves, underwater volcanoes, but also sound pollution from human activities such as navigation, echolod soundings or boring for oil. The water world is also full of echo-effects.

6.2 The appearance and function of the ear in mammals

In many mammals the outer ear, the ear conch, functions as a sound receiver. This is particularly obvious in mammals with well-developed ears such as horses, elk, roe deer, hares, rabbits and wolves. The fact that they can also move their outer ears makes it easier for animals to determine where the noise comes from. There are some species of bat, in particular, which have very special skin folds that contribute to highly efficient sound reception.

The outer ears also have other biological and social functions. Dogs and cats show their moods with the help of their ears and also use their ears to indicate their social position when faced with other members of their species. The over-dimensioned ear flaps of the elephant have both a social function, when unfolded and extended in a threatening way, and an important biological function as temperature regulators, since their large area can give off surplus heat when it is too hot.

Whales, dolphins and porpoises, which spend all their lives in water, perceive sound in other ways than mammals that live on land. The same principle applies, i.e. that sound vibrations are transmitted to the sensory cells in the inner ear, but their route differs. These mammals have no outer ear but do possess an outer ear canal, which is believed not to function as it is filled with wax, and which has no contact with the eardrum either. How do the sound vibrations reach the middle ear then? Well, the bone in their lower jaw is in contact with the middle ear, and that is the way vibrations from the water can be led to the middle ear and the inner ear.

6.3 What do animals hear?

Most mammals (including Man) perceive sounds with frequencies in the range of 20 – 20 000 Hz. Elephants can perceive sounds down to 16 Hz, while bats can perceive frequencies as high as 200 000 Hz. Certain species of whale and dolphin produce and perceive sound within a very wide frequency range, from below 10 Hz to over 200 00 Hz. Dogs can hear sounds with frequencies up to 40 000 Hz. Many rodents also communicate with ultrasound, often with frequencies of around 45 000 Hz. Sometimes, when speaking of how well animals hear, the concepts pitch (frequency) and sound level (volume) are confused.

Bats make use of ultrasound (above 20 000 Hz) to navigate by emitting sounds that are reflected by objects in their surroundings and, with the help of the reflected sound, the echo sound, can rapidly assess in what direction to fly. They can hunt up very small prey, e.g. flying insects, with the help of the high frequencies. Whales give off clicks and other transitory sounds, and they can discover prey and navigate in the ocean deeps with the returning echo. Dolphins can use sound in a similar way to discover and identify an object the size of a golf ball at a distance of 100 metres. Thus, the hearing sense of these animals functions almost like the echolod on a boat.

Elephants and whales communicate with each over very long distances with the help of infrasound (below 20 Hz). Whales use it primarily to look for a partner but also to keep the group together. They use lower frequencies when they are close to each other to maintain the social interplay between mother and offspring, to show aggression, or simply to identify each other. In recent years, researchers have discovered that the whales' communication is disturbed by all the noise caused by human activities on and in the water, particularly from all the ships crossing the oceans. The problem is most acute in the northern hemisphere, for the simple reason that more activities take place there. Just imagine if the whales couldn't find each other or hear what the other one is "saying"?

Whales and dolphins are particularly known for their use of sound, but many fish and invertebrates such as prawns and lobsters also use sound to survive. Fish can perceive sound vibrations via what are known as the sidelines visible along their sides. They also have an organ that functions in about the same way as the inner ear of the mammal, and they can use it to sense vibrations in the water. The outer ear, the outer ear canal and the middle ear are missing altogether. It is known that certain kinds of herring can sense sounds of up to 180 000 Hz, and that the catfish can sense sounds higher than 3 000 Hz.

In the spring the frogs croak their mating songs. The common frog sounds almost like a small, sputtering motorbike, while the song of the field frog may be compared to the barking of a dog. They can perceive the croaking via the eardrum that is visible just behind their eyes. Another sign of spring is the chorus of courting songs from all the eager male birds. Every species has its special song, and the male sings to mark his territory, i.e. to scare away all other males of the same species, and to attract a female, of course. It is a question of singing better than all the males round about! Birds also have a variety of other calls in order to communicate between themselves. They can be warning calls when danger is near or the fledglings' chirping for food. How would life function if you were a bird and could not hear?

Insects also have organs of hearing in the form of an eardrum, which covers sensory cells that can register vibrations. The "ears" are situated on the insect's body or in the legs, as in the case of the grasshopper.

6.4 Listening to sounds

There are tapes and CD recordings of sounds from different animals, such as birds, frogs, toads, mammals, etc. There are also recordings of other sounds produced by natural phenomena, such as the roar of waves and "singing" of spring ice. There are also a number of resources on the Internet:

- Animals and Sound in the Sea.
  www.dosits.org/animals/intro.htm [Available: 2008-01-15].

Swedish speakers can avail themselves of the following:

- The National Resource Centre for Biology and Biotechnology has a website containing sound recordings of some common birds, the common frog, the field frog and the toad.
  www.bioresurs.uu.se/myller/ [Available: 2008-01-15]
  Click the link ”multimediagalleri”.

- You can find sound recordings of the cow, duck, pig and other animals on ”Musiknet”, which is run by ”Stiftelsen Musiknet”.
  www.musiknet.se/mla/sve/ [Available: 2008-01-15].

7. CONCEPTIONS ABOUT SOUND AND HEARING

The research literature contains a number of studies that concern different age categories, ranging from children aged four to students reading physics at university level. Some deal only with students' conceptions of sound and hearing without any reference to teaching, while others relate conceptual understanding and knowledge development to the design of the teaching. A summary of this research is presented below. In addition, section 7.7 contains a table summarising what scientific conceptions in school science correspond to the everyday conceptions that the reader will find in the research review.

7.1 The origin of sound

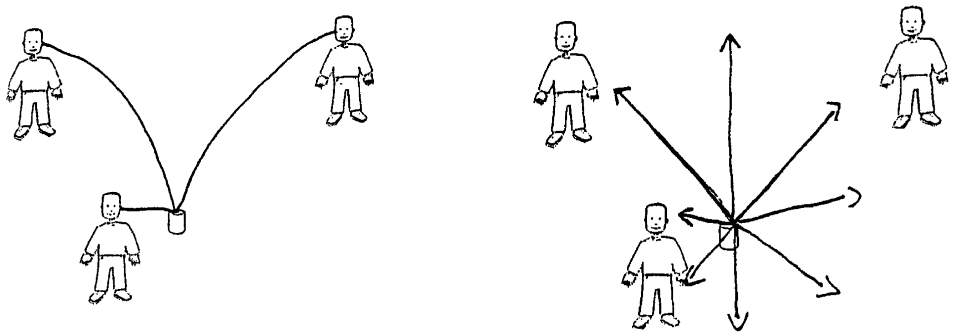
An English study[1] shows that preschool children and pupils of early school age use different ways of explaining how sound arises. They either focus on the properties of the sound source (e.g. that the object is made of plastic or rubber, that it is thick, thin, taut or hard), or their starting point is the effect that accounts for the production of sound (e.g. that a person beats a drum, and that the effect of a force is required for sound to arise). Yet another explanatory model is that the children talk of vibrations when they describe how sound arises. The older they get, the better they are at explaining the mechanism underlying the sound.

Another study[2] of some 200 English children between the ages of 4 and 16 showed similar results. However, this study demonstrates even more clearly that the children's and pupils' conceptions are connected with the kind of object that emits sound. It is easier for them to describe the origin of sound when it is a question of guitar strings and cymbals than to describe the same thing when two stones are hit together. Many children, even younger ones, link the origin of sound to vibrations of guitar strings and the cymbal, while very few of the 16-year-old pupils associate the sound of the stones with vibrations. The researchers draw the conclusion that the pupils lack a general understanding that sound is generated by vibrations.

7.2 Transmission of sound

Many children in preschool[3] do not appear to think that sound is transmitted. Their explanations of why sound can be heard from different objects are based instead on the properties of the sound source, what they are doing themselves, or the significance of the ear. Examples of such statements are that you can hear a clock because it ticks, because you listen or because you have ears. Piaget[4] has also described that four to five-year-olds imagine that the sound exists by the sound source, and at six years that the sound goes somewhere and then returns to the sound source. A few years later one finds the conception that sound spreads out in all directions, while after the age of eleven the explanations contain air, either through sound being spread via air or that sound in itself is regarded as air.

That children of this age conceive of air being spread in all directions also comes out in an interview study[5] of 89 children and pupils aged 6-10 years. The children/pupils were given a picture illustrating three people and a sound source, in which they had to draw how the sound spreads, in answer to the question: Does the sound spread only to the people or does it also spread in other directions? Most 6-year-olds and less than half of the 8-year-olds illustrate in different ways that sound is only spread to the human beings in the picture. Examples are shown in figure 7.1.



A B

Figure 7.1. Examples of pictures in answer to the question: Does the sound spread only to the people or does it also spread in other directions[7]?

Nearly all the 10-year-olds draw the sound spreading in all directions, irrespective if anyone is listening or not (B). Children/pupils in another study[6] made similar drawings.

Many studies[8] show that sound is commonly understood as something material, in other words an object in itself. This conception is expressed in different ways among preschool children and school pupils, and even among physic students at university. In addition, some descriptions are found among preschool children[9] that indicate that the children imagine light as something living, that has opinions about what it does. Conceptions of this kind are called animistic.

In the study[10] with children and pupils aged 4-16 years, the participants had to listen to a ticking clock that was then covered over in different ways. They had to explain why it was possible to hear the clock although it was covered. Examples of pupils' answers follow below:

The sound comes out with the air. It comes out of the aquarium and it crawls out under the opening, in the air (5 years – Why can sound be heard through a plastic aquarium?).

It can come out a little "kind of under the bottom" (8 years – Why can sound be heard through a tea cosy?).

Some sneaks through cracks" (16 years – Why can sound be heard through a cardboard box?).

The answers show that the children/pupils imagine that sound is something material, an object in itself, which needs space or a free way in order to get through.

In one study[11] of children/pupils aged 6-10 years, the majority of the preschool think that you can hear sound from another room through the wall only because it passes through small invisible holes or cracks. The sound cannot come out otherwise, i.e. it gets shut up in the room. Just over one third of the 8-year-olds and one quarter of the 10-year-olds have this explanation. The children also had to rank, with the help of a picture, how easily the sound from a TV passes through walls of different materials, e.g. wood, cardboard, iron, plastic, concrete and glass (figure 7.2).

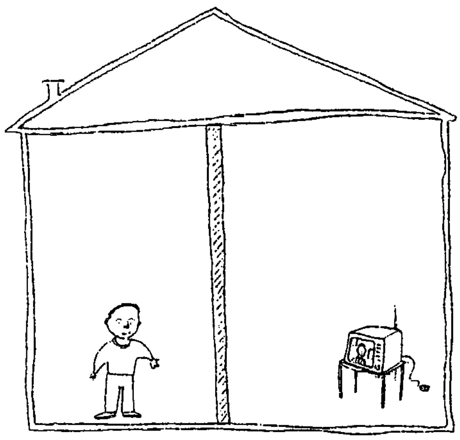


Figure 7.2. The children had to rank, with the help of this picture, how easily the sound from a TV can pass through walls of different materials, e.g. wood, cardboard, iron, plastic, concrete and glass.

They often believe that the sound is transmitted best through walls of plastic, cardboard or wood and worst through iron. One third of the 8-year-olds' and a smaller proportion of 10-year-olds' explanations are that sound can only be transmitted through a material if the sound is "harder" than the material. The "material" sound takes itself through the wall like a stone thrown through a pane of glass. None of the preschool children have this idea. Other signs of thinking of sound as matter are conceptions that sound is something permanent or that sound weighs something. The majority of the older children imagine, however, that sound gradually switches off*, and even that the weight of a sound source does not change when it emits sound. Half the 10-year-olds use no explanations of a material nature at all. Here instead we find the ones who compare sound with ghosts and other immaterial beings. Barely a third of the 10-year-olds have explanations of this type. An equal number of them explain sound transmission with the help of the term “vibrations”.

In an Israeli interview study[14], ten pupils in school year 8 had to draw and explain what sound is and what they thought about sound transmission through air, water, the ground and a vacuum. All the pupils express, in one way or another, that sound is something material that moves from one place to another. The results show both that the pupils use different ways of explaining sound and sound transmission, and also that one and the same pupil uses different explanatory models according to the context in which sound transmission is discussed. An example of this is the pupil who draws sound as bubbles in air but as waves on the ground. Consequently, the pupils lack a general theory for sound transmission. Common ideas are that sound is something that is pushed forward, as when, e.g. air pushes out the sound from someone who is talking, or water pushes out sound from under the surface of the water. The latter is illustrated in the following response from a pupil.[13]

> The sound inside the bubbles is carried along by the water.

This response also shows that the pupil imagines that sound moves inside some kind of bubble in water. In other studies[14], some of the pupils aged 11-16 years who think that sound can be transmitted through water explain their answer by declaring that the water must contain gas, air or oxygen. When pupils answer that sound can be transmitted through water, it follows that there can be alternative explanations for how this happens.

In other common explanations of a material nature, it is assumed that different substances offer different degrees of resistance. One recognises this approach among university physics students[15], who believe that sound is transmitted in a vacuum because it does not meet any resistance. This conception is linked with the idea that sound cannot be transmitted through solid substances. It seems that the denser the medium is, the more difficult transmission is thought to be. It was mentioned earlier that one and same student can have different explanatory models for sound transmission according to the context in which it is described. Again this is something also found among the physics students. The explanatory models used are descriptions at the micro level, e.g. that sound consists of small “objects” that are transported by the separate molecules, or that sound is something abstract that is transferred from one molecule to another. Others assume properties of the media itself, e.g. that sound is a “a packet of molecules” (air, wind...) that is transported. These explanations are similar to the ones previously found among the schoolchildren.

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* “Sound” is kinetic energy that is transmitted and that is gradually transformed into thermal energy.

Different studies show[16] how sound transmission is illustrated in many different ways. There are curves, lines, bubbles, waves, spiral-shaped patterns, round rings, words, musical notation, lightening, arrows, shadows, whirls, continuous lines, etc. The older pupils sometimes draw lines at right angles to the transmission of sound, when asked to make a careful drawing of how sound moves. It is assumed[17] that the teaching of physics in school is partly responsible for this type of drawing. All pupils in school year 8 in the interview study[18] describe sound transmission in some context with the help of waves, while also illustrating it in other ways. The results show, however, that they are unable to link the wave form with the other illustrations. Numerous studies[19] describe precisely this problem with the concept of sound waves. The concept is used in different senses, and pupils very seldom have any idea about its proper meaning. Sound waves can also be described as something material that collides with the air particles, and air can be described as obstructing the sound waves. Sound waves are most often compared with waves in water.

7.3 The speed of sound

When the pupils eventually understand that sound moves, they often entertain the idea that it moves at a constant speed regardless of the medium.[20] It is quite common for both younger and older pupils and students to think that the speed of sound is dependent on the sound volume, i.e. that a louder sound should have a higher transmission speed than a soft sound. We recognise these conceptions from the historical resumé. Many pupils know that the speed of sound depends on the media, but they place them in reverse order: sound is transmitted more rapidly in a vacuum than in water and steel. After teaching just over one third of the pupils in the age group 11-15 years still reply that sounds of different volume have different speeds.[21] Even university physics students struggle with the same problem when they think that the molecules in a medium act as an obstacle, either because they are large or because they exist close together, which would result in sound travelling faster and faster the closer it approached a vacuum.[22]

7.4 The reflection and absorption of sound

Various studies[23] show that students between the ages of 7 and 12 attach different meanings to the term echo. Echo may, for example, mean to copy, vibration, sound in general, resonance ("there's an echo inside the guitar when you strike the string") or sound transmission. The pupils who understand sound as a material object that moves from one place to another describe echo as the object that bounces against walls or on tables. Many pupils know that sound is louder in a room with hard walls than in a room with soft walls, but they do not know why.

7.5 The ear and hearing

In one study[24] of the conceptions of sound among 1900 English 11 – 16-year-olds, the pupils had, amongst other things, to answer the question: "How do you think sound moves so that the person can hear the radio?" Only one pupil declared during the interview that the sound came out of the ear, while more of them imagined that light waves radiated from the eyes when it was a question of seeing.

Many preschool children[25] believe that you hear because you listen. Usually they do not know why they hear, just that sound simply comes in through the ear and then it is heard. A few of them think that the sound goes to the brain, and the brain tells you what kind of sound it is. In the studies[26] that were done in parallel with the production of the present material, the pupils had to answer the question: "What happens to a sound that has reached the ear? Draw what you think just now." It was shown that before the pupils have had any lessons they generally include the brain even if they do not know anything about the innermost parts of the ear. When they do mention any part of the ear, it is usually the eardrum. Hearing is mostly described as an impulse going from the ear to the brain. Few pupils mention the tiny sensitive hair cells that transform vibrations into nerve impulses. In an English study[27] of pupils of early school age, one fifth of the pupils mention that the eardrum, and one tenth the brain, is connected with hearing. Some of these pupils mention that the eardrum vibrates. One pupil describe that there are small bones inside the ear.

When the children meet the terms eardrum, hammer, anvil, stirrup and ear trumpet (the latter term is used in Sweden and with reference to the shape of the tube), they try to link them up with their earlier understanding, which may lead to associations that are well worth discussing in the classroom. The pupils express[28] the idea that the hammer beats on the drum, that there are a saddle and a stable in the ear (associations based on the term stirrup), and Swedish children have the idea that there is a trumpet in the ear, etc. The meaning of words can vary according to the context, and the terms used for the parts of the ear refer to certain similarities in appearance between them and the objects they are associated with.

Many pupils in the age groups 10-16 years[29] believe that their hearing will not be impaired as long as they do not get earache when listening to loud music. This is worrying. Another misconception is that their hearing will stand loud noises of a temporary nature, which is naturally also worrying. After being taught, many pupils show greater interest in using earplugs at the cinema, rock concerts and discos. They are also more critical about the sound level at discos and more motivated to measure it. Faced with a conflict about the sound level at a disco, their tendency to decide the issue by taking a vote or drawing lots of some kind has declined.

7.6 Impact on teaching

Many researchers[30] recommend that teaching about sound should be brought into a larger context: sound source, sound transmission, the ear, auditory nerves and the brain.

At the beginning of this chapter it is shown that pupils, even older ones, lack a general theory of the origin of sound that they can use or apply in new situations. In order to be able to develop a general understanding, pupils must be given the opportunity to practise and reflect upon how sound arises, both in obvious and less obvious situations. The next step is to give the pupils the opportunity to construct a general theory of sound transmission. The researchers[31] conclude that if the pupils are to have a chance of building up a scientific knowledge of sound transmission, they need to understand what air is. Pupils who do not understand air as matter, but thing of it as “nothing” or “a vacuum”, are unable to develop the idea that matter is required for the transmission of sound. The pupils need an understanding of sound as vibrations in matter and these vibrations are transferred to the matter that is adjacent to it. Pupils who work on the basis of a particle theory of matter will have the possibility of understanding that sound is transmitted by means of vibrations that are transmitted via particles (figure 7.3).

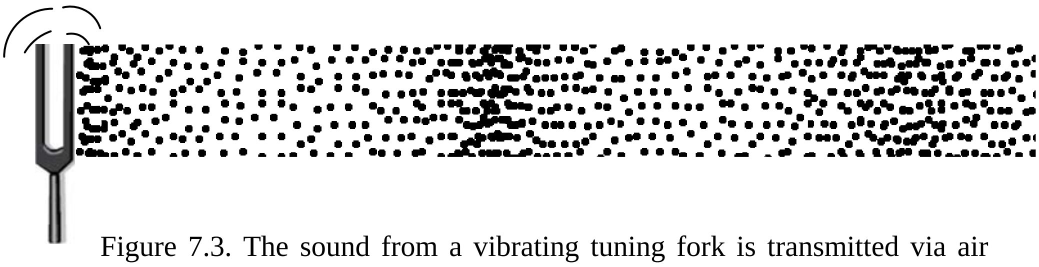


Figure 7.3. The sound from a vibrating tuning fork is transmitted via air particles. The vibrations of the tuning fork are usually said to give rise to condensations and rarefactions. (N.B. In a model that is more true to life, the air particles would be farther apart! Furthermore, the sound spreads in all directions!)

After being taught that sound is transmitted by way of the molecules in a substance, the pupils in one study[32] had to judge whether sound could be transmitted through water, steel or nothing, i.e. a vacuum. Most of the pupils explain quite correctly that sound cannot be transmitted in a vacuum. However, many of them still believe that sound cannot be transmitted through liquid or solid substances either, and their explanations depend on whether the molecules (“the particles) can move or not. An example of the pupils’ answers[33] is given below:

> Steel and a vacuum: no sound is recorded. Sound is transmitted only in media where the molecules move. There are no molecules in a vacuum, and in steel the molecules are stuck.

In teaching this could be precluded by draw the pupils intention to that particles not are stuck in liquids and solids, but they are in continuous movement. The push from a vibrating object thus are transmitted an adjacent particle and so on. No particles are ever completely still unless the temperature has dropped to absolute zero, i.e. -273 °C.

The concept of sound waves is used by many pupils but with different meanings. It is an expression that they have heard and try to use, but it is abstract and difficult for them to handle. If the pupils are to develop an understanding of the transmission of sound, they need help to connect vibration and the particle concept with sound waves to be able to realise that sound waves are a way of expressing that vibrations are transmitted in air via the particles of the air. Literally speaking, sound waves do not exist but rather are a way of expressing the phenomenon sound transmission in a physical/mathematical way. On the basis of the research results reported earlier, it is highly likely that, irrespective of age, very few pupils will understand the meaning of sound waves unless time is allocated to this in teaching.

Pupils easily misjudge the size of the parts of the ear when they see illustrations or models of the ear, since the proportions between the different parts often deviate from reality. The teacher might discuss this with the pupils. To make it easier for pupils to understand the ear's function, it is preferable to use a functional ear model that can show how vibrations are transmitted between the different parts of the ear. A static anatomical "structural" model is unable to do this. A functional model can also help pupils to better understand that hearing impairment can be caused by vibrations not passing through the ear as they should, and that this in turn affects the impulses that the auditory nerve passes on to the brain. One hypothesis is that the pupils' understanding of the ear's function, and the importance of taking care of the hair cells, helps to make them to pay more attention to their own auditory health.

It can be difficult to use analogies of different kinds to explain sound phenomena. A study[33] of Portuguese textbooks and factual study books designed for pupils aged 13 -15 years shows that analogies are common. As it is impossible to "see" sound, it is particularly difficult to illustrate its content with pictures. Although the authors of the teaching material intend the illustrations to elucidate the text, they often achieve the opposite. The illustrations muddle the pupils, reinforce everyday conceptions, or are useless. The illustrations that are considered to facilitate pupils' understanding of sound show how sound spreads at particle level. Domino pieces, waves in water or a large metal spiral ("slinky") are sometimes used to show the transmission of sound. The authors of the study believe that this in its turn entails a risk of supporting the conception that sound is transmitted only in one particular direction via collisions with other particles. Other researchers[34] also think that these and other analogies are more likely to preserve or contribute to conceptual confusion amongst pupils, especially if the teacher is not fully aware of the risks with these analogies.

The research that has been reported in this chapter in various ways forms the basis of the suggestions given in the proposed teaching sequences about sound, hearing and health. Some critical aspects for teaching about sound come out clearly. These are the children's, pupils' and students' conceptions of sound as something material and the problematical use of the concept of sound waves without due attention.

7.7 Summary of the different conceptions about sound and hearing

On the basis of the research done about how pupils and students think about sound, it is possible to identify different conceptual aspects in order to get an idea about common everyday conceptions of sound and hearing. As mentioned earlier, most of these conceptions can be found in our history of famous philosophers and scientists. Knowledge of the pupils' everyday conceptions is an important point of departure for any teacher in his or her attempt to help the pupils approach an understanding based on science.

Sometimes sound/hearing and light/vision are taught as combined subject area. But then teachers must be aware of the difference between sound and light, as pupils often imagine that sound and light have the same properties.

In table 7.1 different content aspects of sound and hearing are summarised, including common everyday conceptions that the research and the tests have revealed. The aim of teaching in school science is to take the pupils from the world of everyday conceptions towards a more scientific one. Different aspects are treated, such as the origin of sound, the nature of sound, sound transmission, sound speed, sound meets different surfaces, and finally hearing and hearing health.

Table 7.1 Aspects of sound and hearing in everyday thinking and in school science.

Contentual aspect	*Everyday conceptions*	*Goal: School scientific conceptions*
How sound arises	Younger pupils believe the origin of sound has something to do with their own actions. The origin of sound has something to do with the properties of the instrument/ material that makes sound.	 All sound arises because objects vibrate.

Contentual aspect	*Everyday conceptions*	*Goal: School scientific conceptions*
The nature of sound	Smaller children often regard sound as something animistic, i.e. sound is something alive with its own intentions.	
	Sound is something material, small things, an object.	Sound is vibrations that are transmitted (=kinetic energy that is transmitted).
The transmission of sound	Sound is a property of the sound source, not something that is transmitted.	
	Sound is something material, an object that moves from one place to another.	
	Sound is a discrete substance, "a single collection of particles or molecules" that is transported, e.g. air, wind.	Kinetic energy is transmitted from one object to another and makes it vibrate.
	Sound is spread through empty spaces in the medium.	
	Sound transmission has nothing to do with matter (no mention is made of air or other matter).	Sound is spread by vibrations being transmitted in different types of matter, including air (= by particles colliding with each other).
	Sound is transmitted in water because there is oxygen or air in water.	Sound is transmitted in water and other liquid substances.
	Sound is transmitted in solid material via small holes or openings inside the material.	Sound can be transmitted through solid materials such as wood, steel etc.
	Sound is only spread in a certain direction, e.g. the domino effect.	Vibrations spread in all directions.
	Sound waves are something material, and they can, e.g. collide with each other or bump into the air particles.	Sound transmission can be illustrated in different ways. Sound waves (i.e. the wave form) is a mathematical way of illustrating sound.

Contentual aspect	*Everyday conceptions*	*Goal: School scientific conceptions*
The speed of sound	Low-frequency (dull, muffled) sounds move at a different speed to high-frequency (squeaky) sounds. Sounds of high volume (loud sounds) are transmitted faster than sounds of low volume (soft, weak sounds).	The speed of sound in air at a certain temperature is the same for different sounds irrespective of frequency and volume.
The sound meets different surfaces	Sound cannot pass between two different media, i.e. the sound is shut in. Sound is something material that bounces on different surfaces. The echo is caused by the sound colliding with an obstacle. Echo can mean a number of different things, e.g. copy, vibration, resonance.	Vibrations in one material can be transmitted to another material. Echo means that a sound, after being reflected by a surface, is perceived by the ear somewhat later than the original sound. Sound is transmitted, absorbed or reflected by different materials.
Hearing	The ear catches the sound, and this makes us hear.	Sound vibrations that reach the ear are transmitted to the sensory cells, which transform the vibrations into electrical impulses that is sent to the brain. In the brain perception takes place – we hear! Kinetic energy (vibrations) is transformed into electrical (e.g. electrochemical) energy in the sensory cells.

Contentual aspect	*Everyday conceptions*	*Goal: School scientific conceptions*
Hearing health	High sound levels do not harm your hearing if you like music. It’s only when you get earache that loud sounds are dangerous. Loud sounds that are temporary do not harm your hearing.	High sound levels harm your hearing (hair cells/sensory cells) regardless of whether you like music or not. Loud sounds may be harmful regardless of whether you have earache or not. Loud sounds that are temporary can harm your hearing.

FOR DISCUSSION

What everyday ideas about sound and hearing do you recognize in yourself?

What everyday conceptions about sound and hearing will you probably meet among the children/pupils in your group?

8. TEACHING GOALS

8.1 Previous knowledge

The subject didactic research on sound and hearing reported above shows that the pupils need to have a concept of matter. Experience from teaching trial sequences confirms that the pupils need to have an understanding that gaseous substances as well as liquid and solid substances are built up of matter. With the help of the particle theory, the pupils have a chance of understanding the difference between the different phases. Previous knowledge of this kind will facilitate the understanding that sound is dependent on matter for its transmission.

8.2 Goals

A number of goals formulated by help of the presented subject matter didactic research are presented below. Our intention is that the teacher/the team of teachers choose which goals to work towards in consideration to pupils' age and current curricula/syllabuses in the country of concern.

<u>Possible</u> content goals concerning nature and Man

The pupil should

- have a general knowledge of the fact that sound is produced when objects vibrate
- have a knowledge of the fact that sound needs matter (solid, liquid or gaseous) in order to be transmitted and that transmission takes place in all directions from the source
- know that it is vibrations that are transmitted in the medium, not something material (e.g. sound particles)
- be able to describe sound transmission with the help of different models and reflect on the merits and limitations of the models
- be aware of the fact that when sound strikes a surface it can be transmitted, absorbed or reflected (echo)
- know that sound has different properties like frequency (pitch) and sound volume

- be able to show how sound frequency (pitch) and volume can be changed

- be aware of the phenomenon of resonance

- know that the transmission of sound takes time, that speed in air does not depend on pitch, sound volume and how far the sound has travelled

- know that sound vibrations that reach the outer ear make the eardrum vibrate and that these vibrations are transmitted to bones in the middle ear and then to the inner ear

- know that the vibrations are registered by the hair cells (sensory cells) in the inner ear, and that these transform the vibrations into electrical impulses (electrical* energy) that are sent to the brain

- know that the perception of sound takes place in the brain and that sound memories are stored there

- have a knowledge of the fact that problems with different parts of the ear (e.g. damaged hair cells) can give rise to hearing impairment

- have a knowledge of how to maintain good hearing health (especially how tinnitus can be prevented)

- be able to design and build instruments that produce sound and describe how they work.

Possible goals concerning scientific activity

The pupil should

- be able to carry out simple systematic observations, measurements and experiments and also be able to compare his/her predictions with results.

Possible goals concerning use of knowledge

The pupil should

- learn to listen, discuss, argue and use his/her knowledge as a tool to
  - formulate and test assumptions and solve problems
  - reflect on experiences
  - critically examine and evaluate claims and conditions

* More exactly: electrochemical energy.

- gain insight into how arguments in an everyday health or environmental issue can be produced with the help of personal experiences and scientific knowledge

- be able to discuss the importance of a good sound environment.

TO DISCUSS

Compare these goals with the ones set out for your target group in the current curricula/syllabuses in your county. Which of the goals given above do you find suitable? Are there any goals not listed above that you think should be included? If so, what?

Do you think there should be other goals than the proposed ones in comparing with the curricula/syllabuses? If this is the case, which?

8.3 Proposals of criteria as regards marking

In Sweden there are at present three levels of marks apart from fail. The first level is simply called Pass, the one above is called Pass with distinction, and the highest level is called Pass with special distinction. The national steering documents, Syllabuses 2000, lay down criteria for assessing whether the pupils have fulfilled the goals with regard to Scientific understanding of the world around them, the nature of Science, and Science as a human and social activity. The marking criteria for the area Sound, Hearing and Health have to be formulated and interpreted in relation to the goals of the national syllabus and the assessment criteria.

The pupils must know what goals and marking criteria apply for the working area before teaching starts. One of the fundamental assessment criteria in science is that pupils should be able to express their thoughts and questions with the help of concepts, models and theories. Another basis for assessment is the pupils' awareness of the interaction between the development of concepts, models and theories, on the one hand, and experience of investigations and experiments, on the other. The suggestions for assessment criteria that have been formulated are intended as a basis for the teacher when explaining the criteria to the pupils, and therefore the language has been simplified. For the same reason, general formulations concerning concepts, models and theories have been avoided. The content is, however, based on conceptual understanding, theories of sound transmission and reasoning with models, as well as the above-mentioned interaction, and it is important that the teacher bear this in mind when making assessments.

The Appendix "What have I learned?" is adjusted to the goals and marking criteria given below and the teacher may use it to help him/her a check-list for the pupils. The pupils will receive the list after a suitable number of lessons and reflect on what they have learned in privacy (self-assessment, known as "meta-reflection", see also section 9.2), and what they have left to learn in relation to the goals set up. The teacher goes round and discusses with the pupils.

To obtain the mark PASS the pupil must

1) have scientific knowledge about:
– sound arising by means of vibrations
– vibrations being transmitted via matter in gaseous, liquid and solid substances
– how models can be used to explain sound transmission
– sound transmission taking place in all directions and taking time
– the difference between pitch (=sound frequency) and sound volume (sound level)
– that sound can be reflected when it hits a surface and what an echo is
– practical examples where resonance is used
– how sound vibrations are sent to the inner ear and how they are registered and transformed into electrical impulses in that part of the ear
– the perception of sound taking place in the brain and sound memories being stored there
– problems with different parts of the ear causing hearing impairment
– how different kinds of hearing impairment (particularly tinnitus) can be prevented.

2) should be able to carry out:
– a practical study/an experiment, e.g. sound measurement, by formulating a study question, making predictions, making observations, reporting on method and results.

and know about:
– what is typical of a scientific way of working, and that this is important for obtaining new knowledge.

3) be able to use their scientific knowledge in everyday discussions about sound, hearing and hearing health by:
– listening to others in group discussions
– taking a stand in different questions and formulating arguments for AND arguments against the stand-point
– distinguish between scientific knowledge and everyday opinions.

To obtain the mark PASS WITH DISTINCTION the pupil must

1) have scientific knowledge:
– so that he/she can use the knowledge required for a PASS in new situations to describe and explain the course of events and phenomena in the world around us what have to do with sound, hearing and health.

2) be able to do:
– what is required for a PASS and be able to reflect on the results of experiments and draw reasonable conclusions.

3) be able to use his/her scientific knowledge in everyday discussions by:
– mastering the PASS level and using scientific knowledge to examine and evaluate stand-points in questions concerning sound, hearing and health.

To obtain the mark PASS WITH SPECIAL DISTINCTION the pupil must

1) have scientific knowledge:

– so that he/she can use the knowledge required for a PASS and PASS WITH DISTINCTION in order to create new questions and propose hypotheses about phenomena in the world around us.

2) be able to do:

– what is required for a PASS and PASS WITH DISTINCTION and to be open to several possible explanations of results and reflect on the reliability of the measuring method.

3) be able to use his/her scientific knowledge in everyday discussions by:

– mastering the PASS and PASS WITH DISTINCTION levels and using scientific knowledge to examine arguments about sound, hearing and hearing health and the interests and values underlying them.

FOR DISCUSSION

What concepts, theories and models may be possible for the pupils to use to express their thoughts and questions in the area?

How can the assessment of pupils' knowledge of concepts, theories and models be made at qualitatively different marking levels?

9. THE PUPIL AND FORMATIVE ASSESSMENT

The importance of formative assessment has been emphasised more and more during the last few years. Formative assessment means that the teacher uses evaluation as a tool to plan and design his/her future lessons. There are many studies from around the world on the subject of formative assessment. All of these studies point to the fact that formative assessment improves the pupils' motivation, self-confidence and learning. Many of these studies also show that formative assessment helps weak pupils even more than it helps the clever ones. The knowledge gap between pupils decreases at the same time as the group's overall level of achievement increases. This chapter is based on the overview of research by Black and William.[1]

9.1 What can be problematic?

Black and William show in their overview that certain strategies used in teaching or for assessments might have negative effects on pupils' learning. Strategies that risk these negative effects might be that:

- Used tests often encourage superficial, by-heart, learning in spite of the teacher believing that he/she wants to develop the pupils' understanding. Many teachers do not seem to be aware of this imbalance.

- Evaluation issues and other evaluation methods are not discussed amongst the teachers at the same school, and that they are not examined critically in relation to what they are actually evaluating.

- There is a tendency to emphasise quantity and presentation of projects instead of focusing on the quality of learning.

- There is a risk of overestimating the importance of marks and grades, and underestimating the importance of giving useful advice on the learning process itself.

- The teacher tries to stimulate the pupils by creating a competitive atmosphere rather than encouraging them individually. This results in weak achievers learning that they are not "capable" which makes them believe that they are not good enough to be able to learn anything. Therefore, they do not put their hearts into learning, since this only leads to disappointment. They try to build up their self-confidence in other ways, instead.

Naturally, the teacher's role to support and encourage pupils is important. However, it is sometimes used in a way that does not promote learning. For instance, the teacher may:

- only give the pupils feed-back of an encouraging and personal nature rather than of a learning kind

- believe it to be more important to collect grades than analyse the pupils' work so as to gain awareness of what his/her pupils need to learn

- not pay attention to previous evaluations that other teachers have made of what the pupils know and what they have learnt

- know too little about his/her pupils' needs and use or imitate earlier tests uncritically.

When classroom work is focused on rewards in the form of gold stars, grades or ranking, the pupils will find other ways of getting rewards instead of improving their learning. Research shows that pupils will avoid answering difficult questions if they have a choice in the matter. They will put time and energy into looking for clues to find the "right" answer. Many of them will, in fact, be unwilling to ask questions because they are afraid of being wrong.

9.2 Creating a culture of success

What is needed is a culture of success linked with a belief that all pupils can be successful. The feedback to the pupils should comprise the special qualities in his/her work, with advice on what the pupil can do in order to develop his/her learning. How can we create such a culture of success?

Self-evaluation
An important component of formative assessment is to train the pupils to evaluate their own learning themselves. This cannot be realised until the pupils have a clear picture of the learning goals to be reached. The pupils also need information on how far he/she has come in the process and have some form of understanding of how he/she can continue to progress.

Formulating one's own understanding
Discussions where pupils are given ample opportunities to formulate their own understanding create favourable prerequisites for increased understanding and promote learning. The teacher can use various strategies in his/her teaching. Here are a few examples:

- Give the pupils time to answer. When the teacher answers his/her own question after only two or three seconds or when not even a minute's silence is allowed, the pupils are not given a chance to think out an answer. The only questions that give an answer after such a short time are factual questions, and this type of question will predominate. There is an obvious risk that many pupils will not even try to think out an answer since they know that they will not have time, and this results in only a few of the pupils in the class answering the teacher's questions. In this way, the lesson simply goes on without the majority of the pupils really understanding the content.

- Ask the pupils to discuss how they think, either in pairs and/or in small groups and after that let one pupil from each pair/group report what conclusions they have come to. Black and William claim that giving the pupils the opportunity to express their understanding should be included in every part of their lessons since this interaction of teaching and formative evaluation leads to more effective learning.

- Give the pupils a choice between a number of possible alternatives and ask them to vote on the different suggestions.

- Ask everybody to write down an answer and then let some of them read out what they have written to the class.

> The dialogue between the teacher and the pupil should be thought-provoking, reflective and focused on challenging and probing into the process of how the pupils understand. This process should be carried out so that all pupils have the possibility of thinking and expressing their ideas. It is only then that some form of formative process can begin. An important prerequisite here is an open and permissive classroom climate and that both teachers and pupils show respect for the pupil's attempts to express their thoughts in words.

Tests and homework

It is better to have several short tests than one long one. Each new discrete piece of learning should be tested, at the earliest, a week after the pupil has been confronted with the content for the first time. A good test can be an opportunity for learning. Homework and tests give the teacher the chance to give the pupil feedback. The quality of the test questions, as well as their relevance to teaching goals and how these are communicated to the pupil, requires careful thought. Good questions are difficult to think out, and it is an advantage if teachers can cooperate with other teachers in their school or with other resource persons outside school. The teacher's feedback is important, and research shows that learning is improved when feedback gives each pupil guidance regarding his/her strengths and weaknesses, preferably without the pupil's results being graded.

> When the pupil gets feedback on a test, schoolwork or homework, he/she should be given supervision and guidance as to how he/she could make progress. Each pupil must get help and be given the possibility of working on his/her own learning process.

Obstacles

There is not one simple way of developing formative assessment, and each teacher that tries to change the way he teaches by using more formative teaching methods will probably encounter a number of difficulties in the beginning. However, what is essential for all formative evaluation is the teacher's attitude and him/her being realistic and asking him/herself the question, "Do I really know enough about my pupils' understanding so that I can help each and every one of them?"

When pupils encounter a form of evaluation they are not used to, you can expect them to react with resistance and insecurity, or experience this new idea as something threatening. The pupils do not automatically believe in improved learning until they have experienced the advantages of this working method themselves. Change takes time!

The teacher must be able to tackle two basic questions that often cause problems when school practice is to be redirected towards a system of formative evaluation. The first of these is a question of the teacher's philosophy and conception of learning. The only solution is not necessarily individual teaching but our purpose should be to develop a new "question culture" and to stimulate deep thinking where pupils learn from common discussions between the teacher and his/her classmates. The second problematic question is the opinion the teacher has of all his/her pupil's potential for learning. If the teacher presupposes that the pupils have "unused potential", this will help all pupils to learn, and this can be of particular help for those pupils that have to struggle.

FOR DISCUSSION

What can you as a teacher do to get to know so much about your pupils' understanding that you are able to help each of them?

10. SUGGESTIONS FOR TEACHING

10.1 Introduction

This chapter contains suggestions for teaching that have been worked up after we had tested them at different stages with teachers in schools. The research data that have been collected during the testing of the teaching sequence have also been analysed and used in the continuous revision of this manual. The pupils that participated in the lessons were aged 10-15.

The suggestions for the teaching sequence that follow are grouped according to a progression of content, and each individual sub-heading is *not* intended to be a lesson. There are suggestions for a number of items where the individual pupil is given the opportunity to work out and reflect on the content and formulate his/her ideas. Such activities are an essential part of the teaching. One such activity is having a discussion in small groups of two to four pupils, and the learning potential of small group discussions is easily overlooked. There can, of course, be class discussions led by the teacher. Many teachers think that this is more effective and saves time. However, research shows that small group discussions are important for challenging and developing the individual pupil's understanding of terminology since all of the pupils are given the opportunity to formulate their own ideas and test them on the others in the group. This means that the teacher will need to guide these discussions so that they will not become too general in nature.[1]

The teaching sequence is founded on formative assessment, i.e. that the teacher continuously assesses the pupils' knowledge development and understanding of terminology (see Chapter 9, Formative assessment). Naturally, the results of the assessments affect the content of the lessons and it is therefore impossible to design an exact teaching sequence from the start. It is only when the individual pupils have developed sufficient understanding of the content they have worked with that teaching can continue. One recommendation is to introduce each lesson with a single question which assesses how the pupils have understood the content of the previous lesson. Another alternative is to end the lesson with individual assessment questions that test the pupils' understanding of the content that has been dealt with (see Chapter 11, Experience of testing). There are a number of suggestions for evaluation questions in the problem collection which can be a source of help and inspiration. The teacher can choose from among the questions and use them for pre- and post-tests, as a basis for group discussion and for formative assessment. Formative assessment, as mentioned earlier, encourages all pupils, particularly the less-gifted ones. The teacher can also find out which pupils have already reached the goals set up, thereby giving them the opportunity to work with more challenging assignments.

When the pupils' post-tests were analysed in connection with testing the teaching sequence, it was shown that the pupils who had been allowed to formulate their understanding of different concepts themselves had a better understanding than those who had not had this opportunity (see Chapter 11). The teachers' written replies to the individual pupil regarding formative assessment questions and similar items further contributed to a qualitatively better understanding. This emphasises the importance of giving each individual pupil the chance to formulate him/herself in speech and writing.

In the lessons it is essential to bring out and work with the pupils' everyday conceptions, and that they can be used as a basis for discussions. Knowledge is just as much knowing what theories are unacceptable and why as knowing what is accepted as knowledge today. The questions in the collection of problems (see appendix) may also be used for this. Another suggestion is that the teacher simply selects a number of different answers pupils have given in the pre-test of a suitable question and lets the pupils discuss and form an opinion about what answers might be reasonable. The collection of problems also contains argumentation exercises to give the pupils a chance to practise forming an opinion and to become aware of the arguments for and against a choice. The purpose of this section is also to increase pupils' competence in distinguishing between opinions and scientific knowledge and to train them to use scientific knowledge in an everyday context. An important aspect in this connection is the progress of science.[1] Researchers and research teams today present their theories at scientific conferences and in scientific journals where other researchers critically examine and discuss what is reported. Sometimes it happens that the theory fails and new theories have to be sought, tested and discussed. The natural sciences that we know today evolved in historical times in much the same way. Long before Christ the philosophers already discussed their theories in a similar way, and since then scientific discussion has been refined more and more. One example of such a historical discussion is the one previously described about the speed of sound in air, where it took well over 1000 years before a consensus was reached. A well-known example of a completely different kind is the theory that the earth was the centre of the universe, a theory that was questioned at the beginning of the 1500s. After many discussions and astronomical observations among contemporary researchers, a new theory evolved that instead placed the sun at the centre. This theory was met with great scepticism during the whole of the sixteenth century before it was finally accepted. The knowledge of natural science in our society today has grown and is growing in a similar way, a fact that is important for young people to understand. Otherwise there is a risk that, thanks to the media, they will not pay due respect to conflicting research results and consider researchers to be unreliable. The scientific knowledge we have is the one we have today.[2]

As mentioned earlier, the progress of natural science was largely due to scientific experiments. In a similar way, the pupils in school carry out their own investigations to try to understand the world around them. Like the researcher, they then need to know how to carry out a scientific investigation so as to be able to obtain reasonable results and deal with them. They need to be able to formulate a research question/problem based on a hypothesis that they have, plan their investigation (e.g. a controlled experiment), carry out observations and measurements, treat data, draw conclusions, and reflect on the results and the reliability of the measuring method. When the pupils work in this way, the teacher has an opportunity to emphasise and discuss how important scientific investigations are for the progress of the natural science that exists today. Reports on laboratory experiments have their equivalent in an article in a scientific journal. In this teaching sequence, it is assumed that the pupils will carry out investigations of their own design according to the above.[3]

The appendices contain an outline of a preliminary time scheme that may be used as a basis for making a rough plan of the area (see appendix, Preliminary time scheme). One tip when planning is not to carry out many experiments at the same time as this leads to too many different sounds occurring in the same room at the same time. Some activities also cause sounds that are too loud, and some precautions are recommended.

10.2 Formulating goals

Before teaching starts it is important to set up suitable goals. What goals are chosen naturally depends on the ages of the pupils and what syllabus they have at that time. The teacher chooses suitable teaching content from the stipulated goals. Chapter 8 in this manual presents several goals that can be selected for the teaching. The teaching sequence suggested is based on the integration of several different subjects (see also Introduction). Research shows that one of the risks of integrated teaching is that the learning of conceptual content is neglected. It is therefore essential to select goals and consciously work towards their attainment.[4] Further research in the field of design emphasises the importance of clear goals.[5]

The goal/s that are being worked on will be presented in the introduction to each section of this chapter. The main emphasis here is on the goal contents. The goals concerning scientific activity and use of knowledge are of a more comprehensive nature and are therefore not presented in each section.

Pupils' learning
It is advisable to show the pupils the set goals and marking criteria for the area in question after a number of lessons. Let the individual pupil reflect on his/her own learning, which is known as meta-reflection. The appendix "What have I learned?" could be used here. It is mainly based on goals for the "Pass" level. It was tested during the trial teaching, and the pupils reacted to it very positively as they saw clearly what they had learnt. They also had the chance to reflect on their own learning in relation to the marking criteria and to discuss it with the teacher.

10.3 How do the pupils express themselves?

It is important to know how the pupils express themselves about sound and hearing. Bearing in mind the research that was presented earlier (Chapter 7), it is clear that the pupils will naturally have many everyday conceptions that differ from the school scientific goals.

Start your teaching by asking the following questions:

- What everyday conceptions do my pupils express?
- What scientific conceptions, if any, do the pupils have before the teaching starts?
- What impact will the answers to these questions have on the teaching?

Introduce the subject matter with an interesting object that makes a sound: a toy that makes a sound, an instrument, an animal call, a popular song, or suchlike. Then tell the pupils that you would like to know how they think in connection with a few questions about sound before you start on this area of work. Also tell them that their answers are important since they will be used as guidelines when planning future lessons, and also that their results will decide what they are to learn in class in the near future. In Sweden pupils in the later school years should possess knowledge from earlier teaching, because in school year 5 there already are attainment goals connected with sound. Point out that this is not a knowledge test that will be marked! In trial teaching sequences, it has been seen that pupils who are not used to the teacher finding out what the pupils know beforehand easily become frustrated about getting questions they do not know the ”right” answers to. That is why the introduction of diagnostic questions, the pre-test, is important. When trying out this sequence, the term “teacher’s guide” is therefore used for the pre-test. It is a good idea to let the pupils read the answers they have given in the pre-test one more time when the entire teaching sequence is completed (see section 10.16 Assessment). They are often surprised at the answers they have written earlier and it becomes obvious to them that they have actually learnt many new things. To discover for yourself that you have learned something contributes to increasing motivation (see section 9.2 about self-evaluation).

Choose questions from the problem section or make up your own questions from the goals that have been drawn up and use them to put a pre-test together i.e. a teacher’s guide. One suggestion is to select one question for each goal area that tests how the pupils express their thinking. The appendices contain a survey of the goal areas found in this material with appropriate questions (see “Appendices – Overview”, part 3). Then compare your pupils’ conceptions with those that are common among other pupils and think about which everyday conceptions need to be challenged in relation to the goal drawn up (see section 7.7).

10.4 Sounds around us

Goal: Being aware of the fact that we live in an environment full of sounds and that sound is important for people and animals in different ways.

The lesson starts with each pupil thinking about:

What sounds can you hear when it is completely ”quiet” for five minutes?

The pupils listen and make notes about the sounds they perceive. When the time is up the teacher writes down the pupils' different answers. After that, the pupils, in groups of two or three, try to sort out these sounds into different categories. It is the pupils themselves who decide how they want to categorise the sounds. After a while the groups tell the rest of the class how they have chosen to sort out the sounds. Complete this task by allowing the pupils to discuss in groups the importance of sound to human beings and different animals (see even section 6.1), and which sounds we experience as pleasant or unpleasant.

Another alternative is to let the pupils go out for a sound walk and note down all the different sounds they hear. This exercise is followed up in a similar way to the alternative above.

10.5 Sound arises when objects vibrate

Goal: Understanding that all sounds arise by means of vibrations.

Each pupil gets a rubber band to try and make different sounds with. The question is:

How does sound arise?

The pupils then discuss this in pairs. After that the pupils give an account of their different ideas and these are written on the board. Is there any common agreement? The result affects the way in which the teacher will continue. It is important that all the pupils' suggestions are taken into consideration both now and in the future (see even Chapter 9.2 about success culture). The pupils will very likely have suggestions such as the rubber band moving, vibrating or the like, and the next step will be to examine the movements that other objects that give off sounds have.

It is important to continue with objects that *clearly* vibrate when they give off sounds. Simple things to use are plastic rulers and wires. The plastic ruler can be placed over the edge of a table and the part that is sticking out can be made to move. The wire is tied between two nails on a board. The one end is firmly tied to one of the nails and the other end is wound a few times around the other nail. In this way the pupils can easily alter the tension in the line. Another alternative is, of course, to use stringed instruments. The pupils can work in small groups so that all pupils are given the opportunity to try things out. Alternatively, this second part can be saved till section 10.9 where the concept of frequency is dealt with in more detail.

The question is:

What does the movement that causes sound to arise look like?

The teacher gathers all the suggestions on the board, has a discussion with the pupils and also introduces them to the term "vibration" if this has not come up earlier. If suitable, depending on the choice of goals, pupil group, time etc, the next task can be to make different sounds with the ruler and the wire. Then the question is:

How do different sounds arise in the ruler and the wire respectively?

The sound is affected by how long a part of the ruler is made to vibrate – the shorter the piece sticking out from the table, the higher the tone. The harder the wire is tightened, the higher the tone. The sound level is also affected – the more force behind what makes the ruler vibrate, the louder the tone.* The pupils can see and hear that one and the same object can give rise to different sounds depending on how it vibrates.

In small groups or all together, the class can finally examine other objects that give off sound. They can hit a large pan lid with a stick (or even better use a cymbal, if there is one available) and feel with their fingers how it vibrates (but mind your ears!). In the same way, you can feel the vibrations of a tuning-fork that is struck with a rubber hammer or demonstrate with a triangle, a jew's harp, a guitar string, or a drum for example. It is possible to feel that the membrane in a loud speaker vibrates when there is a sound (bass tones are easiest to

* The phrase high sound level is the same as high sound volume, the first could be called scientific usage, the second colloquial (everyday). The opposite is low sound level/volume. A sound can be described as loud (and variations on this, e.g. deafening) or soft (weak, feeble). These adjectives refer to the sound level/volume. If you talk about high and low sound, high and low tones, high and low pitch, this only refers to the frequency.

demonstrate). Pupils can make sounds with their own vocal chords and feel the vibrations from them in their throats. There is no end of possibilities.

Each pupil needs to experience how sounds arise in a number of different ways, from clear vibrations to less clear vibrations, in order for her/him to be able to build up a *general* theory of how sound arises.

If the teacher wants to connect the subject area ”sound” with the subject area ”technology”, the pupils can be given the opportunity to make their own objects that generate sound and demonstrate them in the next lesson (see further possibilities in section 10.14). Another alternative is to let them build their own instruments in school. This task can be connected with the pupil being able to give an account of:

What is vibrating in my instrument when sound is heard?

Examples of teaching material that can be put out are wires of different thickness, bottle tops, ice-cream sticks, metal rings, string, drawing pins, different kinds of wooden sticks, planks, sand, dried peas, glue, sand paper, plastic cartons, balloons, nails of different sizes, scissors, hammers etc.

The class takes a look at the instruments that have been constructed and discuss what it is that vibrates and gives rise to sound. They can also examine what it is that vibrates in ordinary instruments.

The pupils’ learning process is assessed before teaching continues. The teacher finds out how well the *individual* pupils have learnt that sound arises when things vibrate. The intention is that every pupil should be given the opportunity to reflect on and put her/his answer into words.

The teacher makes a sound with 1) an object (where it is easy to understand that it is a question of vibrations) which the pupil has not come across before and 2) knocks two stones together.

The pupils have to answer the question:

How does sound arise?

Each pupil writes down her/his answer (the teacher collects the answers) and then group discussions follow. The group discussions contribute to the pupils developing their understanding of terminology in that the pupil teaches him/herself when s/he has to formulate her/his understanding and discuss it with other people. There are probably quite a few pupils that have not thought that even sounds from stones depend on vibrations.

10.6 What substances transmit sound?

Goal: Know that sound is transmitted via matter in gaseous, liquid and solid substances.

Sound transmission via matter in different substances: gaseous (air), liquid and solid substances, is purposely dealt with in this order so that the pupils will gradually be able to build up a general theory of the transmission of sound.

Transmission via gaseous substances

This section is introduced with a demonstration that has been shown to catch the pupils' attention. A number of different alternatives are suggested below (Question 2, in the different alternatives below, about what there is between the object and your ears, aims at making the pupils aware that there is ”something”, i.e. air, in between. This focuses their attention on the matter for sound transmission):

- Alternative 1
  Play a popular song on a CD player and ask the following questions (in this order):
  1) ”How does the sound from the CD player come to your ears?”
  2) ”What is there between the CD player and your ears?”

- Alternative 2
  Tell your pupils something funny or exciting that catches their attention and ask the following questions in this order:
  1) ”How does the sound from my voice come to your ears?”
  2) ”What is there between my voice and your ears?”

- Alternative 3
  In the trial teaching this was shown to be interesting but a bit more complicated. Have a snare drum in the classroom (make sure that the metal strings on the underneath skin are taut). Play a suitable bass tone on an electric bass guitar that is connected to an amplifier some distance away (try out a suitable tone in advance). The bass tone makes the drum skin vibrate and, since the underneath skin vibrates against the metal strings, a clear sound is heard from the drum. The vibrations can even be felt with your fingers.
  Ask the following questions (in this order):
  1) ”How does the sound come from the bass guitar to the drum?”
  2) ”What is there between the bass guitar, the drum and your ears?”

  This phenomenon is actually called resonance, but it is not introduced here. This experiment is used only for showing that vibrations are transmitted via air!

Regardless of which introduction is chosen, the pupils can think about the questions selected and discuss them in pairs or in smaller groups. Each group presents their ideas. Collect all the different ideas randomly on the board. The pupils will probably have many different explanations for how sound is transmitted (see Chapter 7 about pupils’ conceptions).

1. The first step to understand is that sound can be transmitted via the air. It is suitable to do new experiments if there are some pupils that have ideas that need to be challenged. In the trial teaching sequences, in the example with the electric guitar and the drum, there were pupils in every group that thought that the sound went from the electric guitar to the drum via the floor and the drum stand! In order to challenge this idea the teachers hung up the drum by a string from the ceiling in the next lesson!

2. The next step to work out is ”How is sound transmitted in air?” The pupils have probably expressed this in their explanations. Their explanations can be ”there are vibrations”, ”sound waves”, ”there’s an echo”, ”the electric guitar/CD player plays tones that become waves that follow the flow”, ”finally sound waves come to the ear”, ”the sound travels with the air”, ”it is air that travels” etc. The pupils’ answers are grouped in a suitable way

e.g. vibrations, sound waves, air is moved etc. The follow-up of these answers is done later. See section 10.7.

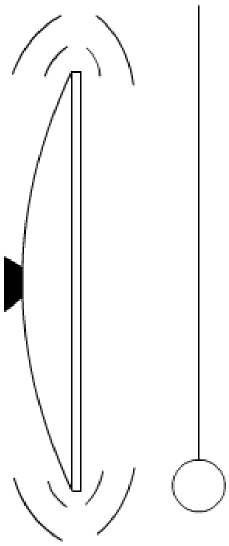
3. The last step for the group to discuss is ”What is air? Is it something or is it just nothing (a vacuum)?” The aim of this is for the pupils to gain insight into the fact that air is “something” and that sound is transmitted through this “something”.

Comment: It is an advantage if the pupils have a knowledge of the fact that air is something. If the pupils have not been introduced to the particle theory and the use of particle models before, it is important that the teacher puts extra time into trying to explain why so-called models are used in science, and that it is possible, with the help of a model, to illustrate phenomena that we cannot see, such as the air’s smallest components. Air and everything else round about us is built up of smaller parts. These small parts can be called particles (see Chapter 4). The pupils are given the opportunity to gradually understand that sound is transmitted by particles vibrating in a certain way, which, in turn, get other particles close by to vibrate in the same way.

4. The pupils have now worked with sound being transmitted through air and that there are different ideas about how this happens, i.e. by means of vibrations, sound waves and that air is moved etc. Future lessons will work on these ideas

The pupils will need help in developing an understanding of how sound is transmitted, and that this happens when many particles simultaneously collide with each other. That is how the vibrations are transmitted through the air. You can demonstrate this transmission by using simple models connected with everyday life. You can start on a simple scale by talking about everyday comparisons where “things” bump into each other. It can be balls that collide or pupils that are crowded together in a queue to the dining room. However, the teacher should be aware that there are certain risks with these analogies (see section 7.2). The pupils can think that the particles only move in one direction, or that they are moved away altogether.

The following are suggestions for a number of experiments that can be used when working with the transmission of sound in air.



The air consists of billions and billions of small air particles. If you take just one of these and magnify it many, many times, it would be possible to see it. If we imagine that a table tennis ball is one of these air particles. (The table tennis ball is a visible model of an air particle). Hold a pan lid, cymbal or tuning fork vertically by its handle and make it vibrate (sound) by hitting it with a rubber fork or the like. Then you will be able to show that the vibrations (sound) make the air particle move. Have the following questions as your starting-point:

What happens to the air particle when the pan lid/cymbal/tuning fork makes a sound?

What happens to all the other air particles around that we don't "see"?

Pupils that don't perceive air as matter, but think of it as being "nothing" or a "vacuum", cannot develop the idea of sound needing matter in order to be spread. Another difficult concept to be aware of is that matter is not continuous, i.e. that there is a vacuum, emptiness, between the particles.

When the teaching sequence was tested, the pupils and the teachers in one of the classes had built a model of air (see figure 10.1). It consisted of a number of air particles, ping-pong balls, that hung a little apart and at different heights. The ping-pong balls were firmly taped to pieces of sewing thread, which in their turn were tied to matchsticks stuck in the bottom of a cardboard box. When the teacher placed a tuning fork among the air particles, it was obvious that the air particles were pushed in different directions.

Like other models, the model has its limitations, giving the teacher an excellent opportunity to discuss its advantages and drawbacks. Naturally, the particles in air are not white, nor are they fastened to threads. The distance between particles in air is in the order of 10 times the diameter of the particle. Nor does the model show that particles in air (and other gases) are constantly moving at high speed until they collide with other particles, and further that they move in every possible direction. It is also entirely empty between the particles.

Figure 10.1. A simple particle model of air, in which each ping-pong ball represents one air particle. The illustration on the right shows an enlargement of part of it. (N.B. One of the drawbacks of this model is that the particles are so close together that the distance better represents the one that applies to liquid substances. One more drawback is that no uniform air particle exists. See also section 4.1).

No gas – a vacuum

In space there is, essentially, a vacuum and the same applies to the moon. The moon's power of attraction is so small (which, in turn, depends on the fact that the moon is small) that it is not capable of keeping any atmosphere. Suggestions for assessment questions (written questions) can be:

> Is there sound in space?
> or
> Can you talk to each other on the moon?

One possible follow-up of these questions could be to quite simply simulate space (the atmosphere of the moon) i.e. test if sound can be transmitted without air particles, i.e. in a vacuum. It's an exciting experiment, but, of course, the teacher must have access to a vacuum pump! A ticking clock, a ringing cell-phone, or the like, is put into a vacuum pump and the air particles are sucked out. (Put a piece of foam between the clock/cell-phone and the bottom of the pump to avoid the sound being transmitted that way. You can also hang the clock/cell-phone up by using a piece of sellotape). When carrying out this experiment there is the risk that the pupils think that "the vacuum takes away the sound" if the pupils don't conceive that air is "something" and that the vacuum is the lack of this "something".

The testing of the teaching sequences showed over and over again that pupils often attach exactly the same meaning to the concepts of air, oxygen and gas. One recommendation is therefore to let the pupils think about and sort out what the different concepts stand for.

In order to assess how pupils think about the transmission of sound in air, there are useful questions in the problem collection. See “Appendix-overview” part 3, where there are references to a number of appendices under the headings “Vacuum” and “Air”.

Transmission via liquid substances

It is naturally simplest to use water in order to exemplify transmission through liquids. The pupils must first write their own hypotheses about the question:

Can sound be transmitted in water? Explain your answer.

Then they can discuss their hypotheses in smaller groups and then try to design one or more experiments in order to test their hypotheses. The pupils have probably got many ideas, and this is maybe quite sufficient. Before the pupils get started they should show the teacher what experiment they intend to do.

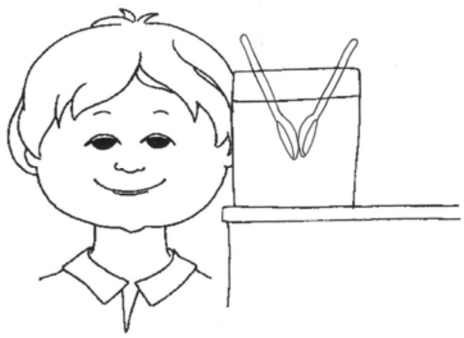
Those pupils that have a bath at home can take the opportunity to test different experiments when they are having a bath! Or why not go the swimming baths with the whole class? In the trial teaching period one class visited the swimming baths during a sports lesson, and they had been given the task of finding out if sound could be transmitted in water. They carried out various tests, including amongst others one where one of the pupils knocked on the pool ladder while the rest tried listening under water.

In the trial teaching sequences, it was seen that the pupils, as a rule, think that sound can be transmitted in water, but many pupils believe that this is due to the presence of air or oxygen in the water. One way of challenging this opinion is by getting them to test whether sound transmission can take place through several kinds of liquids other than water. Experiments can be done with water and e.g. cooking oil and ethanol. Furthermore, experiments with different liquid substances make it easier for the pupils to build up a general theory of transmission of sound in liquid substances.

The pupils first write hypotheses about the question:

Can sound be transmitted in water, cooking oil and ethanol?
Why? Why not?

Fill three similar beakers, metal tins, or something similar, with the same amount of water, oil and ethanol. The pupil presses her/his ear against the beakers/tins one by one, while covering the other ear to shut out any sound from her/his surroundings. Another pupil knocks two spoons together under the surface of the liquids in the tins. Listen carefully! What liquids can transmit sound? Pupils gladly tell how well or how fast the sound is transmitted. However, you cannot prove this with these experiments. The aim of these experiments is *only* for them to be able to test if sound can be transmitted or not.



Liquids are also built up of smaller parts. We can say that water consists of water particles, oil of oil particles and ethanol of ethanol particles. Sound vibrations can be transmitted through these substances by the particles "bumping into" each other.

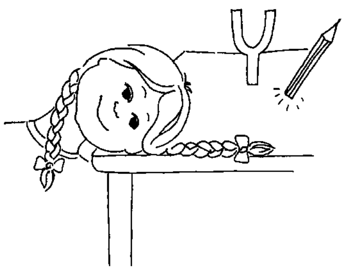
Transmission via solid substances

Experience shows that pupils gladly bring up the subject of the speed of sound even in experiments with solid substances, but it is also impossible in these experiments to decide what substances transmit sound faster than others. The aim is *only* to give the pupils the opportunity to test whether sound can be transmitted via these materials or not. We can use our little particle theory and say that wood is composed of wood particles, iron of iron particles, plastic of plastic particles etc.

Since it is a question of finding out which different substances, i.e. which material transmits sound and not which things transmit sound, it is a matter of focusing on the material itself. For example, the pupils can come to the conclusion that a table, a window, and a chair transmit sound. Then the question is what material in each of the objects they have tested transmitted sound, and in the example mentioned above it was maybe the wood (i.e. the table top, the seat of the chair and the window frame). The table top consists of wood which, in turn, is built up of wood particles.

The pupils think individually and write their own hypotheses. They then discuss in pairs or in a small group. What experiments can they make up in order to test their hypotheses? Before the pupils make a start, they tell the teacher what experiments they have thought of doing (also see section 10.1).

The following suggestions might also be useful.

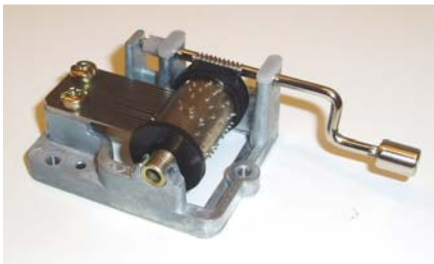


A pupil knocks on the table with a pen or something similar. Another pupil stands a bit away and listens with one ear pressed against the table. S/he should put her/his hand on the other ear.

If you have a tuning-fork you can strike one of the prongs with a rubber hammer so that it vibrates and gives off a sound. After that you can hold the stem of the tuning fork against the table (see picture), and carry out the experiment in the same way as the previous one.

Other simple experiments involve using the pen to knock on different materials such as iron (radiator), glass (window) and plastic (a big plastic box) etc. Listen in the same way.

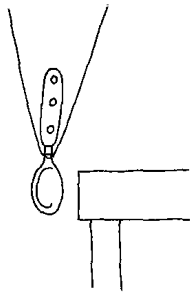
This experiment can also be carried out using small musical boxes (which has turned out to be popular in the trial teaching). A pupil can hold the bottom of the musical box against the radiator, the table or the plastic box etc. and play on it while another pupil/other pupils listen to it from a distance. The listening ear must be held close to the material in order for you to be able to judge whether the sound is being transmitted in this material or not.

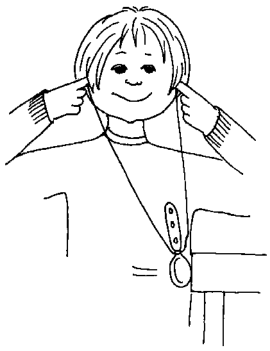


(When you play a tune with the musical box placed on the table and listen to it, the sound is heard much better than if you play a tune on it with it in the air. The pupils often observe this. This is because the table amplifies the sound, so-called resonance. The reason why this phenomenon is not dealt with here is that the focus is on sound transmission itself).

It is easy to test whether bones conduct sound. Bend your left arm and hit the elbow (your elbow-bone) gently with the tip of your finger and listen (via the air) what it sounds like. Do this one more time, but this time block your outer ear opening with the middle finger of your left hand. This experiment shows, in a simple way, that the bones in your arm transmit sound. If you have any bones from animals in your school, you can even use these to test the suggestions mentioned above.

Hang a metal spoon in the middle of a piece of string. Let the spoon swing so that it hits the edge of the table. Listen carefully!



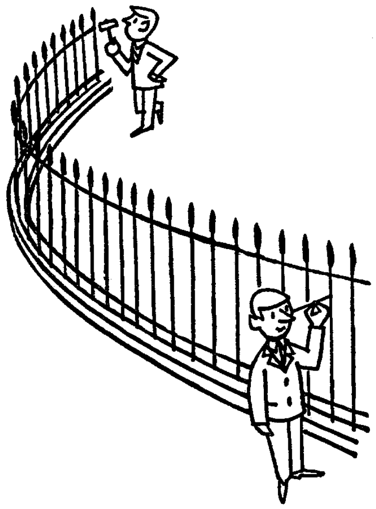


Then hold the ends of the string in your ears using your index fingers and hit the spoon, which is swinging from the string, against the edge of the table. Can sound be transmitted through the string?

What difference can you hear? (You can hear a sound similar to that from a clock, which is quite loud when you hold the ends of the string in your ears).

Your pupils can test transmitting vibrations via a string by doing experiments with home-made string telephones. Furthermore, they can test what happens when someone holds the string so that it cannot vibrate. A string telephone can be made with the help of two plastic mugs, two matches and a long (at least 5-metre-long) strong piece of string. You make a hole in the bottom of the plastic mugs, put a match inside each mug, push the string through the hole in each mug and tie it round the matches. Then you can test talking or listening in the mug when the string is taut (without it touching the side of the mug). The string must go straight out from the bottom. If the pupil holds the mug at right angles to the string, sound transmission will be worse if the string touches the bottom of the mug. What happens when the string slackens?

Why not do this experiment outdoors, but watch the sound volume! You can, for example, test if the sound can be heard through the iron fence when a person knocks on at a short distance away by placing your ear against the fence and listening.



When the pupils have done their experiments, they can jointly sum up the fact that sound can be transmitted in solid substances. Sound vibrations are transmitted by particles bumping into each other.

Now your pupils have done different experiments that show that sound can be transmitted through gases (air), liquids and solid substances. The collection of problems contains an appendix: “What substances can transmit sound?” Here the pupils can note down the combined results of their experiments. The intention is to clarify that all matter can transmit sound. Now the pupils have experience that can be used to build up a *general* theory of sound transmission.

Summary:

- **There is sound when an object vibrates.**
- **Matter in gaseous, liquid and solid substances transmit these vibrations.**
- **All matter can transmit sound.**

The collection of problems contains suitable questions for assessing how the pupils express their ideas about how sound spreads in solid substances. See “Appendix-overview” part 3, where there are references to appendices under the heading “Solid substances”. One of the questions deals with how sound can be transmitted through a closed door. N.B. Pupils commonly express that sound goes through wood because there are small holes, slits, etc, through which the sound passes! But do they think of the sound also being transmitted via the material in the door itself?

There is also a question about sound transmission in gaseous, liquids and solid substances that may be used: “The containers”. Let the pupils answer individually and then discuss the question in pairs or in small groups as usual.

10.7 How is sound transmitted?

Goal: To be able to describe the transmission of sound with the help of different models and reflect on the merits and limitations of the models.

During the testing of the teaching sequences, the great challenge has been shown to be the concept of sound waves. One successful way has been to really work hard at understanding this concept, first by letting the pupils "draw sound" and discuss statements/questions in groups where common everyday conceptions are emphasised (see chapter 7). Knowing something is just as much knowing why it is the way it as knowing why it is not another way. This part of the teaching sequence is one of the key components of all teaching about sound, and a carefully thought out strategy seems to be absolutely necessary. It is now time to sort out what concepts there are and how they are connected. Among the concepts or words that the pupils put forward are particles (molecules and atoms), air, oxygen, gas, liquid, solid, matter, vibrations, condensations and rarefactions, sound waves, or even other concepts and words.

How can you possibly "draw" something that you can't see? How do different groups of people solve this problem? The teacher draws two men on the board and says that one of them makes sounds in different ways and the other one listens. The pupils are placed in small groups (preferably in pairs) to get everyone to participate and to bring out as many pupils' conceptions as possible. They are given the following task and questions connected with it:

> Draw as many examples as possible of ways the sound can be illustrated.
>
> - When do you draw sound in the different ways shown?
> - Who draws sound in these different ways?
> - What are the advantages and disadvantages of drawing sound in these different ways?

The pupils' different ways of illustrating sound are listed on the board. They may be balloons (enclosing words), vertical or horizontal lines, circles, musical notes, dots, small packets of air setting off somewhere, waves etc. An example taken from the testing of teaching sequences of what the board can look like when the pupils have presented their suggestions is shown (see figure 10.2). Then the last three questions are discussed together. If the pupils have saved suggestions from earlier lessons (see section 10.6), they should take them out to add details to the picture of how they can think about sound transmission.

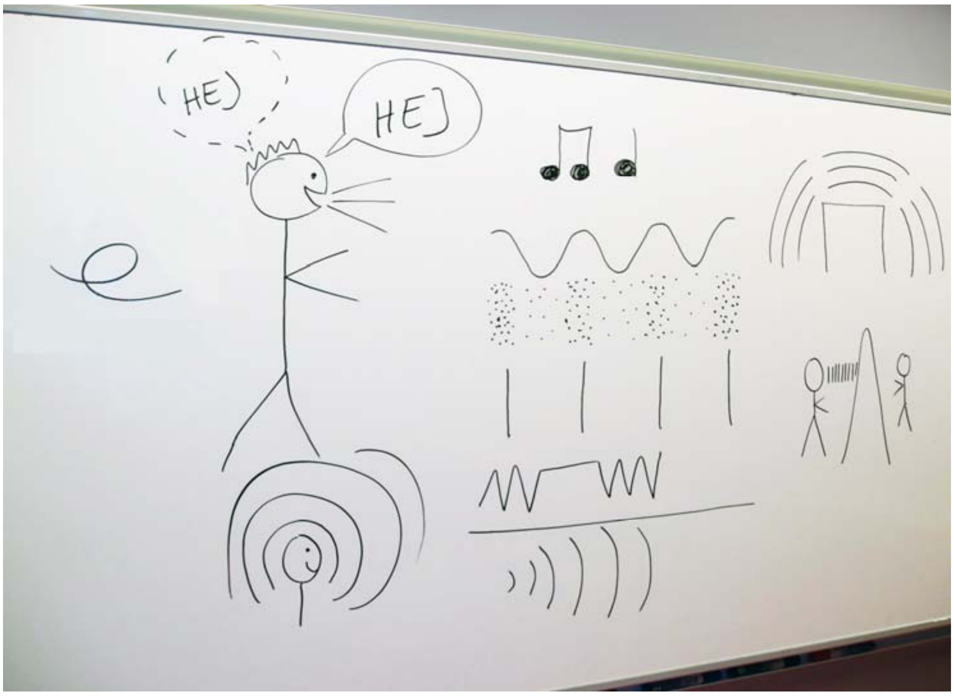


Figure 10.2. A table of pupils' different ways of illustrating sound obtained during tests of teaching sequences.

The pupils have previously been taught that sound arises by means of vibrations, and that vibrations are transmitted via matter in gaseous, liquid and solid substances. With the help of the particle theory, we say that sound transmission takes place through the action of particles colliding and "pushing" each other. This may, of course, be illustrated in different ways. The aim is to show that one and the same sound can be illustrated in many different ways, but that, basically, it is a question of one and the same thing anyway, namely that vibrations are transmitted via matter.

It is time to sort out what sound waves really are. If the pupils have not drawn any sound waves, the teacher him/herself has to be sure to draw them instead. Some pupils think, for example, that sound waves are something on their own that move in air and collide with the air particles (see chapter 7). Other pupils mix up the different meanings of sound waves altogether. The concept of sound waves is, however, a way that natural scientists and mathematicians have chosen to talk about and illustrate how vibrations are transmitted. The advantage of this way of illustrating sound waves is that it is easier to use a mathematical model when questions about sound are dealt with at a more advanced level. There are, of course, other ways of illustrating sound professionally. Musicians have agreed to draw vibrations as notes, and the cartoonist can use balloons to enclose dialogue. On the other hand, it is not so practical to draw heart sounds with the help of musical notes, the roar of a moped with the help of balloons, a greeting on a postcard with the help of sound waves or bird song with the help of the particle model. Regardless of the way used, it is still the transmission of vibrations via matter that we are talking about.

All the pupils' illustrations consequently deal with one and the same thing; that sound transmission takes places via air particles and that this can be illustrated in many different ways.

The collection of problems contains questions for discussion: "What ideas are scientific?" These challenge common pupil conceptions (see also chapter 7). The latter are freely mixed with scientific conceptions in the exercises. The question is: what scientific explanations could replace the wording used in the texts? The following everyday conceptions that are *not* compatible with the scientific conceptions may be found:

- sound waves are something material
- sound is transmitted in water only because there is air/oxygen
- there are bubbles with sound
- air particles hinder the transmission of sound
- water or walls hinder the transmission of sound
- sound is only transmitted through walls and doors if there is some form of narrow opening or hole that lets the sound through
- the term echo is used synonymously with sound transmission or hearing.

It is good to let the pupils work at their understanding of the different ways of illustrating or talking about sound in this way, or in another way (see also chapter 11). The teacher can choose one or more of the statements. The pupils have to discuss what ideas are scientific among the things said. N.B. It is, however, *absolutely* necessary for the teacher to follow up the pupils' discussions and help them to sort out the concepts!

10.8 The transmission of sound takes time

Goal: The transmission of sound takes time.

Many pupils have noted that they hear a sound some time after it has "arisen". They can, for example, find out what happens when a classmate stands a good distance away (more than 150 m) and hits two pan lids or something similar together (ear muffs!) You must be able to "see" when sound arises. (Sound transmission takes place at a speed of about 340 m/second. Light transmission, i.e. when the pupils see when the pan lids are hit together, is in principle instant as the speed of light is 300 000 000 m/second).

The pupils can also think about the time lag between lightening and the roll of thunder. The sound travels about one kilometre in three seconds. Count 101 (takes 1 second), 102, 103, and so on. The problem collection contains questions about the speed of sound. See "Appendix - overview" part 3, where there are references to a number of appendixes under the heading “The transmission of sound takes time”.

10.9 Why do sounds sound differently?

Goal: To know that sound has different properties: pitch (frequency) and sound level (sound volume) and to know that the transmission of sound takes time. The speed of sound in air is dependent on the medium but not the pitch, the sound level or how far the sound has travelled.

Let the pupils do experiments with objects that emit sound. A simple variant is to give each group of pupils an open tin/jar or open plastic box and a rubber band to slip over the opening of the tin/jar or box. The task is first to write a hypothesis and then to experiment:

1. How can you obtain a high tone and a low tone?
2. What is the difference between a high tone and a low tone?
3. What can you do to get the same tone but different sound levels?

The teacher follows up the pupils’ work and introduces the concepts of frequency and sound level (sound volume) (see sections 4.5 and 7.3). Models are used in natural science to visualise phenomena that are invisible. Previously particle models were used to explain the transmission of sound, but explaining the transmission of different frequencies, and particularly sound levels, with the help of particle models is possible but can be difficult. All models have limitations of some kind. The teacher can possibly content him/herself with discussing what the vibration that gives rise to different tones and different sound levels looks like. Physicists usually use a mathematical model to demonstrate these phenomena.

Humans cannot hear all sounds at all frequencies but only the ones between about 20 and 20 000 Hz. If there is a tone generator available, it is an excellent opportunity to let the pupils listen to different frequencies and test how high and how low a tone they can hear. It is also easy to show what the difference is between the concepts of sound level (loud/soft sounds) and frequency (high/low tones). The pupils can also use the tone generator to test if they can hear infrasound and ultrasound.

When the teaching sequences were tested, the pupils appreciated a discussion exercise in groups in which they learned about the hearing of different animals and at the same time worked on their understanding of the concepts of frequency (pitch), hertz (Hz), sound level, decibel, infrasound and ultrasound with the help of “animal cards”. The pupils were given the task of working out:

In what way do animals hear differently from humans?

Then the pupils received a number of cards with information on the hearing of animals. The text on one card at a time was read aloud, and the pupils discussed and made notes. When all the cards had been studied, first the group and then the whole class together summed up in what ways differently from humans, while bringing out, working on and clarifying the concepts mentioned above (see also chapter 6). They concluded with discussing suitable answers to the original question. Before the pupils start on this exercise, it would be good for them to know the frequency range within which humans hear. Material for the preparation of cards may be found in the appendix “Animals and hearing – copying material”.

For those pupils who are interested in learning more there is a more difficult exercise intended for working on in small groups, “Why do they call it sound waves?” It points out the connection between the particle theory and the physicists’ way of illustrating sound waves with the help of mathematical representation. A tone generator is required to solve the last two tasks. There is yet another exercise at this higher level of difficulty: “Do you hear the car traffic more easily on certain days?” This deals with the transmission of sound in air at different temperatures. In this exercise, sound is drawn with the help of curved lines, in other words, yet another way to illustrate the transmission of sound. There is an explanation in answer to the question that the pupils can get when they are ready with their suggestions. See appendix: “Explanation - Do you hear the car traffic more easily on certain days?”

After that let the pupils discuss and work on their understanding of whether the speed of sound is influenced by a change of frequency or sound level. Suggestions for discussion questions may be found in the following appendices in the problem collection: “The speed and frequency of sound”, discussion question no. 5 in “What ideas are scientific?” and “The mystery of the speed of sound”. (In the exercise “The mystery of the speed of sound”, the statements should be marked as follows: 1=false; 2=false, 3=true, 4=false, 5=true, 6=false.)

The teacher follows up the discussion questions when the pupils have finished their discussions. The understanding of the pupils can be assessed now or somewhat later by getting them to write answers to the following question:

Laura and John are standing hand in hand at one of goals at the football field waiting for Louis. Suddenly they catch sight of Louis walking nearby the other goal. Both call out at the same time. Laura has a higher voice than the male voice of John. Louis hears the calls, but which of them does Louis hear first?

In connection with this section, the pupils, in small groups, can carry out measuring experiments with a sound level meter (noise monitor). Start by letting the pupils tell about places where loud sounds (noise) may occur, and where they have experienced that it is almost silent. Then show them how sound levels can be measured with the sound level meter. Here is a suitable opportunity to discuss how the sound volume changes with distance because the sound spreads in all directions. For example, there is a difference between measuring the sound level of car traffic at a distance of 5 metres and at a distance of 100 metres, something that is important to keep in mind when carrying out their measurements.

Sound levels are measured in bels, or really in the smaller unit *deci*bels, dB. This may be compared with measuring distance in *deci*metres and volume in *deci*litres. The ear does not perceive all the frequencies we hear equally well. For example, we perceive sounds at lower sound levels at the frequency where speech lies. That is why we usually use what is known as an A filter, which registers sound levels in a way that imitates the ear's. Fifty decibels A (dB(A) is roughly the sound level in a normal home environment, a street with heavy traffic gives about 70 dB(A), next to the loudspeakers at a disco it can reach 120 dB(A), and a gunshot close to the ear 160 dB(A)! (See also section 4.5: The properties of sound).

The pupils can, for example, do work based on the following question:

Where might there be loud sounds in school or in the school's surroundings?

The pupils discuss in small groups where they think it might be suitable to carry out measurements, learn how to use the meter (e.g. set the meter to dB(A)), plan how the measurements should be done, show the plan to the teacher, and then carry out their measurements (see also section 10.1). Measuring and reporting are easier if they note down their observations and measuring values in a table. The headings in the table can, e.g. be Object/Place, Distance to sound source and Sound level (dB(A)).

The sound level measurements can also be saved or extended in section 10.12 when the pupils have worked with hearing.

10.10 How do we hear?

Goal: Knowing that vibrations that reach the ear make the eardrum and other parts of the ear vibrate. The vibrations are registered by the hair cells (sensory cells) that transform vibrations into electrical impulses. The electrical impulses are transmitted via the auditory nerve to the auditory centre of the brain, where the impulses are interpreted. We hear.

First a little follow-up of previous sections. Let each pupil think about the following by him/herself:

Why does the patient hear the dentist's drill better than the dentist does himself?

Collect in the individual answers. Let the pupils discuss the question in groups. Class follow-up and revision of the ability of air (gas), bone (solid) and water (liquid) to transmits sound.

Introduce teaching about the ear with, e.g., the question:

What happens when sound that reaches the ear turns into something that we hear?

Let the pupils discuss this in pairs or in small groups. After this the teacher and the pupils together can discuss how the ear and hearing function. The pupils will have many suggestions how the vibrations are transmitted through the ear. Suggestions for questions: "How are the air's vibrations transmitted to the ear?"; "How are the vibrations transmitted to the inner ear?" and so on. It is important that the teacher focuses pupils' understanding of the ear on the parts that transmit and receive vibrations instead of the pupils learning the names of the parts of the ear out of context. A functional ear model showing how vibrations can be transmitted via the different parts of the ear makes it easier for the pupils to understand. A model of this kind also helps the pupils to understand that impaired hearing can be caused by vibrations not passing through the ear as they should, and that this in turn affects the electrical impulses that the auditory nerves forward to the brain. The most common ear model available is, however, usually one that shows the anatomical structure, and this is an excellent supplement to a functional ear model. It is difficult for pupils to understand how small the parts of the ear really are when they look at ear models or the illustrations of the ear commonly found. Small natural-sized ossicles in plastic are available and have been shown to fascinate the pupils. Whether the teacher has access to ossicles in plastic or not, it is worth reflecting on their smallness and their position in the ear.

If no ear models or auditory bone models are available, the teacher should base lessons on an illustration of the ear.

Be prepared for the pupils asking a lot of different questions while you are going through this material. You will find a resumé of the basic facts in Chapter 5 about hearing.

The eardrum vibrates, the small ossicles vibrate, the oval window vibrates, the liquid in the cochlea transmits vibrations that are then registered by the small sensory cells – tiny, tiny hairs that are called hair cells – inside the cochlea. When the hair cells register the vibrations, they transform the movement (kinetic energy) into electrical impulses (electrical energy) that are sent via the auditory nerve to the brain. Not until the impulses are perceived and interpreted by the auditory centre of the brain do we hear.

It is of decisive importance that the tiny, sensitive hair cells function as they should in order to allow the vibrations to be transformed into electrical impulses. It is therefore important to *take care of your hair cells* so that your hearing works well! Many children and adolescents believe that it is not until loud sounds make your ears hurt that there is any risk of injury, but that is a myth. Here is a little story, drastic but comparable. If you suddenly injure your hand so badly that you lose a finger, it does not hurt you beforehand, but it does hurt you afterwards when your finger is no longer there. Then it's too late! It's roughly like this with your hair cells. You have to take care of them *before* your ears start hurting when loud music is played. Another myth is that music that you "dig" does not injure your hearing even if the sound level is high. Humans are sensitive to loud sounds to different extents, but you can never tell how sensitive you are in advance!

Let the pupils work up their own understanding of the ear's function with the following question:

Imagine that you hear a cat miaowing. Write a little story about what happens when the sound vibrations reach your ear and are further transmitted through the ear until you perceive that it is a cat.

One recommendation is to let the pupils use a picture of an ear, where the names of the different parts are given, as support. The task may be found in the problem collection: "How does hearing function?" During the testing of the teaching sequences, it was shown that those pupils who have practised formulating their understanding of the ear's function in this way, who had been allowed to discuss this with a classmate and then had some response from the teacher achieved very good results in the post-tests.

The appendix “How do we hear?” in the problem collection is designed to assess the pupils’ understanding of hearing. The appendix “The dog” may be used for assessment or the pupils may use it to revise how they think about hearing and perception.

Section 10.15 contains various argumentation exercises, and some of these would be very suitable to introduce here.

10.11 Where does the sound come from?

Goal: Understanding that having two ears helps you to decide the direction of the sound.

Begin by letting the pupils discuss the following question in pairs for a short while and then suggest answers.

What use are two ears to us?

Here follow suggestions for an exercise that can be done in pupil groups of different sizes. Place a pupil on a chair in the middle of the room and blindfold her/him. Ask her/him to put a finger over her/his ear. The rest of the pupils sit in a circle several metres from the pupil on the chair. The pupils in the circle make sounds with different objects (sound sources): peas in a little jar, a triangle, a pen tapping a metal can, and so on, so that the sounds come from different directions in the room. The pupil on the chair points to where the sound is coming from. Then repeat the experiment but let the pupil listen with both ears. Does the pupil notice any difference?

It is difficult to decide where a sound comes from with only one ear. When we listen with both ears, a sound from the right will reach the right ear a little before it reaches the left ear. This small time difference is perceived by our brain when the sound is interpreted, making it possible to decide what direction the sound comes from. The sounds that come from straight ahead of you or from straight behind you certainly reach both your ears simultaneously, but it is still possible to decide where such sounds come from thanks to the shape of the outer ear. The ears look different from the front and from the back, after all. We have got used to living with the outer ears that we have, and if a person injures them so badly that their shape changes a bit, it takes a while before that person has got used to listening with the new outer ears so that he/she is able to distinguish between sound from in front and sound from behind.

The exercise may close with the pupils discussing:

Can you think of examples when it's good to be able to know where the sound comes from?

10.12 How can you protect your hearing?

Goal: Knowing how to prevent hearing impairment.

Today children and adolescents are exposed to high sound levels (loud sounds) much too frequently. Adolescents risk impaired hearing and tinnitus when visiting, for example, a discotheque where excessively loud music is often played. The sound level is often turned up during an evening at the discotheque to reach a climax towards the end. Children aged 13-14 years or younger are affected more than adolescents between the ages of 18 and 20. The younger the children are, the more sensitive they are to high sound levels. WHO's recommendation for children up to the age of 12 is that the average sound level should be limited to 90 dB(A), and that the maximum level should not exceed 110 dB(A).

Adolescents often listen to music in headphones. According to current EU directives, the sound level in headphones should not exceed 85 dB(A) when a person listens to music for up to one hour.

There is not such a great risk of suffering hearing impairment as a result of classroom noise, except during music, PE and woodwork lessons, where the sound levels are considerably higher. Even in a school dining room or recreation room, the sound level may be so high that it causes hearing impairment such as tinnitus. (See also, chapters 1 and section 5.2).

Suggestion for a separate assessment question in which the pupils' understanding of the ear's function can be applied (see also section 5.2, Impaired hearing):

How can sound transmission in the ear be affected so that we do not hear?

The pupils discuss the question in groups and the teacher follows up.

Now it's time to do more work on hearing health and loud sounds (see chapter 5.2). Begin with the question:

> When, where and how have you experienced loud sounds in your everyday life?

The pupils write down their answers. Then they have to discuss and make suggestions how to avoid being harmed by loud sounds, i.e. how to manage to maintain their hearing health tomorrow, next week and next year.

Sometimes there is what is known as a Sound Ear in school, in the dining room and maybe in the sports hall. It is really an instrument that measures the sound level, and it is usually set up on the wall in exposed localities. With the help of the Sound Ear, pupils can test what the sound levels are when you whisper, talk, shout, play music, and so on. (Avoid excessively loud sounds!) How high is the sound level in the classroom? Perhaps the class would be able to borrow the Sound Ear for a week? The Sound Ear is an excellent device to use when/if a disco is arranged for the pupils at school. (Set the sound level to which the sound ear is to react, about 5 dB(A), on the back of the instrument. Until the set level is reached an orange light will show. Above that the red light will come on!)

If there are normal sound level meters (decibel meters), the pupils can investigate not only what objects cause loud sounds but also the premises or places where there is a risk of such sounds occurring (se also section 10.9). The pupils should discuss in small groups what they think is appropriate to measure, learn how to use the meter, plan how the measurements should be done, show the plan to the teacher and then carry out their measurements (se also section 10.1). Something to remember: if they, for example, choose to measure the sound level in the handicraft room when a pupil is hammering nails, they have to do the measurements by the person's ear to be able to know what sound level the person is being exposed to.

It is important for pupils to know how to use their MP3 players in a healthy way (see also chapter 1). If they want to measure the sound from the earphones of an MP3 player, they must place a plastic tube about 3 cm long by one of earphones to imitate the outer ear canal. The plastic tube prevents the sound from spreading in all directions. If this is not done, there is a risk that the meter will measure a lower level than the one the real ear is exposed to. One recommendation is to start this experiment by letting the pupil listen to a series of three favourite songs in the MP3 player and let him/her set the sound volume he/she prefers. Then measure what sound level is used. Please note that the quality of the sound level meter may vary and lead to some measurement errors.

Other ways of increasing the pupils' awareness of the sound level in the MP3 player is to ask them to make a note of what sound level they listen to when they are going by train, bus or car. Then they listen to the same sound level in a silent room. Often this sound level is experienced as too loud when there is no background noise.

The following anecdote is an example of what can happen when the pupils do their measurements:

> In the trial teaching sequence, some 10-year-old girls had planned to investigate sound in the handicraft room, sports hall and dining room. But they were unlucky – no lessons were taking place in either of the rooms, and there were no pupils in the dining room. Crestfallen, they went further. They saw some children playing outside the preschool buildings and they took the chance and went in there. A little 3-year-old girl was sitting inside the door playing with a blaring cuddly toy that she had brought with her from home. The girls were curious and measured the sound level by the child's ear. The meter registered 90 dB(A)! The girls were horrified and immediately informed the staff about their measurements. They also urged the staff to inform the child's parents. The girls' interest in toys that make noises, including their own small siblings' toys, was aroused, and they wondered about what responsibility a toy manufacturer really takes!

There are various types of devices for protecting your hearing, e.g. ear muffs or ear plugs. What experiences have the pupils of such things? When do they think they should be used? An excellent idea is to show different types of protective devices and let the pupils discuss in what connection they are appropriate. Many of them probably recognise the ear plugs of yellow foam plastic or similar, that protect hearing in an excellent way, e.g. at concerts. The foam plastic plugs dampen the sound substantially, but the sound quality deteriorates. That is why it is good to know there are also special hearing protection devices for music, which lower the volume without changing the quality (see section 5.2). Show these to the pupils by all means! This is so that they do not simply give up on ear plugs altogether when they aren't satisfied with the plugs of foam plastic. It's a question of preserving your hair cells!

There is a discussion exercise in the appendix that connects to hearing health: ”Tinnitus”. The exercise starts with each pupil forming an opinion about the given alternative actions by putting an X in the yes or no-box. Then they discuss one question at a time in small groups. Since the exercise contains controversial statements intended to *challenge* the pupils' thinking, it is important that the teacher follows it up with the pupils. For example, it is *directly inappropriate* if the pupils are led to think that “if you only listen to music you like, you won't get tinnitus even if the sound is loud” or “it's only if you get an earache from the loud music that there is a risk of getting tinnitus”. The “Tinnitus” can also be used for assessment of pupils' ideas.

10.13 The sound strikes different surfaces

Goal: Experiencing that a sound that strikes a surface of another material can be transmitted, absorbed or reflected.

What materials absorb sound?

The pupils discuss and make suggestions about materials that can be used to muffle sound, i.e. the kinds that transmit sound less well. They can make up experiments and test their predictions, or go round different premises, rooms, corridors or similar places to investigate whether sound is muffled to a small or large extent. What does it look like where the sound is muffled?

Porous materials with an uneven surface do not transmit vibrations as well as other materials. It can be difficult to explain why with the help of particle models, there being a risk that everything will become too complicated. (The particles collide in every possible direction and the regular movement dies out). It is sufficient that the pupils learn that there is material that absorbs sound.

Suggestions for follow-up questions. How is this kind of material used? Is there any of this kind of material in the classroom? At home? In other places?

Try to describe the properties of a material that absorbs sound well.

How can sound be reflected?

It has been shown that many pupils attach different meanings to the concept *echo* (see section 7.4), and it is now time to approach what meaning scientists attach to echo (see section 4.4). When the pupils know what is meant, it is time to look for places where echoes can occur. Many pupils have previous experience of echoes, and they can predict where it should be possible to hear an echo.

Hard surfaces, for example a cliff-face, reflect sound. Some vibrations continue on in the material, certainly, but many are reflected, i.e. “the vibrations come back”, and an echo occurs. We can hear the echo because it takes a certain amount of time for the sound to be transmitted, otherwise this would be impossible. There has to be 0.1 s between the moment the sound is emitted to the moment it returns for the human ear to be able to register the difference. As sound spreads out at a speed of 340 m/s, then it must move at least 34 m. This corresponds to the distance to and from the wall. Then the distance to the “echo wall” must be at least 17 m. If you are in a space where the sound is reflected forwards and backwards, you get echo effects without being so far away since the sound is reflected back and forth several times. Many people have perhaps experienced how lovely their singing is in the bathroom? The pupils can look for spaces where they get echo effects.

What is the difference between material that absorbs sound and material that reflects it?

Why not let the pupils make suggestions how a cosy corner can be furnished to ensure a pleasant sound environment?

You can investigate how sound is reflected by using a metal bucket or a plastic bucket or both. You place the bucket over your head and sing or speak. “What does it sound like inside the bucket compared with outside it?” “Why is there a difference?”

The sound is reflected inside the bucket, and the character of the sound is affected by the echoes that occur inside the bucket. The metal bucket has a different sound from the plastic one, as it reflects the sound better, and because the plastic absorbs the higher frequencies so that the sound has another tone. Singing in the shower is like singing inside the metal bucket because the bathroom walls are good sound reflectors, and the small space creates echo effects when the sound reflects backwards and forwards.

10.14 Technology

Goal: The pupil should

- **be able to design and to build an instrument that produces sound and describe its function**
- **be able to show how the pitch (frequency) and sound volume can be changed**
- **be aware of the phenomenon of resonance and where it arises in the instrument.**

The school subject technology gives good opportunities for pupils to apply and develop their knowledge about sound. In Sweden there are relevant goals to attain both in year 5 (age 12) as well as in year 9 (age 16). One goal to attain in year 9 is that the pupil should be able to build a technical construction using their own sketches, drawings or similar support, and describe how the construction is built up and operates. In this sequence this goal is applied when constructing instruments. Furthermore this construction is connected with the use of knowledge about sound and sound transmission (see chapters 4 and 7).

During the test of this teaching sequence the pupils were asked to design and construct an instrument. The requirements, apart from a good design, were that 1) it should be possible to play at least three different notes, 2) it should be possible to vary the sound volume and 3) the sound from the instrument should be amplified by way of resonance. The pupils should be able to explain how and why there were different notes (frequencies) and different sound volumes and, further, should be able to discuss the phenomenon resonance.

10.15 Being aware of your standpoints and being able to argue.

Goal: The pupil should

- **have insight into how to build up the argumentation in a common everyday environmental and health issue concerning sound with the help of personal experience/s and scientific knowledge**
- **practise formulating his/her own opinions on the basis of both knowledge, rational thinking and ethical considerations**
- **be able to discuss the importance of a good sound environment.**
- **train him/herself to be aware of his/her own standpoints.**

People have to take many personal and ethical standpoints about scientific issues in everyday life. Pupils encounter not only a mass of information via the Internet, TV, the press or other media, but also from their schoolmates and other people in their surroundings. It is not easy to have a critical attitude towards this flow of information, particularly in sensitive issues. It requires both an awareness of the standpoints one has oneself and on what grounds these are based. It is important to raise not only the quality of young people's understanding of the process of argumentation in general but also their competence in arguing on the basis of scientific knowledge.

Another aspect is how the knowledge of natural science in society has grown and is growing thanks to the argumentation that goes on constantly among different researchers (see section 10.1).

The pupils now have all the requirements for understanding how sound originates and is transmitted through different materials. They also have all the requirements for understanding how sound is transmitted through the different parts of the ear and is transformed into electrical impulses that proceed to the brain. Not until the impulses are interpreted by the brain do we hear. They also hopefully know that impaired hearing may mean that the sound transmission is not functioning as it should, and this, in its turn, depends on several different things. In today's society, adolescents are frequently exposed, or frequently expose themselves, to loud sounds. So are they capable of applying what they have learned by taking active steps in their daily lives? A good start is to be aware of one's choices and being able to distinguish between scientific knowledge and opinions.

A number of difference exercises have been designed to offer the pupils the opportunity to work up their knowledge further and stimulate them to acquire skills that promote their development into responsible people and members of society. The exercises are based both on scientific knowledge and everyday conceptions found among pupils, adolescents and the general public. Solid knowledge and understanding are a product of knowing why certain ideas are correct and of being able to judge why certain ideas are wrong.

This part of the teaching sequence is important since the pupils are given the opportunity to refine their stand-point in, for example, issues in everyday life where they can decide how to react in situations with high sound levels The exercises also give the pupils opportunities to deepen their knowledge about sound levels and health when working with the content.

Below are suggestions for many different exercises and tasks. It is not intended that the pupils should do all of these, but that the teacher should choose items that are appropriate to the level of the pupils. Some of these exercises could easily be done earlier in the sequence, e.g. in connection with section 10.10.

Science and Opinions

Every day the pupils encounter a mass of information that they are consciously or unconsciously influenced by. It can be via the news, entertainment or advertising programmes on TV or the radio. It can be via the Internet, books, newspapers or advertising brochures. It can be song texts in music that they like, or what friends, parents and other people say to them.

What can we trust out of everything we hear? It can be difficult to know, and it is important to be able to sort out what's what amongst all the information we receive. What is based on scientific knowledge, and what is based only on what we think, i.e. our opinion or standpoint? This question is so difficult that many adults are unable to handle it either. The exercise may thus be seen as an introduction to developing this competence, i.e. that the pupils on the whole will be able to distinguish between scientific knowledge and opinions. In this exercise, like in everyday life, you can find statements that look like pure opinions but are nevertheless based on scientific knowledge, and the vice versa!

The purpose of this exercise is to train the pupils' awareness and competence to

1) distinguish between scientific knowledge and other information.
2) take decisions that concern oneself and others on the basis of scientific knowledge.
3) to distinguish ethical and moral standpoints from other types of standpoints.

The pupils are given a bundle of cards displaying statements of various kinds. Some of the statements are based on the scientific knowledge we have today, and others are based on opinions. There are also pure quotes from the pupils themselves, which come from the National evaluation of the Swedish compulsory school 2003.[7] Copy all the pages with the statements, preferably sorting them into sets of different colours, and cut out the statements. Bundle these together according to colour and let each group of 2- 5 pupils work with a bundle.

The pupils start by laying out the two sorting cards. ”Scientific knowledge” and ”Opinions” well apart. Then they go through one statement at a time and discuss whether it contains scientific knowledge or opinions. If they think that the statement does not belong to either category, they put it on one side for the moment, with the intention of discussing the content later or when the teacher follows up the exercise with them.

a. Discuss what they think about the statement as such and
b. Discuss whether they think the statement is based on scientific knowledge or ”opinions”, or on both. If they consider that the statement belongs to both categories or alternatively to neither, they put the card on one side for the present.

There is no exact answer to all the statements; the evaluation depends on how the text is interpreted. The intention is that the pupils’ discussions should contribute to further scientific development and greater awareness of how to distinguish scientific knowledge. The aim is not that the pupils should come upon what the “right” or the “wrong” answers are. One problem with the exercise that came to light during the testing is that pupils prefer to sort the cards as quickly as possible, thereby missing the point of the exercise. Therefore, it should be pointed out to the pupils that it is the *discussions about each card* that are the important thing. The teacher needs to follow the work in each group of pupils so that they keep within these limits. This exercise has been very much appreciated by pupils of all ages who have participated in the testing of the teaching sequences.

Since the exercise contains controversial statements intended to challenge the pupils’ thinking, it is important that the teacher follows it up with the pupils in a suitable way. For example, it is *directly inappropriate* if the pupils are led to think that in future it will be enough to lower the bass in loud music if they want to protect their hearing (see also appendix “Science and Opinions - Comment material”).

In the follow-up, both ethical and moral aspects can be taken up in connection with this exercise, e.g. “Those who don’t want a loud sound volume at a disco can go home”. If the sound level is high but does not exceed the prescribed limit all the same and a person is hypersensitive to sound (see section 5.2), should the sound level be lowered or should the person go home?

The statements may be found in the appendix: Material for producing cards for the exercise ”Science and Opinions – card copying material”. Teachers will also find supporting material in the form of comments: “Science and Opinions - Comment material”.

The sound level at discos

Below you will find two different ways of working with this task. The teacher can choose between alternative 1 and 2.

Alternative 1

The aim of this exercise is to train the pupils in taking a standpoint and in formulating plenty of arguments for and against a standpoint concerning the sound level at a disco.

First of all each individual pupil must make up his/her mind and motivate what he/she would do with the sound volume at an imagined disco. The teacher introduces the task by reading a text about a school disco aloud. Then the pupils have to make up their mind, without looking at each other, about what they would like to do with the sound level in a situation such as the one described in the text and state their arguments for and against this standpoint.

The exercise continues with the pupils judging the quality of their arguments. Do they only use opinions? Can they present arguments with the help of their subject knowledge? Are they aware of arguments that oppose their own standpoint? To do this, place the pupils in small groups in which each and every one states his/her choice and arguments. The next step is that the members of the groups go through which of the stated arguments are probably based on scientific knowledge (shown by underlining them) and which are only based on opinions. Then the whole group tries together to discover as many new scientific arguments as possible for and against different standpoints. When this is finished, the exercise is concluded by each pupil supplementing and improving the quality of his/her own arguments, both scientific and other, for and against the standpoints made. It is important for the individual pupil to formulate arguments both for and against his/her standpoint. One is allowed to think what one likes, but one has to be aware of what arguments there are for and against the standpoint and be able to argue with the help of scientific knowledge.

Appendices: “The sound level at the disco – Verbal introduction” and “The sound level at the disco – pupil’s sheet”.

Alternative 2

A simpler alternative exercise is to let the pupils make up their own minds about the arguments that pupils in school year 5 formulated in the national assessment of the Swedish 9-year compulsory school in 2003.[8] First the individual pupils make up their minds about the different alternatives, then they discuss them in groups. The exercise is concluded by the teacher following up the pupils’ discussions. The basic ideas stated in alternative 1 are also applicable in this exercise.

Appendix: What do the pupils think?

It’s up to me to decide

The purpose here is to raise the pupils’ awareness of the fact they themselves are constantly making their own choices that affect their and other’s lives.

The exercise starts with each pupil forming an opinion about the given alternative actions by putting an X in the appropriate box. The intention is that the alternatives given may be interpreted in various ways, as they are to be used as a basis for discussion later on. Then they discuss one question at a time in small groups. *Each pupil* in turn states her/his opinion and gives the reasons underlying the choice of this alternative (argumentation exercise). The group’s task is to try to reach a consensus (shown by putting a ring round the chosen square) with the help of the different arguments that have emerged during the discussion. If they do not reach a consensus, they simply conclude that they are not in agreement. The purpose of the exercise is to give the individual pupil the opportunity to work out what she/he thinks and why, and to refine his/her standpoint.

An alternative way of working with this task is for the teacher to read out each option for action aloud to the class. The pupils have to demonstrate if they choose or do not choose a particular option or perhaps choose “don’t know”, as follows. Those who agree stand up and those who do not agree remain in their chairs but raise both their arms straight up in the air. The ones who are uncertain remain sitting and firmly cross their arms. The teacher does not continue until all pupils have clearly indicated their standpoint.

One question to let the pupils think about when the exercise has been completed is how honest they have been in their answers. Have they dared to air their opinions if few or no other classmates think the same? This can be a sensitive topic for the pupils to discuss, but it is important that each and every one thinks about what his/her own opinion or standpoint has been based on. How honest does one dare to be with oneself?

Appendix: ”It´s up to me to decide”.

10.16 Assessment

Since formative assessment permeates the whole teaching sequence, both pupil and teacher are likely to have a good understanding of what each pupil has learned. One recommendation is thus to finish with a post-test, i.e. the same test that was used in the pre-test, “the teacher’s help”. The teacher can use the results both to assess how much the pupils have learnt from the teaching sequence and to reveal any ways in which the teaching sequence may be improved for future use.
Another recommendation is to let the pupils practise self-evaluation by comparing what they have answered on the post-test with their own answers on the pre-test. This might help to improve their self-confidence and motivation. Then each pupil

should think out/formulate *what* he/she has learned. In this way the pupil him/herself can evaluate whether he/she has fulfilled the goals set up_and the criteria for marks.

This was done a couple of times during the testing of the sequence, and several times pupils were really surprised when comparing answers in post- and pre- tests in this way. When looking at the pre-test one pupil exclaimed:

> Did I really write that (giggling)?

11. EXPERIENCES WHEN TESTING THE TEACHING SEQUENCE

11.1 Introduction

The suggestions for teaching found in this compendium of ideas are the result of a number of tests carried out by professionally active teachers and their pupils. The research results obtained in the tests have been continually woven into this manual when it has been revised. Finally, we will present a short summary of some experiences of a more general character.

11.2 Formative assessment

Formative assessment is the part of the work that has had by far the most important impact on the teachers' own learning. It may be said to have been the key to another approach to teaching and pupils' learning. There have been lessons in which the teacher has been convinced that the pupils have developed a good understanding of the content treated, but when the pupils' understanding has been assessed it differs from what was expected. Formative assessment has opened our eyes to the fact that many pupils are not at all where the teacher believes them to be, which in its turn has given the teacher the opportunity to do more work on the content and from other points of entry.

One teacher's comments on formative assessment on two different occasions are given below:

> The thing that I myself learned most of all today is that this teaching method feels fantastically good. I had the chance to explain to them today that the purpose of the pre-test was that I wanted to know what they already knew and what they needed to learn – and that my "final questions" would have the same purpose. What have they understood? Then a boy said "So you mean that if everyone had been able to answer all the questions perfectly then we wouldn't have done this?" Then I said that he was right – because we are here, of course, to learn new things. He didn't believe me……Ugh, what does that tell you about school! I've never had such a good preview of pupils' understanding before – even though I have given a few pre-tests, they have not been so rewarding.

> When I did lesson 2 with the other class I discovered, in the lab books in other words, that their understanding was not at all the same as the first class's. This may be explained as follows: the first lot was split into two halves and had a 60-minute lesson, while the other one had to be a whole class for 40 min. So I had to skip the bit where they got different things to make sounds with themselves while thinking about why sound makes things

> move. This task seems to have given the first class a better chance to check that sound is created by means of vibration – which is then transmitted. I learned: There is no short-cut to deeper understanding – I probably thought that it was alright to "hasten a little" – that that exercise wasn't so important. But in combination with a whole class and a shorter time for their reflections and questions, I got my punishment. I´ll have to take it with them on Monday.

Another teacher writes the following about formative assessment:

> With this formative assessment the pupils have been forced to reflect in practically every lesson. I have made assessments in several different ways, orally, in writing, individually or in groups. But the conclusion is that no one has "got away" by hiding behind anyone else. I had no written test or exam on this, only testing them on their homework. To my surprise, the pupils accepted that it was enough if they showed what they could do in the lessons.

A variant of formative assessment that teachers have developed in the course of their work is "today's question", which turned out to be popular with the pupils. Towards the lesson the teacher formulates a question for the pupils to test their understanding of the content they have been working with. The question has often been linked up with the pupils' everyday life, but the content has been placed in another context than the one just dealt with. The pupils have answered the question individually, the teacher has read and, when time has permitted, given an individual response to the question. The reaction has been positive, i.e. the pupil has had his/her learning confirmed, been asked to clarify something, received a counter-question, and so on, but the teacher has avoided criticising or doubting the pupil. The result has been that the teacher has obtained a very good picture of where the pupils stand, feedback on teaching and ideas about planning the lessons ahead. One example of today's question is given below:

> The lesson yesterday began with a formative question: *What happens to the sound from a moped till you hear that it is a moped that is making the noise?* The pupils answered in their writing books. After reading the pupils' answers I feel there are certain things I have to clarify and go over once again.

The teachers conclude, going by the results of pre- and post-tests, that the pupils who have been allowed to formulate and work up their understanding of a phenomenon in writing or orally appear to have a better understanding than the pupils who have not had the chance to do this when dealing with that phenomenon. With increased insight into the impact of small group discussions on the pupils' learning, the teachers have gradually changed their approach to the pupils in this connection. Previously they wanted to go in and control the subject content in the discussion, but the focus nowadays is more often on stimulating the individual pupil to formulate his/her understanding, on listening to what conceptions there are, and on letting the pupils discuss them. In the beginning there might be some difficulties when changing this way of working. As an example one teacher writes:

> Whether the pupils learned something in the discussion exercises I believe depended a lot on their attitude. If you think you can learn by talking with each other, you learn more than if you sit and think that the teacher might just as well say how things are direct. This applies to all subjects and areas and is not specific to our sound project but even more obvious in, e.g. mathematics. What should we do about it? How do we get the pupils to believe that they can also learn by discussing things with each other?

Two of the teachers said spontaneously, independently of each other in interviews following the teaching, that more pupils achieve the goals when teaching is based on formative assessment. The teacher sees clearly what they have understood and not understood and can therefore help the individual pupils right from the start. The pupils also know that the teacher is continuously finding out what they have learnt, which has helped the pupils to be more active in asking questions. The following quotation from a teacher may serve as an example of this:

> One of my pupils said today that it’s just as well to ask from the beginning because you check anyway if I have understood.

11.3 Communication strategies

A common method of communication in the classroom is for the teacher to ask a question, the pupil to give an answer, and then to have some kind of feedback.

One challenge for the teachers in whole class situations has been to make different pupil conceptions, regardless of whether they are scientifically correct or not, the content of the lesson (see, e.g. section 10.7). This might concern, for example, how the pupils think about the transmission of sound in water or the meaning of a concept, such as, e.g. a sound wave. The teacher does not assess, nor is he/she intent on the pupils guessing what answer he/she wishes to have but is only interested in emphasising the different conceptions that the pupils have and letting them discuss them under his/her guidance. This teacher role is difficult and requires a considerable amount of practice. This communication strategy is also a variant of formative assessment and also aims, with its ventilation of different conceptions of a phenomenon, to improve the pupils’ learning.

Sometimes the teacher has to take command, for example, when introducing a concept, and when following up or summarising the work that has been done. During the testing of the teaching sequences, it sometimes happened that the teacher was either so concerned about letting the pupils give their answers to a question posed, or expected to get a desired answer that was not forthcoming, that he/she failed to tie up the threads.

11.4 The language of the professional teacher

When the pupils’ pre- and post-tests and other written work were assessed, the teachers concluded again and again that the words and concepts that the pupils used were the result of which teacher they had had. The teachers recognised their own choice of words in the pupils´ answers. Some pupils appeared to have understood a phenomenon but lacked the words to express themselves. The more the teacher used well-defined concepts and the more consistent he/she was in the way he/she expressed them, the clearer and more scientifically correct were the pupils’ written explanations. Naturally important in this connection is how much the teacher is aware of the everyday conceptions that the pupils often have and which ones can be problematic and need dealing with. Language is therefore a very important link in understanding the world around us from the point of view of natural science.

At one of the assessment meetings one teacher spontaneously burst out:

> Help, how shall I dare teach again! How enormously important I am!

11.5 Pupils’ learning

The research that was described in chapter 7 shows that it is important for the pupils to understand that sound arises when an object vibrates, and that these vibrations are transmitted via matter, for example air particles. In an early version of the manual, the concept of sound waves was not particularly well developed. Despite the fact that teachers had not taken the concept as a starting-point, many pupils tried, nevertheless, to use the concept in formative assessment or in post-tests but with all sorts of different meanings. Some pupils thought that sound waves were something material that moved around in the air and collided with the air particles. An analysis of the pupils’ answers has shown that the pupils’ conceptions have come closer to that of natural science when the concept of sound waves has instead been emphasised and studied thoroughly (see section 10.7).

Before the lessons many pupils thought that sound is transferred in water via oxygen or air. This conception does not disappear by itself either but needs to be worked on and challenged, a point that has been emphasised in connection with the revision work.

The pupils’ previous knowledge of hearing lay at a much lower level than the teachers had expected. Many pupils did not think at all that sound is transmitted through the inner parts of the ear but believed that sound goes directly to the brain. They were almost completely unaware of the ear’s function, and that the ear contains sensitive internal sensory cells. For this reason, this has been brought out and emphasised in the suggestions for teaching. After the lessons, the answers are full and varied and indicate quite another understanding.

11.6 The pupils' attitudes

The pupils' attitudes to questions of health connected with sound have been evaluated before and after teaching. It has concerned, for example, their awareness of sound levels when listening to different types of music or their attitude to the use of hearing protection. Post-tests have shown that pupils' attitudes have been influenced in a direction that is positive to hearing health. However, the testing sessions show that pupils who have worked with discussion exercises linked with attitude questions show a more health-promoting attitude to sound and sound levels than the pupils who have not done such exercises.

On one of the post-tests the pupils answered the question: "What use do you have of the things you have been taught about sound, hearing and health?" Here follow examples of typical answers that the pupils have given:

> You should take care of your hearing till you are old.
>
> I've actually learnt a lot. I thought I knew everything, but I didn't. Now I know what I expose my ears to, and I can therefore change that. I'm fully aware of what can happen if you do this or that. The knowledge that I've got now I can extend. It's an important topic that everyone should know more about for their own good.
>
> I have learnt how sensitive our hearing is. I still listen to loud music but I am aware of the consequences.
>
> At the disco, rock concerts or when I listen to music.

The pupils' answers show that the pupils' awareness of their own hearing health has increased, which is in its turn a prerequisite for their being able to choose healthier courses of action in future. However, we know nothing about how the pupils will act in reality. One aspect is being aware and having knowledge, but other factors, such as self-image, previous experience, social norms and the pupils' own interpretations of how he/she should be/behave, affect the choices made in questions concerning loud sounds in real life.

NOTES

CHAPTER 1

1. Chung, Des Roches, Meunier and Eavey, 2005; Hörselskadades riksförbund, 2007; Vogel, Brug, van der Ploeg and Raat, 2007; Vogel, Brug, Hosli, van der Ploeg and Raat, 2008.
2. Holgers, 2003.
3. Socialstyrelsen, 2005.
4. AMMOT, Artister och Musiker Mot Tinnitus, 2002; Olsen Widen and Erlandsson, 2004a, 2004b.
5. Olsen Widen and Erlandsson, 2004b; Socialstyrelsen, 1996, 2003; Vogel, Brug, Hosli, van der Ploeg and Raat, 2008.
6. Berglund, Lindvall, Schwela and Goh, 2000.
7. Arbetsmiljöverket, 2005.
8. Vogel, Brug, Hosli, van der Ploeg and Raat, 2008.
9. Vogel, Brug, van der Ploeg and Raat, 2007; Vogel, Brug, Hosli, van der Ploeg and Raat, 2008; Socialstyrelsen, 2005.
10. Berglund, Lindvall, Schwela and Goh, 2000.
11. Konsumentverket, 2005.
12. Arlinger, Uhlén, Hagerman, Kähäri, Rosenhall, Spens et al., 2007; Socialstyrelsen, 2003.
13. Berglund, Lindvall, Schwela and Goh, 2000; Socialstyrelsen, 2005.
14. AMMOT, Artister and Musiker Mot Tinnitus, 2002; Olsen Widen and Erlandsson, 2004a, 2004b.
15. Kähäri, 2002.
16. Kärrqvist and West, 2005.
17. E. Widén, 2006; Kärrqvist and West, 2005; Vogel, Brug, Hosli, van der Ploeg and Raat, 2008.

CHAPTER 3

1. The sources used when writing the historical summary were Brown, 1991; Caleon and Subramaniam, 2007; Eshach and Schwartz, 2006; Hunt, 1978; Mcginnis and Oliver, 1998; Pappas, 2000; Rossing, 2007; Sundin, 1991; Westerlund, 1995.
2. Quotation from Hunt ,1978, p. 19.

CHAPTER 4

1. Part of the content concerning a particle theory of matter is derived from Andersson, 2005.
2. AMMOT, 2002.

CHAPTER 5

1. Rosenhall, 2005.
2. Lagercrantz, 2005.
3. Perkins and Kent, 1986.
4. Quotation from Arbetslivsinstitutet Väst, 2004, p 18.

CHAPTER 6

1. The sources used were Nationalencyklopedin, 2000 and University of Rhode Island, 2005.
2. Perkins and Kent, 1986.

CHAPTER 7

1. Watt and Russel, 1990
2. Asoko, Leach and Scott, 1991, 1992.
3. Ibid.
4. Piaget and Garcia, 1974.
5. Mazens, 1997, 2003.
6. Mazens, 2003.
7. Boyes and Stanisstreet, 1991; Watt and Russel, 1990.
8. Eshach and Schwartz, 2006; Mazens, 1997, 2003; Watt and Russel, 1990; Wittman, Steiberg and Redish, 2003.
9. Mazens, 2003.
10. Asoko, Leach and Scott, 1991, 1992.
11. Mazens, 1997, 2003.
12. Eshach and Schwartz, 2006.
13. Ibid.
14. Maurines, 1993 and results of the studies conducted in connection with the production of this manual.
15. Linder 1992, 1993; Linder and Erickson, 1989.
16. Eshach and Schwartz, 2006; Watt and Russel, 1990 and results of the studies conducted in connection with the production of this manual.
17. Watt and Russel, 1990.
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30. Boyes and Stanisstreet, 1991; Driver, Squires, Rushworth and Wood-Robinsson, 1994; Tiberghien, 2000.
31. Driver, Squires, Rushworth and Wood-Robinsson, 1994.
32. Maurines, 1993.
33. Ibid.
34. Leite and Afonso, 2001.
35. Leite and Afonso, 2001; Linder 1992.

CHAPTER 9

The chapter is based on Black and Wiliam, 1998, and also on Black, Harrison, Lee, Marshall and Wiliam, 2003.

CHAPTER 10

1. Barnes and Todd, 1977; Mercer, Daws, Wegerif and Sams, 2004; Treagust, Jacobowitz, Gallagher and Parker, 2001.
2. Newton, Driver and Osborne, 1999; Osborne, Erduran and Simon, 2004.
3. Newton, Driver and Osborne, 1999.
4. Czerniak, 2007; Venville, Wallace, Rennie and Malone, 2001.
5. Millar, Leach, Osborne and Ratcliffe, 2006.
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APPENDIX – OVERVIEW

The appendix is divided into three parts.

PART 1
Preliminary time schedule

This part contains a basis for planning, and there are also preliminary suggestions for the time needed for each activity. This is, of course, dependent on the goals set up.

Appendix: Preliminary time schedule

PART 2
Self-assessment – pupils

This part could be used for the pupils' own meta-reflections concerning his/her own learning in relation to the goals set up. This is used in discussions with the teacher.

Appendix: What have I learned?

PART 3
A collection of problems,, questions for discussion and questions for formative assessment - overview

This part contains an outline of questions that could be used for pre- and post-tests or for formative assessment. Some of these questions are intended for group exercises and are marked *. In some exercises, it is important that the pupil works things out for him/herself and then discusses the question in a group before the teacher follows up. These questions are marked **. Other questions may be used individually as well as for group discussions.

Appendix:

Sound arises when things vibrate
The cymbal

The transmission of sound in different media

a) Vacuum

Can we record music on the moon?
Can you hear on the moon?

b) Air

The children and the barking dog (*where is there sound*)
The clock in the silent room (*where is there sound*)

c) Water

Under the water
Is it possible to hear sound under water?
The swimming baths

d) Solid substances

June eavesdrops (*wood*)
The fence (*iron*)

e) Several media

The containers (*air, water, vacuum*)
What substances transmit sounds?
What ideas are scientific? *

How is sound transmitted?

The bee
The flute tone
Why are they called sound waves?*

Sound transmission takes time

The lightening
Animals and hearing – copying material*
The trumpeters 1 (*the pitch versus the speed of sound*)
The trumpeters, part 2 (*the distance and the speed of sound*)
The trumpeters, part 3 (*the sound volume versus the speed of sound*)
The trumpeters, part 4 (*the distance and the speed of sound*)
The resounding mountain, part 1 (*echo*)
The resounding mountain, part 2 (*echo*)
In the depths of the sea (*echo sounding*)§
The wire (*vibrations and pitch*)
The singer (*pitch*)
The loudspeaker’s tone (*pitch*)
The speed and frequency of sound*
The mystery of the speed of sound (*sound speed, sound volume and pitch*)*
Do you hear the cars/traffic more on certain days? (*sound speed and temperature*)*
Explanation - Do you hear the car traffic more on certain days?*

Resonance
The guitar

Hearing and the perception of sound in the brain
How do we hear?
How does hearing function?
The dog
Tinnitus**

Being aware of one's standpoint and being able to argue
Science and opinions - Card copying material*
Science and opinions - Comment material*
It's up to me to decide
The sound level at the disco – oral introduction**
The sound level at the disco – the pupil's sheet**
What do pupils say**

Preliminary time schedule

The following suggestions for the teaching sequence are grouped according to a progression of content, and each individual sub-heading is *not* intended to be a lesson. There are, of course, other things that influence the time schedule: the goals set up, the pupils’ age and local conditions.

There are suggestions for many different items where pupils are given the opportunity to work out and reflect on the content. This is an essential part of the teaching, and the learning potential of small group discussions is easily overlooked. If time is short, it is better to reduce the goals and prioritise these activities.

The teaching sequence is based on formative assessment, i.e. the teacher continuously assesses the pupils’ ideas and understanding and uses this as a basis for subsequent teaching. Naturally, the results of the assessments affect the content of the lessons, and it is therefore impossible either to design an exact teaching sequence or to give the exact time needed.

This schedule covers about 14 hours (very tight) to 20 hours’ work.
The number of stars shows the order of priority (*).

Content	***Chapter***	***Activities***	***Time (minutes)***	***Order of priority***
How do the pupils think?	10.3	Pretest (“teachers help”)	20-40	***
”Quiet” sounds	10.4	Listening Peer discussions	Ca 20	**
Sound arises when objects vibrate	10.5	Peer discussions Practical work Formative assessment	60-100	***
Which substances transmit sound?	10.6 - *Air (gaseous substances)*	Peer discussions Practical work Formative assessment	60–100	***
	10.6 - *Liquid substances*	Peer discussions Practical work Formative assessment	40	
	10.6 - *Solid substances*	Peer discussions Practical work Formative assessment	60–100	
	10.6 - *Summary*	Peer discussions Formative assessment	30-40	

Content	***Chapter***	***Activities***	***Time (minutes)***	***Order of priority***
How is sound transmitted?	10.7	Formative assessment - Drawing Discussion	30	***
How do we hear?	10.8	Formative assessment Discussions in the class Peer discussion Demonstrations of ear models alt. work in groups	60	***
Where does the sound come from?	10.9	Practical work in groups Peer discussions	20-40	*
How can you protect your hearing?	10.10	Peer discussions Practical work Formative assessment	40-100	***
The sound meets different surfaces	10.11	Peer discussions Practical work Formative assessment	40-80	**
Being aware of your standpoints and being able to argue	10.13 - *Science and opinions*	Group discussions Practical work (sorting cards) Discussions and evaluation	60-80	***
	- *What do you think one should do if people disagree about the sound level at a disco?*	Individual Group discussions Summary	10-15 25-40 10	
	- *What do pupils think?*	Individual Group discussions Summary	10-15 25-40 10	
	- *It's up to me to decide.*	Individual Group discussions Summary	10-15 25-40 10	
How do pupils express their ideas?		Post test Assessment of pupils' learning	20-40	***
Evaluation and feedback		Pupil's reflections concerning his/her own learning (meta-reflection) Individually Feedback from the teacher	20-40	***

What have I learned?

Name: *Class:*

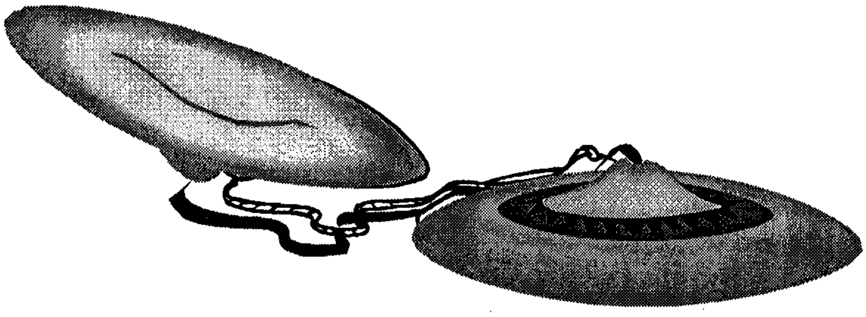
GOALS FOR KNOWING	***I HAVE GOOD KNOW-LEDGE ABOUT***	***I HAVE SOME KNOW-LEDGE ABOUT***	***I HAVEN'T LEARNED THIS YET***
That sound is produced through vibrations			
That vibrations are transmitted via matter in gaseous, liquid and solid substances			
How models might be used when explaining sound transmission			
That sound transmission can be illustrated in different ways			
That the transmission of sound takes time and that sound spreads in all directions			
That you can show how the pitch (frequency) and sound volume can be changed			
That the speed of sound in air is not dependent on pitch, volume or how far the sound has reached			
How you can get an echo			
How you can show resonance			
How sound vibrations are transferred to the inner ear			
How vibrations in the inner ear are registered and transformed into electrical impulses that are transmitted to the brain			
That the perception of sound takes place in the brain, and that sound memories are stored there			
How different hearing impairments might be prevented (especially tinnitus)			

GOALS: BE ABLE TO CARRY OUT AND KNOW SOMETHING ABOUT	***I HAVE GOOD KNOW-LEDGE ABOUT***	***I HAVE SOME KNOW-LEDGE ABOUT***	***I HAVEN'T LEARNED THIS YET***
How to plan, carry out and give an account of investigations/experiments			
How investigations/experiments have contributed to scientific knowledge			
GOALS: BE ABLE TO DISCUSS AND FORMULATE ARGUMENTS			
To listen to others in group discussions			
How you can separate standpoints and arguments			
To formulate arguments that both support AND refute a standpoint			
How to separate scientific knowledge and opinions			
Other comments			

A collection of problems, questions for discussions and formative assessment

The cymbals

Annie's class had a music lesson. Tom took out a pair of cymbal and hit them together so that everybody could hear a sound.



a) When Tom had stopped hitting the cymbals there was still a sound coming from them. What do you think this depends on?

b) When the cymbals were still giving off a sound, Annie put her hands on them to discover how it felt.

What do you think happened to the sound when she put her hands on the cymbals? Put an X in <u>one</u> of the boxes.

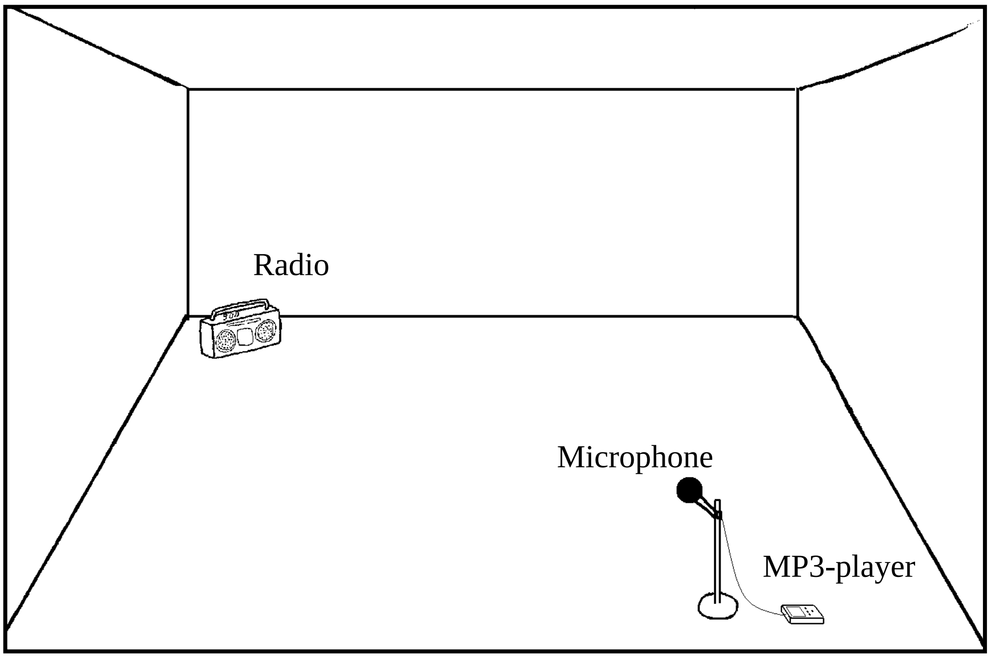
- ☐ The sound was louder
- ☐ The sound was softer but stopped immediately
- ☐ The sound was softer but went on for a long time
- ☐ There was no difference in the sound

Try to tell why you chose <u>this</u> box.

Can we record music on the moon?

June and Bruce are sitting at the breakfast table listening to music from the radio that is on the other side of the room. June is holding a microphone in her hand and is recording the music on her MP3-player.

They wonder if music can be recorded on the moon. Bruce thinks that it is possible, but June doesn't. They know that there isn't any air on the moon, i.e there is a vacuum there. They use their imaginations and think how they can test this by putting the radio and the MP3-player in a room without any air. This would then be exactly like on the moon.



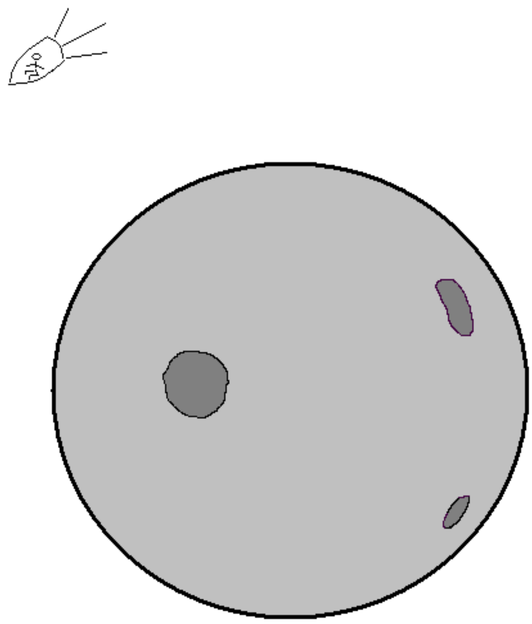
A room without any air (a vacuum)

Do you think that sound can be transmitted in a room without any air?
Put an X in the box that you think has the best answer.

☐ Yes, I think so because

☐ No, I don't think so because

Can you hear on the moon?



If a disaster occurred on the Moon (for example, an earthquake), would an astronaut orbiting around the Moon hear it?

☐ Yes

☐ No

Explain how you thought.

Could we hear it on earth?

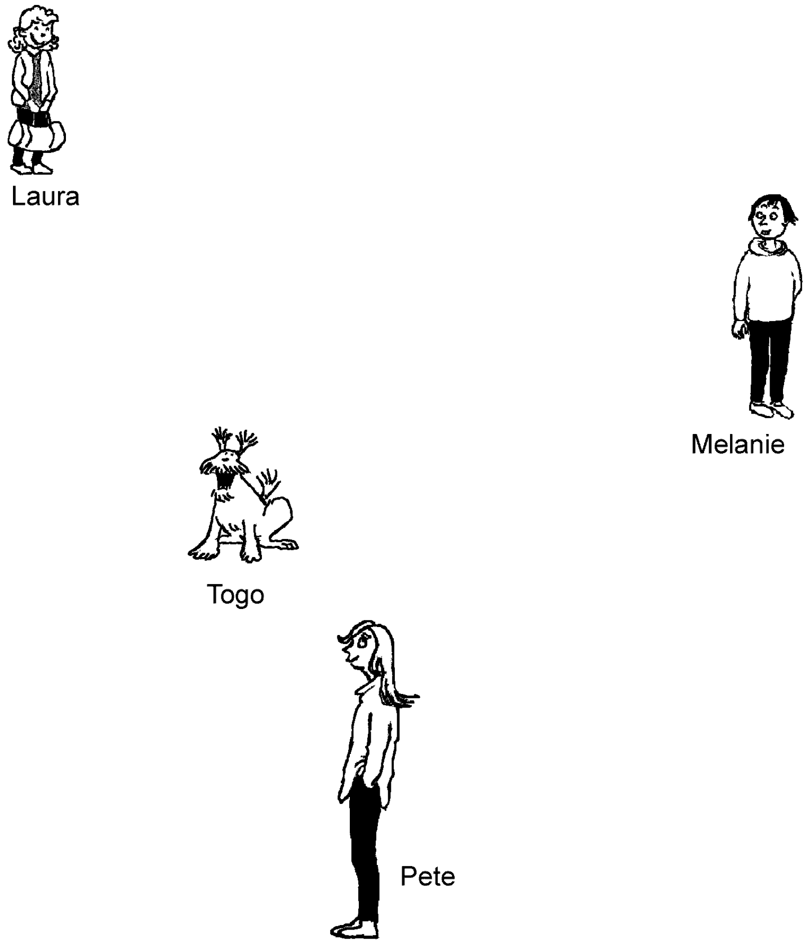
☐ Yes

☐ No

Explain how you thought

The children and the barking dog

Laura, Melanie, Pete and the dog Togo are standing on an open ground. It is all quiet. But then the dog begins barking. Laura, Melanie and Pete hear the barking.

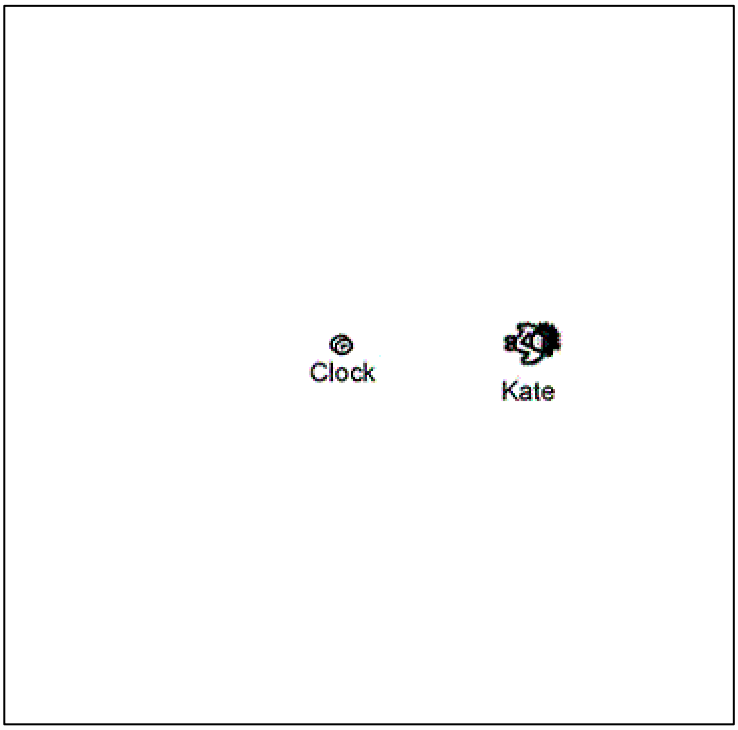


a) Draw where there are sounds on the ground when the dog is barking.

b) Write a short text that can explain how you were thinking when you were drawing.

The clock in the silent room

Kate is in a silent room. It is very quiet. There is only a little ticking clock in the middle of the room. You can look at the picture from above.



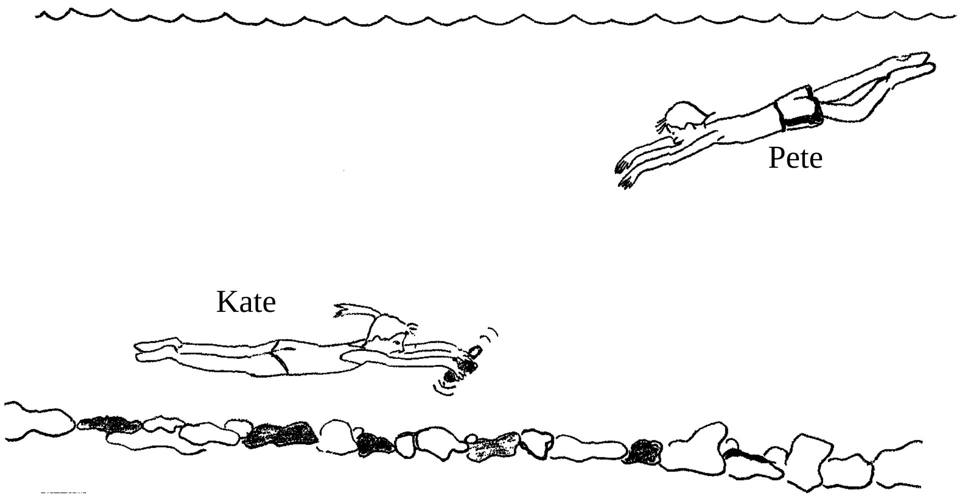
Kate is testing how far away she can hear the clock. She can not go further away than where she is now.

a) Draw where in the room there are sounds from the clock!

b) Explain your answer!

Under the water

Kate and Pete are swimming in Stone Lake. Kate dives to the bottom followed by Pete immediately after. Kate picks up two stones and hits them against each other under the surface of the water.



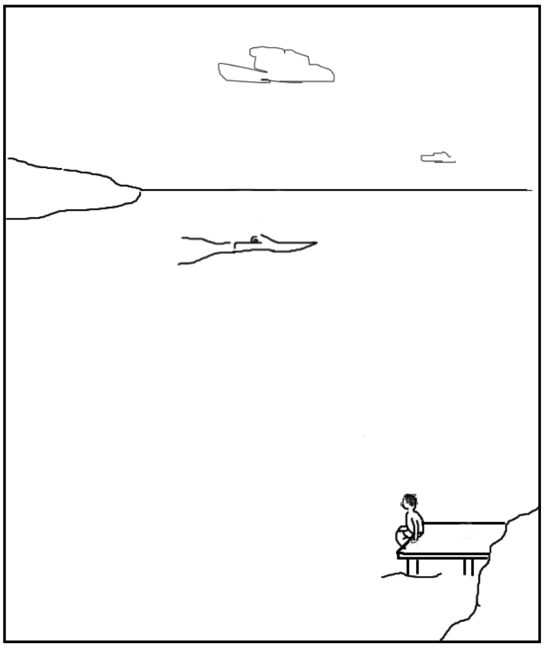
Do you think the sound coming from the stones can be transmitted through the water so that Pete can hear it? Put an X in the box that you think has the best answer.

☐ Yes, I think so because

☐ No, I don't think so because

Is it possible to hear sound under water?

Tony is sitting on the jetty and is just about to jump in the water to have a swim on a hot summer's day when suddenly he hears a terrible noise. He discovers that this loud sound is coming from a motorboat that is roaring past over the water. Think that it can emit such a loud sound!



Tony wonders if it is still possible to hear the sound if you dive in and keep your head under the water?

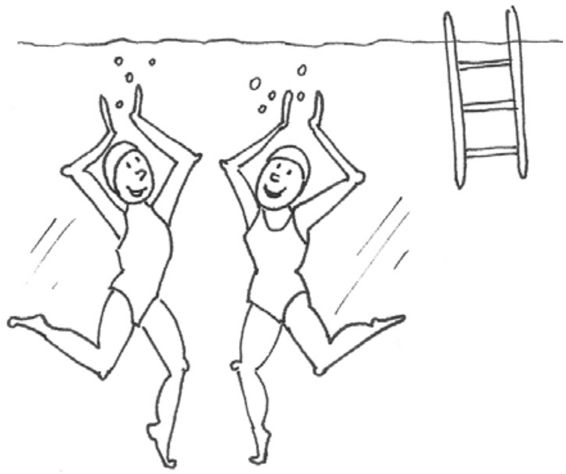
Do you think that the sound from the motorboat can be transmitted through the water? Put an X in the box that you think has the best answer.

☐ Yes, I think so because

☐ No, I don't think so because

The swimming baths

When Lucy was watching her daughter practising dives at the public swimming baths, she heard a rhythmic, metallic sound that could be heard all around. You could even hear music. It turned out to be a group of synchronized swimmers training in other parts of the swimming baths. (Synchronized swimming is a sport where you most stay under the water of the time and do a sort of dance synchronized to music). The metallic sound was made by the coach, who was hitting the bath ladder beating time to the music.



1) Explain as well as you can with the help of your scientific knowledge why Lucy was able to hear the metallic sound though it came from another part of the swimming baths.

2) Explain as well as you can with the help of your scientific knowledge how the swimmers under the water were helped by their coach beating time on the bath ladder.

June is eavesdropping

June's big brother has brought a girl from his class home with him. They are sitting in his room. June is extremely curious and just can't help trying to listen to what they are doing in there. She stands with her ear pressed against the wooden door.

She hears sounds! Ooh, it's really exciting! How come June can hear sounds that are coming from the other side of the door? Can sound be transmitted through wood? What do you think?

Can sound be transmitted <u>through</u> wood? Put an X in one of the boxes!

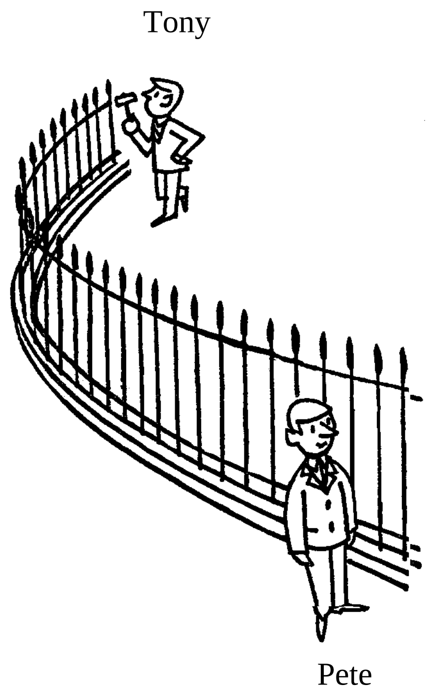
☐ Yes

☐ No

Explain how you thought

The fence

There is a high iron fence outside Tony’s house. Pete wonders if he can hear when Tony hits the other end of the fence with a wooden hammer (a mallet). First of all, Pete stands beside the fence (as in the picture) and then he doesn’t hear anything.



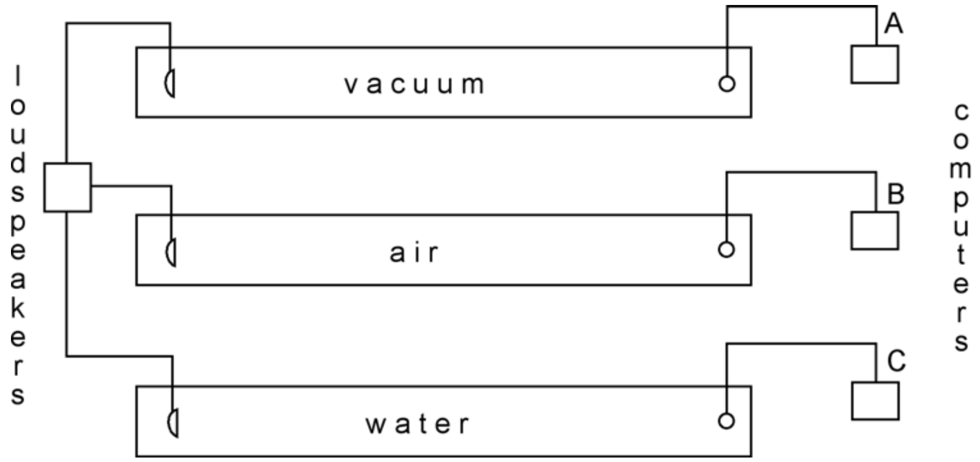
Then he puts his ear against the fence. What will happen then?

Do you think that sound can be transmitted <u>through</u> iron?
Put an X in the box that you think has the best answer.

☐ Yes, I think so because

☐ No, I don’t think so because

The containers



The picture shows three big completely sealed containers. In one of them there is a vacuum. The others contain air and water.

In each container there is a small loudspeaker on one side. On the other side there is a microphone that is connected to a computer. All the computers are on and in a recording position.

All three loudspeakers start emitting a tone at the same time. They also stop at the same time.

Which computer or computers will receive sound to record from the loudspeakers? Put an x in the table.

	record sound	do not record sound
A (vacuum)	☐	☐
B (air)	☐	☐
C (water)	☐	☐

Explain your answer!

What substances can transmit sound?

		Transmit sound Yes	Transmit sound No
GASEOUS SUBSTANCES			
Air…………………………		☐	☐
……………………………...		☐	☐
LIQUID SUBSTANCES			
Water………………………		☐	☐
Oil…………………………		☐	☐
……………………………...		☐	☐
……………………………...		☐	☐
……………………………...		☐	☐
SOLID SUBSTANCES			
Object	Substance		
Table	Wood……………...	☐	☐
Window pane	Glass…………….	☐	☐
………………………..	……………………..	☐	☐
………………………..	……………………..	☐	☐
………………………..	……………………..	☐	☐
………………………..	……………………..	☐	☐
………………………..	……………………..	☐	☐
………………………..	……………………..	☐	☐

What ideas are scientific?

Discuss what ideas in the statements below are scientific and what ideas are not scientific.

1. You can hear sound much better on the moon than on earth. The reason is that there is no air. There is nothing that blocks the sound waves. Therefore the sound waves can travel around on the moon and even out into space.

2. John and his cousin are on their way to the bathing place on the bay when John says: Do you think the fish can hear if I fart? I mean while I'm bathing? The cousin giggles.
- That is typical of you! Of course, the fish don't hear it because the water is so dense!
John hears a roar of laughter and turns around. He turns as red as a beetroot.
- Sooo embarrassing! he thinks when he catches sight of Jane, Mavis and Laura from the other class in the school. Not least because he is interested in Laura. He is ready to sink into the ground with shame and disappear!
- Hi, hi, says Jane. Don't you know that fish can hear!
- And that there are molecules in the water that knock other molecules, Mavis calls out gaily.
- Well, aren't there sound waves in the water? Laura wonders and looks bewildered.
- But I think there is air in the water and therefore the sound can be heard, Jane answers. I mean, without air in the water it wouldn't be possible to hear the sound. I know there're both oxygen and air and such in the water otherwise the fish couldn't survive.
- But do you mean there are some sorts of bubbles filled with sound in the water, Laura wonders.

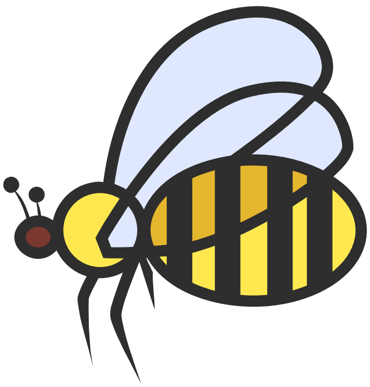
3. John and Steve change clothes in the dressing-room. Soon their PE lesson will start. It's always so cold in the dressing room! Suddenly they hear their PE teacher? blowing his whistle. The gym hall lies next door to the dressing room.
- Have you thought about us always hearing the whistle through the wall, says Steve.
- No, John answers. You can't hear the whistle through the wall, can you? The sound must be transferred through the openings under the doors and surely through the keyhole too! But not through the wall!
Patrick, who is also in the dressing room, gets interested in the talk.
- I think we can hear the whistle because there is an echo through the wall, Patrick says.
- What, an echo through the wall? John comments. Isn't an echo something else?

4. Jane and Steve suddenly catch sight of a little dog running over the street in front of a car. The tyres screech when the car brakes, and luckily the dog survives.
- How can you hear when the tyres screech really? Steve wonders.
- I think it's because there are sound waves that push the air away, Jane guesses. And then there will be an echo in the ear… hmm!
- You mean that sound waves are something flying around in the air? Steve goes on. And that there can be an echo in the ear?

5. Class 8 F is having music lesson. Almost everybody has got one musical instrument. Jane plays bass drum, the big one with muffled, low tones. Boom, boom… Laura plays high, clear tones on a transverse flute. Nowadays she is really good at playing the flute. The popular bass guitar stays with Mavis, and Paul strums on the piano. Together with all the others in the class they sound like a whole orchestra playing. Fred has broken his arm and he and Joy are sitting at the back of the room.
- Just imagine, how groovy! Fredrik says.
- What's groovy, Joy wonders?
- Well, I mean that the muffled sound from the bass drum and the sound from the bass guitar don't move through the air at the same speed as the clear tones from the transverse flute!
Joy looks very confused and says:
- But how will the sound be at the music festival then? I mean if the sound speed varies from instrument to instrument? I mean…that the speed of different sounds…tones will vary? Or can it be that different tones move at the same speed, but the sound speed varies by means of the sound volume? Oh, this is so confusing!

The bee

The sun is shining, at last it's the summer holidays! Jane and Steve are sitting eating an open sandwich in the garden. Suddenly a bee settles on the marmalade just as Jane is about to put it into the mouth. Jane immediately pushes the sandwich away.
– Such luck you saw the bee! Steve exclaims.
– But I didn't see it! I heard it! Jane says.



Steve is thinking and wonders:
- I know that the sound goes from the bee to my ears. But what's going? What is happening between the bee and my ears when I hear?

How would you answer Steve's question?

The flute note

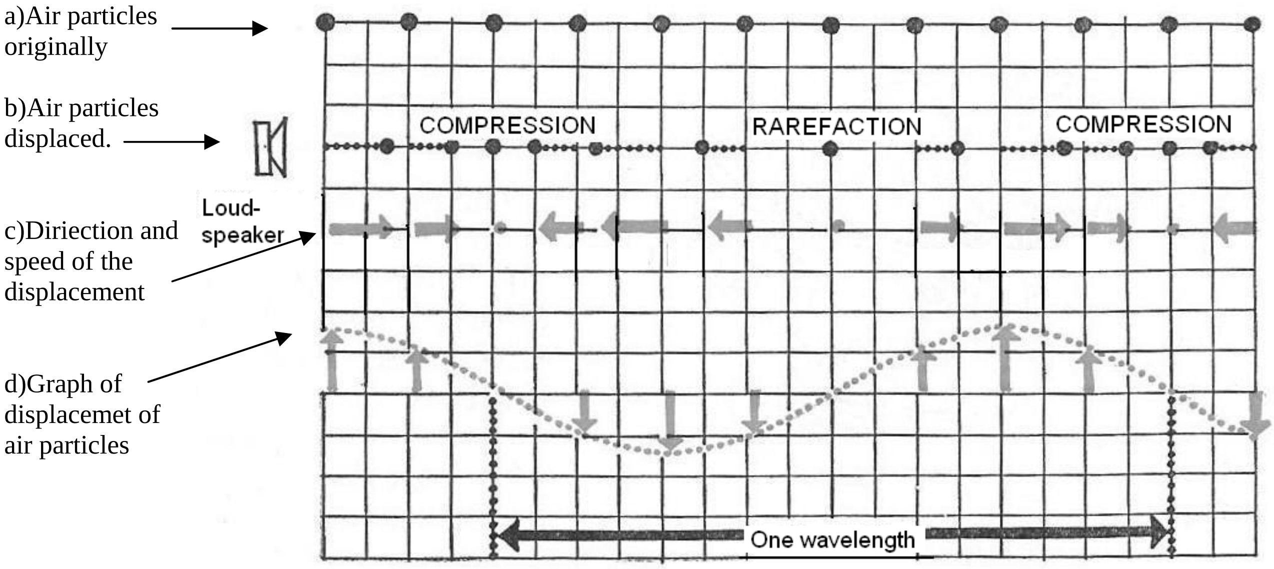
Steve and Jane are playing the transverse flute. Jane blows a long C. The note sounds nice and clear.

Steve is thinking and wonders:
- I know that the sound goes from the bee to my ears. But what's going? What is happening <u>between</u> the flute and my ears when Jane plays and I hear?

How would you answer Steve's question?

Why are they called sound waves?

One often hears about sound waves, and that is because the movement of the particles is usually described in a mathematical way. Sometimes one draws a sort of figure called a graph, which you could say is a mathematical translation of the movement of the particles – describing what this movement looks like when a sound is passing.



A. Look at the figure and discuss with your peer what it shows.

B. Discuss with your peer and draw on a piece of squared paper what the graph would look like

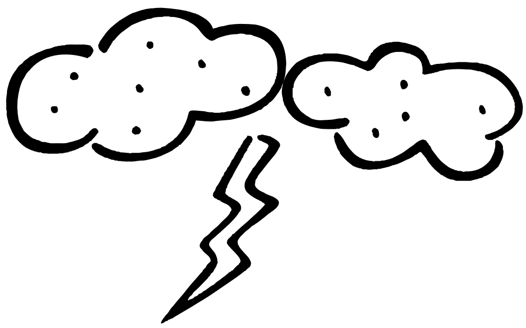
a) if the sound volume were increased very much?
b) if the sound volume were decreased very much?
c) if the pitch (i.e. the frequency) were increased?
d) if the pitch (i.e. the frequency) were decreased?

C. Use an audio oscillator connected to a microphone and investigate if the graphs you drew in the previous exercise correspond with what you see on the audio oscillator. Use your own voice; try to make as clean a note as possible. Make the note loud, soft, high and low. How well does it correspond? If it doesn't correspond, you are challenged to find the reason. Why doesn't it correspond?

D. Try to think of a new task based on the figure above or for the audio oscillator. Can any of your peers solve the task?

The lightning

Marie looked through the window during a stormy night. She saw lightning and heard thunder a few seconds later.



Explain why she saw the lightning before she heard the thunder.

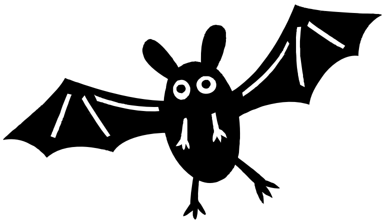
Animals and hearing - card copying material

The dog can hear sounds at a higher pitch than human beings can (pitch is the same as frequency, i.e. the number of oscillations per second).

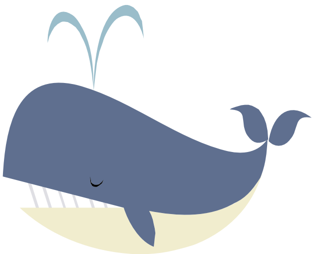
A dog can separate two notes that are as close as an eighth tone. That is why it recognizes the sound from his master's car even it is mixed with other sounds.

Cats have a good sense of hearing. Their outer ears are very flexible, and they can turn them about 180° in the direction of a particular sound source.

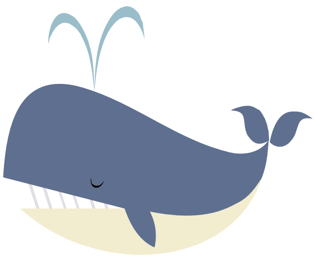
It is enough to look at a bat to realise it ought to have a good sense of hearing. In many cases the outer ears are so big and in certain cases they completely dominate its appearance. Not surprised that one of the species is called the long eared bat.



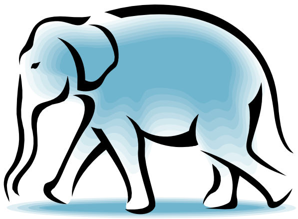
Whalebone whales communicate by sound over very long distances. They make sounds at rather low pitches but of very high volume, which reach very far.

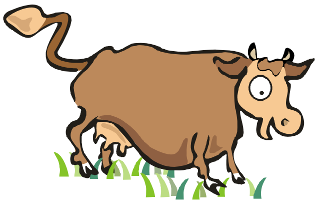


It is said that the whistles from the blue whale have a sound volume of 188 decibel and that they reach about 800 kilometres! Reasons for this are, apart from the sound volume, that water transmits sound better than air and that sounds of lower pitch (lower frequency) reach further than sounds of high pitch (high frequency).

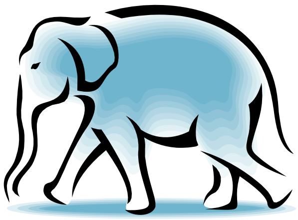


Elephants and cattle can also hear within the area of infrasound; that is, below the frequency range of human hearing. They can hear sounds as low as 16 hertz (Hz).

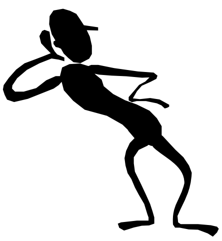




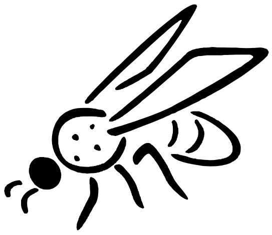
As low pitches reach further, elephants can communicate over distances of five kilometres.



Human beings can hear sound within the range 20 and 20 000 hertz (oscillations per second). Sound of a lower frequency than 20 hertz (Hz) is called infrasound, and sound of a higher frequency than 20 000 Hz is called ultrasound.

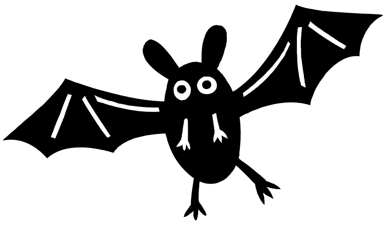


Certain insects can hear with sensitive hairs that not only react to audible sounds, but also register the smallest movements in the air, for example. from moving hands. That's why it is so difficult to swat a fly!



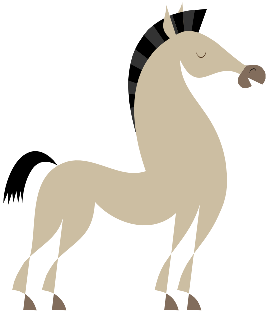
In many mammals the outer ear is very important for hearing. Many of them can manipulate their ears in different ways. Can you find an animal of this kind?

Bats can register frequencies as high as 200 000 hertz (Hz). But they also register very low frequencies.



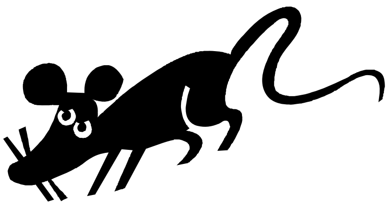
Dogs can hear within the frequency range 40 to 46 000 Hz.

Horses can hear sounds with frequencies as high as 40 000 hertz (Hz).

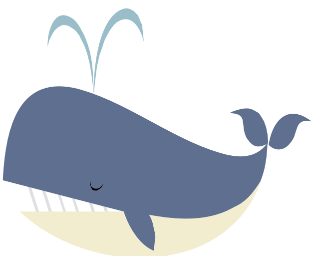


Cats can register higher frequencies than we can. Therefore they can more easily hear high tones from the mouse’s squeak and the twittering of birds. Sounds with higher frequencies than we can register are called ultrasound.

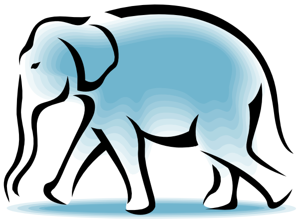
Many rodents (mice and rats) can hear sounds of up to 45 000 hertz (Hz).



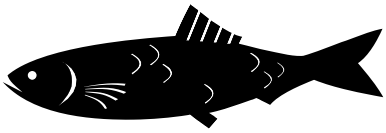
Whales communicate at low frequencies.



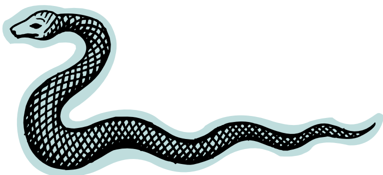
Elephants communicate at low frequencies.



Herrings can register sounds of up to 180 000 hertz (Hz). Consequently they hear sound of higher frequencies than we can register; this sound is called ultrasound.

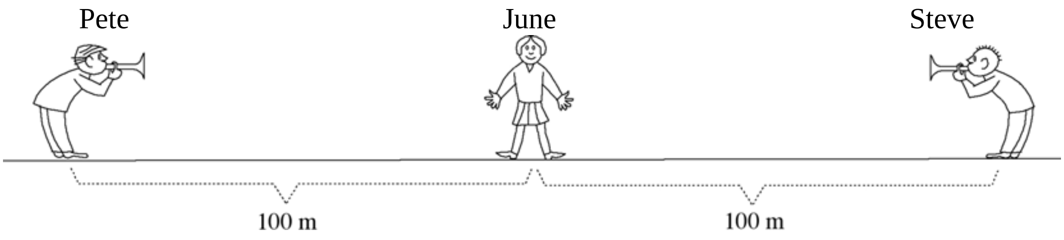


Snakes have no outer ear, including the outer ear canal, nor a middle ear. The inner ear exists, however, inside the cranium, and they can hear low tones (100-700 hertz (Hz)). They can register vibrations from the ground.



Most lizards have bad hearing. The gecko is an exception. It communicates with sound.

The trumpeters, part 1



Pete, June and Steve are standing on a straight road that is surrounded by open fields. There is no wind.

Both Pete and Steve are 100 metres away from June. They start playing the same tone (an A) on their trumpets at the same time. They both blow their trumpets for exactly 3 seconds.

Pete blows his trumpet in his usual way, but Steve blows his as hard as he can. So his note is louder than Pete's.

How will it be for June? (Put a cross in the box with the answer that you think is best!)

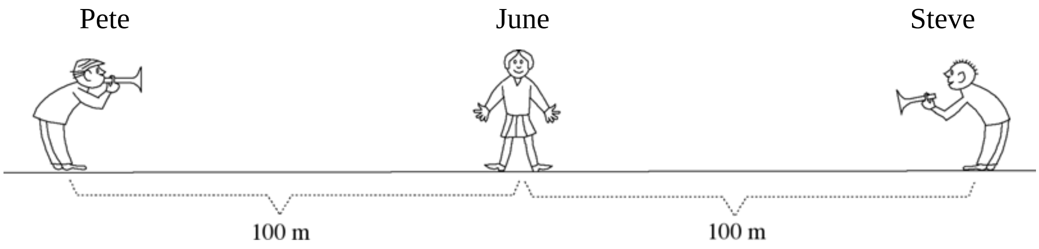
☐ She will hear Pete's trumpet before she hears Steve's.

☐ She will hear both trumpets at the same time.

☐ She will hear Steve's trumpet before she hears Pete's.

Explain your answer!

The trumpeters, part 2



Now it's only Pete that is blowing (an A) his trumpet. He blows it for exactly 3 seconds.

How will it be for June? (Put a cross in the box with the answer that you think is best!)

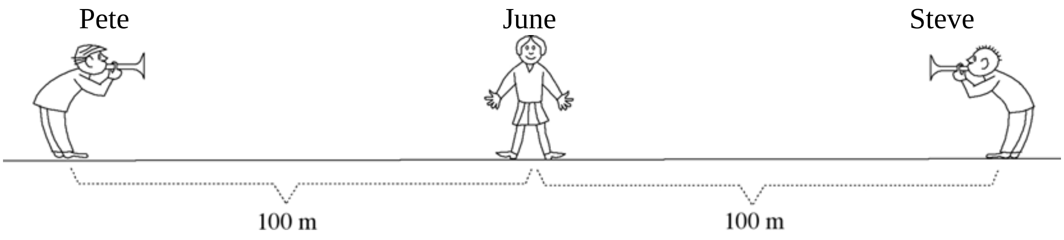
☐ She will hear Pete's trumpet for shorter than 3 seconds.

☐ She will hear Pete's trumpet for 3 seconds.

☐ She will hear Pete's trumpet for longer than 3 seconds.

Explain your answer!

The trumpeters, part 3



Once more both of them are blowing their trumpets. They start at the same time, playing the same tone (an A) on their trumpets. They both blow for exactly 3 seconds.

Pete blows as usual and Steve blows as hard as he can. So his note is louder than the one Pete blows.

How will it be for June? (Put a cross in the box with the answer that you think is best!)

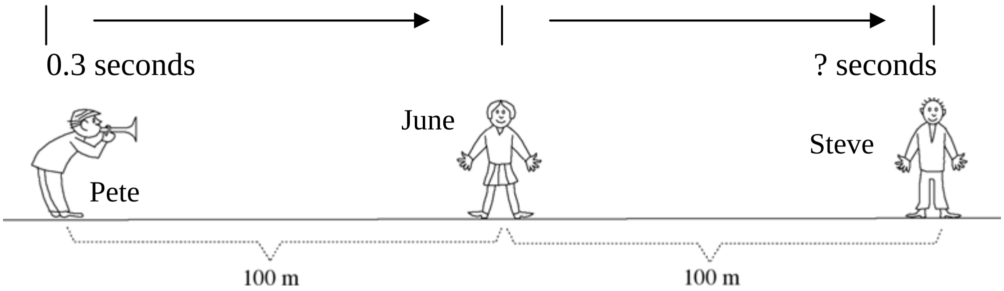
☐ She will hear Pete’s trumpet for a shorter time than she hears Steve’s trumpet.

☐ She will hear Pete’s trumpet as long as she hears Steve’s trumpet.

☐ She will hear Pete’s trumpet for a longer time than she hears Steve’s trumpet.

Explain your answer!

The trumpeters, part 4



Now it’s only Pete that blows one loud and short trumpet blast.

It takes the sound 0.3 seconds (”three tenths”) going from Pete to June.
How long will it take for the sound to go from June to Steve? (Put a cross in the box with the answer that you think is best!)

☐ More than 0.3 seconds

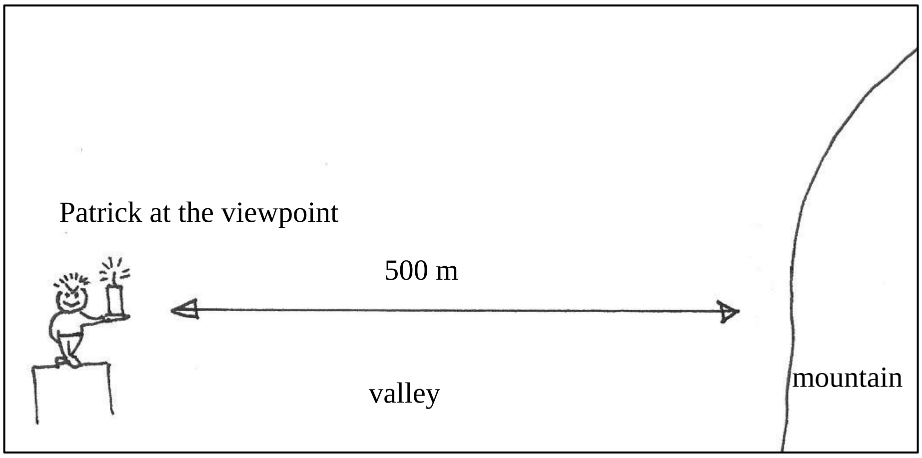
☐ Exactly 0.3 seconds

☐ Less than 0.3 seconds

Explain your answer!

The resounding mountain, part 1

Patrick is standing at a place with a view. In front of him there is a valley and a mountain. It's big, high and steep. There are no trees on it.



Patrick lets off an Easter firework at the viewpoint. BANG! After three seconds an echo can be heard from the detonation.

Then Patrick lets off a larger firework at the same viewpoint. BANG!

How long does it take before he can hear the echo from the larger detonation?

☐ Less than three seconds

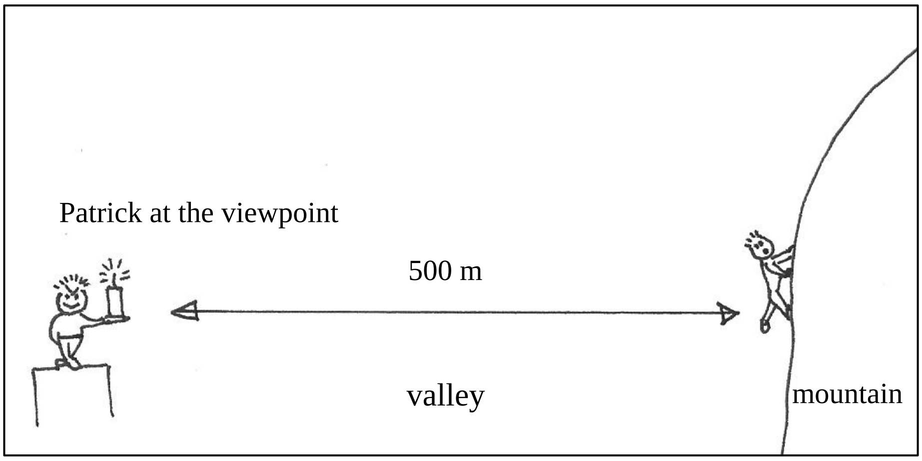
☐ Just about three seconds

☐ More than three seconds

Explain your answer!

The resounding mountain, part 2

Remember it took three seconds before Patrick could hear the echo from his first detonation.



How long will it take before the climber hears the explosion from this firework?

☐ Less than one and a half seconds

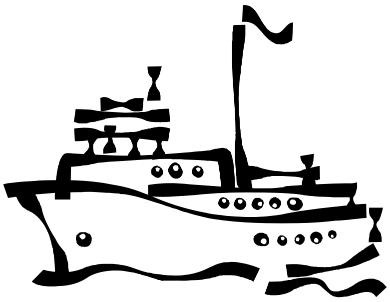
☐ Just about one and a half seconds

☐ More than one and a half seconds

Explain your answer!

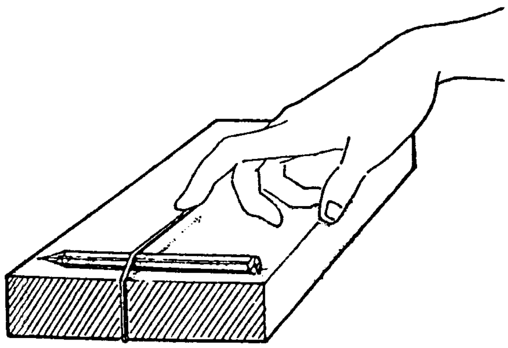
In the depths of the sea

Jane has been lucky as she has found a summer job with the coast guard. She's sitting with the captain in the wheel house looking at a screen with mysterious graphs. The captain explains that the mysterious graphs actually represent the contours of the sea bed, so this instrument can be used to measure the depth of the ocean. This is done with the help of sound.

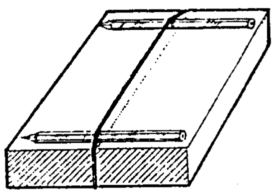


Jane wonders how it is possible to use sound for measuring the depth. How would you explain to Jane how it works?

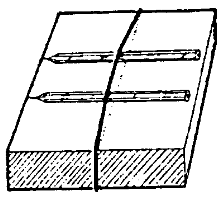
The wire



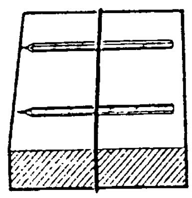
John stretches a wire tightly across a box and two pencils like this. It makes a musical sound when it is plucked. Moving the pencils along the box changes the sound the wire makes, like this:



low note



high note



medium note

Explain how the length of the part of the wire that is plucked is connected with the note it makes.

The singer

A very good song artist easily sings different notes in tune. But what happens to the speakers when she sings different notes?

You have learnt that when something vibrates it moves back and forth. The more vibrations back and forth per second, the *faster* the vibration. The longer the swinging distance, the *larger* the vibration.

Now imagine one of the speakers used to help the listeners to hear the song properly. The song artist first sings at a low pitch – that is, she uses the lower part of the musical scale. You can feel the speaker vibrating with your finger. Then the tone changes to a higher pitch, higher up the scale. The volume doesn't change. How do the vibrations of the speaker change?

Put two crosses

☐ The speaker vibrates faster
☐ The speaker vibrates as fast as before
☐ The speaker vibrates more slowly
☐ The speaker's vibrations become larger
☐ The speaker's vibrations are as big as before
☐ The speaker's vibrations become smaller

Explain your answer!

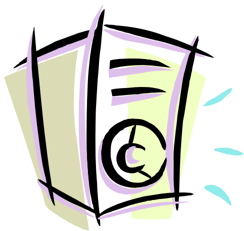
The loudspeaker's tone

When something vibrates it moves back and forth over and over again.

The more it swings back and forth per second, the *faster* it vibrates.

The longer the swinging distance, the *larger* the vibration.

Now imagine a speaker. It gives off a specific tone (an A). You can feel its vibrations with your finger. Then the speaker changes and gives off a louder sound. Your ears almost hurt. But it's still the same tone (an A). What happens to the speaker's vibrations?



Put <u>two</u> crosses

- ☐ The speaker vibrates faster
- ☐ The speaker vibrates as fast as before
- ☐ The speaker vibrates more slowly
- ☐ The speaker's vibrations become larger
- ☐ The speaker's vibrations are as large as before
- ☐ The speaker's vibrations are smaller

Explain your answer!

The speed and frequency of sound

The sun is shining gently between some clouds and the chaffinch is singing its spring song when Maves comes walking slowly to school. She looks as if she's in a different world. Suddenly she stops and stands below the tree with the chaffinch. Pete, who is coming from the opposite direction on his bike, stops and says:

- Hi Maves! But Maves doesn't react.
- Hello, hello, hello….Pete shouts! Maves moves quickly and looks frightened.
- Oh, you frighten me! Maves turn her eyes to Pete. I'm listening to the bird … I'm thinking…, she says. I was at a concert last Saturday and listened to "The Face". Ok, they are really good…but have you ever been to a concert standing listening a bit away from the loudspeakers?
- Yes, of course I have, but what about it? Pete wonders.
- Yes, or listened to someone talking? Maves continues. Do you remember the last end of the school year when the headmistress held the finishing speech …you know when she made up the joke about the school year lasting another week? When we stood at the back and heard what she said, with the loudspeakers at the very front. You remember don't you?

Mmm, Pete mumbled.

- But have you ever thought of the fact that the sound is transmitted to your ears at the same speed no matter if they play loud or soft? Maves continues. Or if someone speaks loudly or softly, then it must be the same! I have not thought about that before. Not until now.
- No, I've never thought of that, Pete replies.
- And have you thought of the fact that it doesn't matter what the notes are either! Maves continues. I mean the low notes, the deep ones, get transmitted to the ears just as fast as the high notes do!
- Hm…Pete goes into deep thought, one can almost hear him thinking, and then he says:
- But that's cool! No, I haven't thought of that! But think if things had worked differently, if different sounds had different speeds, what would the music be like then? And what would it have been like listening to choir singing? Or when someone speaks at a distance!

Maves and Pete go and sit down on the bench under the tree and start fantasizing while the sunshine becomes brighter and brighter. The singing from the chaffinch is mixed with the bubbling laughter from Maves and Pete.

Yes, what would it sound like if loud and soft sounds were of different speeds? And if high and low notes were of different speeds? What ideas do you have?

The mystery of speed and sound

Below follow a number of statements. Which ones are true and which ones are false? And why?

1. If I shout at 100 dB(A) the sound will move faster through the air than if I speak with a normal voice, approximately at 70 dB(A).

2. If a girl shouts at a high frequency (high note) the sound will move faster through the air than if a guy shouts equally loudly but at a lower frequency (lower note).

3. A roaring lion sounds both muffled (low frequency) and loud (many dB(A)). Nevertheless the sound moves as fast through the air as when a mouse squeaks higher (high frequency) and lower (lower dB(A)).

4. The music teacher is sitting in the music hall and you around her in a circle on chairs. She hits the G string on the guitar, very softly. Then she repeats this but now very firmly. If you could see the vibrations of the string, they are now moving back and forth many more times per second than when she hit the string softly.

5. The music teacher is sitting in the music hall and you around her in a circle on chairs. She hits the G string on the guitar, very softly. Then she repeats this, but now very firmly. If you could see the vibrations of the string, they are now moving back and forth more violently (further out) but still as many times per second as when she hit it more softly.

6. The owner of the brand new racing boat is driving way too fast – non-attentive he hits a rock underneath the water. There is a loud bang that can be heard from a long distance, both above and in the water. A submarine and a fishing boat are both at the same distance from the scene of the accident. The fisherman, who’s clearing his nets on deck, can hear the noise before the seaman in the submarine.

Do you hear the car traffic more easily on certain days?

Jane and Steve are on their way home from school. The sun is shining, the great tit is singing “lit….”, “lit…”. The biology teacher says you can recognize the great tit that way. The air is a bit chilly, it’s late winter, still it feels as though it’s spring time. The snowdrops have come out in bloom even though it’s only February.

- I’ve thought of something, says Jane. When I sit on the bench outside where I live, I hear the traffic more easily some days than others.

- Of course it must be the wind blowing from different directions, Steve replies.

- Yes that’s one way of reasoning, but that’s not what I meant, Jane mumbles, chewing a piece of candy. Every time I’ve noticed this it has been dead calm. Every time! She continues:

- There was once a show on TV about this, a science school or something, where they talked about this, but I don’t remember how it all worked. They mentioned something about hot and cold air in levels in some way… but I just don’t quite remember how.

Steve unwraps a piece of candy and puts it in his mouth. He is thinking so intensely that you can almost hear his brain cells crackling when he scratches his dark hair.

- Hmmm…he says.

This problem is a little tricky. Discuss how to explain this phenomenon. Write down the different explanations you come up with.

Explanation - Do you hear the car traffic more easily on certain days?

The warmer the air is, the faster the sound will be transmitted. A warm surface heats up the air above it, and the sound is therefore transmitted more quickly. A cool surface, in contrast, will cool down the air so that the sound is transmitted more slowly. In summary, the speed of sound increases with temperature.

On a warm day the ground gets heated up by the sun beams, and the air gets warmer the closer it is to the ground, which in turn makes the sound move faster closer to the ground. As the air cools the further above the ground it gets, the sound from an object will move more slowly. The direction of the sound also changes when sound passes through different air layers of different temperature. Accordingly, the sound "turns away" from the ground. The result will be that the noise from the traffic on such days is not transmitted so far *along* the ground.

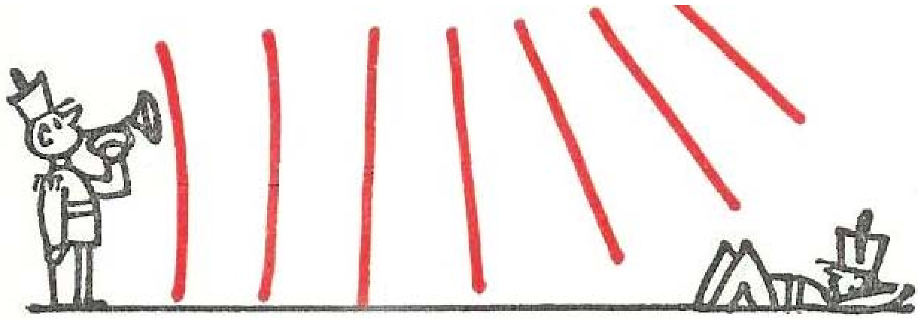


Figure 1. A warm day

On a cool day or night, the air layers closer to the ground cool down more than those above, and consequently the speed of sound becomes lower closer to the ground. The sound from an object will therefore move a little faster in the warmer air above than in the lower and colder layers. The result will be that the noise from the traffic on such days is transmitted more efficiently along the ground.

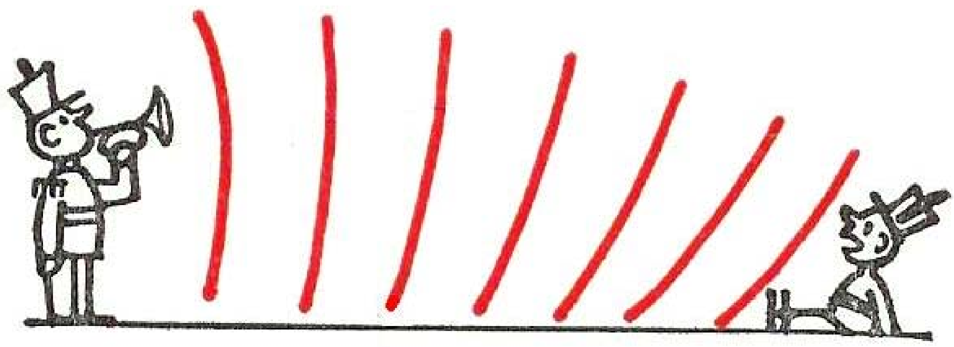


Figure 2. A cold day

The guitar

Steve's little brother Patrick has built a simple guitar with a flat piece of wood and six strings fastened to it. He has shaped the wooden piece so that it looks almost like Steve's real guitar. Patrick is very proud of it! Now he wants to play in a band together with Steve. But when they start playing together Patrick is disappointed because the sound from Steve's guitar is so much louder!

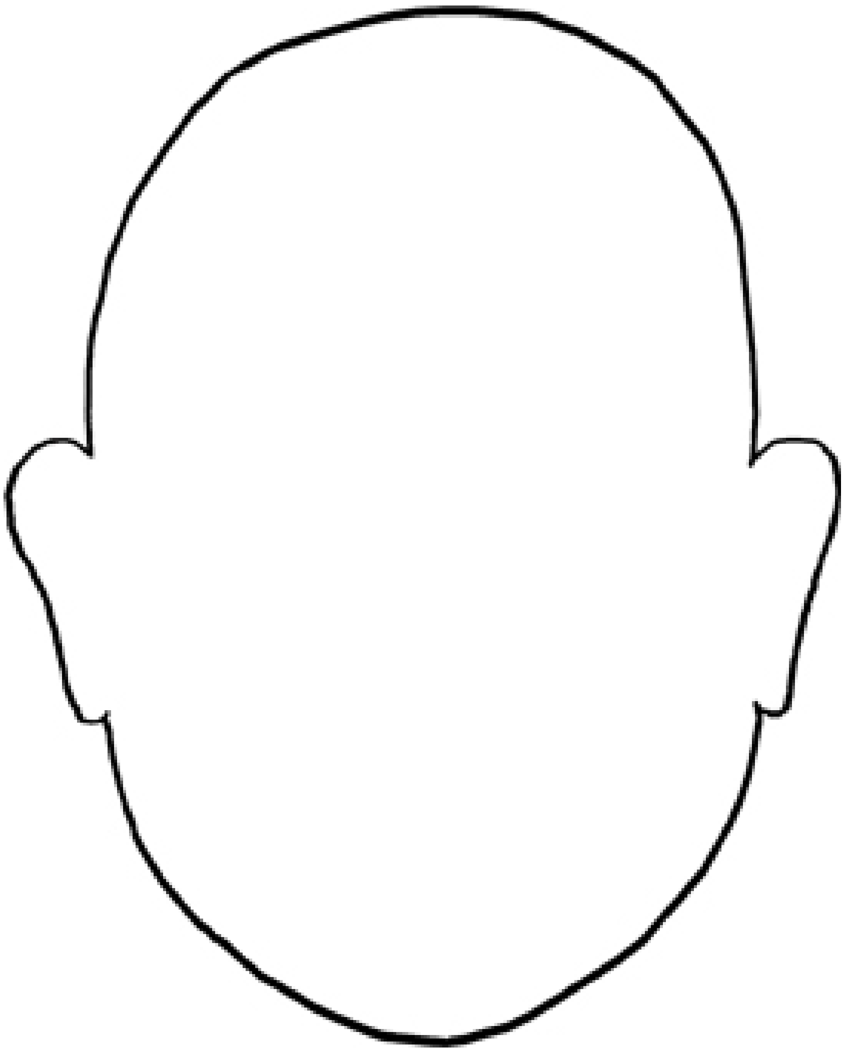
Patrick's guitar

Steve's guitar

How would you explain to Patrick the reason why Steve's guitar sounds so much louder? Explain in as much detail as possible.

How do we hear?

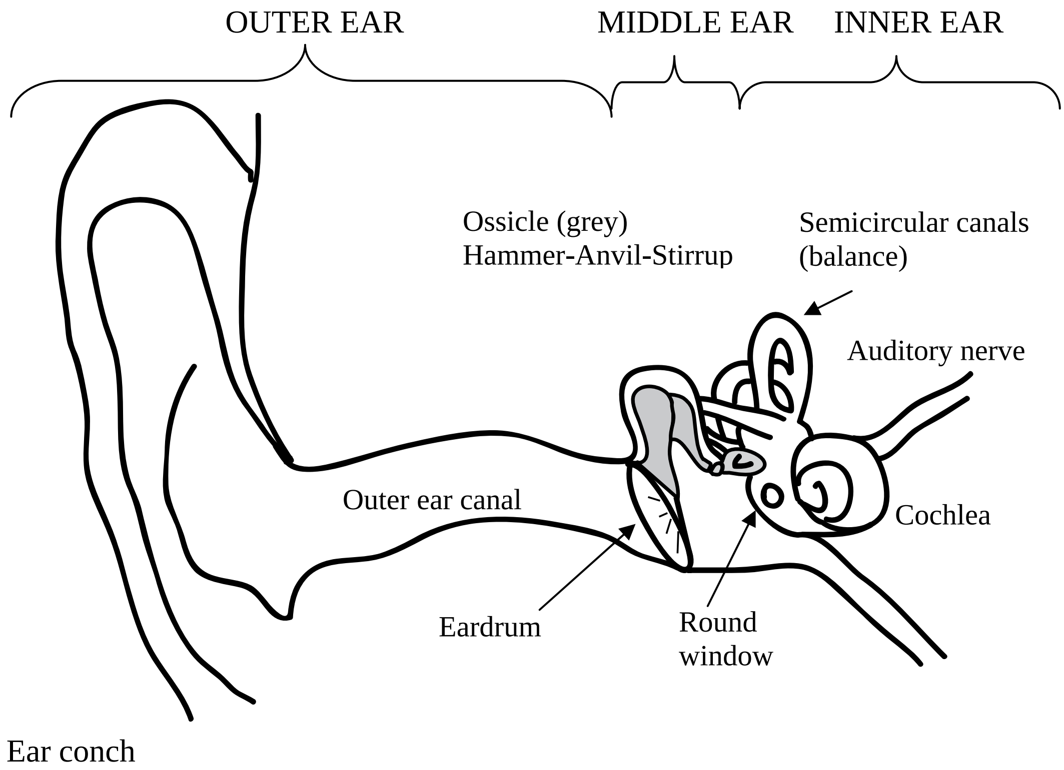
What happens to a sound that has reached the ear? Draw what you think right now.



Write a short text below that explains how you were thinking when you were drawing.

How does hearing function?

Imagine that you hear a cat miaowing. Write a story about the sound's path from the cat to your ear and further on through your ear until you perceive it's a cat. Use the following picture to support your explanation.



The dog

Annie and her brother Kevin are sitting having supper. It’s evening and outside the window it’s completely dark. Suddenly a noise can be heard out there in the dark. In spite of the fact that neither Annie nor Kevin can see what it is that is making this noise they are both in total agreement that it’s a dog. But it could just as well have been a cat or a car or an aeroplane or something else, couldn’t it?

How can they know that it’s a dog they can hear? That it is a dog that barks.

Tinnitus

Tinnitus means that you hear sounds in your ears or your head that are not real sounds. These sounds can seem like buzzing, whistling or tooting. Tinnitus can be temporary or chronic i.e. you can hear the sounds all the time. Put an X for yes or no!

	Yes	**No**
A rock concert can cause tinnitus.		
You can get tinnitus by listening to loud music in a walkman or an MP3.		
If you only listen to music you like, you won't get tinnitus even if the sound is loud.		
Small children can get tinnitus if they are exposed (listen too much) to loud sounds.		
It's only if you get an earache from the loud music that there is a risk of getting tinnitus.		
Stress, anxiety and tiredness can also induce tinnitus.		
One single occasion with loud sound can cause tinnitus.		
Loud music can give tinnitus that can bother you for many years.		
Chronic tinnitus can always be completely cured.		
You can get help to cope with permanent tinnitus.		

Science and Opinions - Card copying material

Important teacher instructions for this exercise – see section 10.15!

The sound level at a disco and concerts where young people are under the age of 12 should not be more than 90 decibels. They are more sensitive since their outer ear canal is shorter.

The one who don't want high sound levels at a disco can go home.

A disc jockey can hire sound equipment that can damage a person's hearing in a short period of time. Some people are of the opinion that the people who hire equipment like this should have a "sound (driving) licence"!

If we put our hand on a red-hot plate on a stove, we immediately snatch it away before we've even had time to think about it. However, when our ear is exposed to loud sounds, there is no such protection. We cannot feel when the sound level is harmful.

The ear can stand a certain amount of noise, but then it must rest. If you have been in environments with a lot of noise, it is important to be in a quieter environment for the rest of the day.

Permanent tinnitus caused by loud sound cannot be cured. However, there is help to be got in order to be able to cope with it.

One way of protecting your hearing is to raise the volume of the ’cool’ songs and lower the volume of the soft ones.

You can always rely on the disc jockey making sure that the sound levels are not so high as to be harmful.

In a study from 2003 done by a Swedish researcher, it was found that 74 % of the rock musicians had some form of hearing impairment.

Adults should take responsibility and look after the sound volume at discos in school so that the sound level does not get too high.

It’s not good to have loud music because there are tiny hairs in the cochlea. If they break, your hearing can be damaged.

The medical definition of tinnitus is: Sound that is heard all the time but which does not come from any outer sound source.

It’s better that some people think that the music is too low rather than some people getting a pain in their ears.

If I were at a disco I would lower the sound volume if it was too loud cause I want to take care of both myself and others. Those who listen to loud music risk getting tinnitus, which is rather common nowadays.

You can turn down the base in your CD player or in your hi-fi and then it’s not so risky to have a loud volume.

You should put loud speakers high up on a shelf so that the people that are dancing don’t get the sound straight into their ears. The sound level gets less the further you are from the loud speaker.

If you don’t agree about the volume at a party or at a disco you should vote. Then the decision will be a good and fair one that nobody can complain about.

Those who are bothered by tinnitus at a disco should go home or take a walk with a mate to feel better. Then come back if he or she feels better. All the others that want to lower the volume can manage high sound levels if they aren't bothered by tinnitus. Otherwise they can go home as well. That is why I think it is unfair to say: "Lower the volume!" If I were one of those that like high sound levels, then it would be a crashing bore if they lowered them.

In a study from 2003, it was shown that in nearly half of the discos in Sweden the sound level was too high. The same problem existed in many premises used for sports training.

A banger or a rocket can cause hearing loss if you stand too close. A number of people have damaged their hearing in this way.

Research shows that the sound level at a disco is often raised in the course of an evening.

Those who are sensitive to loud sounds can carry earplugs with them whenever they go to a hockey game, handball match or a musical event. Then we would get rid of the problem of having to check sound levels.

Several studies show that musicians prefer loud sounds even though they are worried about their hearing at the same time.

There is special music hearing protection that muffles the loud. The sound can be reduced by 9, 15 or 25 decibels. The advantage of music hearing protection is that all tones are muffled without spoiling the sound quality, which most other kinds of hearing protection do. Therefore the music quality is like the one you get in reality but just a little softer.

You can get help to cope with your tinnitus by practising thinking of something else besides the disturbing sound. This method might work rather well, but it can take a long time to change to this way of thinking. Experts in hearing care centres can provide such help.

Worry and stress (even unhappy love) might make your tinnitus worse.

Auditory experts sometimes use something called a sound simulator when helping people with severe permanent tinnitus. The impaired person wears an apparatus that makes sound so you don't only hear the noise from tinnitus. This helps the brain to concentrate on other sounds than the frustrating tinnitus sound.
If they use an apparatus of this kind 8 hours a day, it can take 1-2 years for many impaired persons to learn to live with a difficult form of tinnitus.

We are born with approximately 20 000 hair cells and if they are damaged, they can never grow again. It is the hair cells in the inner ear that transform vibrations into electric impulses. These impulses are then sent on to the brain via the auditory nerve.

All the talk about high sound levels is exaggerated. I often listen to loud music and **I** haven't got any hearing impairment.

You can get life-long tinnitus after listening to loud music in MP3 players.

It doesn't matter whether you like the music you listen to or not. You can get tinnitus in any case.

Children and young people that listen to far too loud music in their MP 3 players are mostly unconscious of it. Besides, they don't believe they themselves will ever suffer from hearing impairment.

The most common way of thinking among young people is: Loud music is only risky for others but not for me.

In groups of young people there are those that unconsciously think "being young and strong is the same as standing high sound levels". In order to feel accepted in such a group you won't use hearing protection even if there is a need for it.

SCIENTIFIC KNOWLEDGE

OPINIONS

Science and opinions - Comment material

There is no absolutely correct answer to all the statements made. How we evaluate and judge these statements depends on how we interpret them. Our primary intention is not for the pupils to come up with the ’right’ answer, but that their discussion of the different statements will contribute to developing their competence in judging what is scientific knowledge and what is not. In addition, this exercise contributes to pupils learning more about health issues in relation to sound environments.

One way of classifying these statements (which can be of help to teachers) is presented below.

The following statements are based on scientific knowledge:

The sound level at a disco and concerts where young people are under the age of 12 should not be more than 90 decibels. They are more sensitive since their outer ear canal is shorter.

If we put our hand on a red-hot plate on a stove, we immediately snatch it away before we’ve even had time to think about it. However, when our ear is exposed to loud sounds, there is no such protection. We cannot feel when the sound level is harmful.

The ear can stand a certain amount of noise, but then it must rest. If you have been in environments with a lot of noise, it is important to be in a quieter environment for the rest of the day.

Permanent tinnitus caused by loud sound cannot be cured. However, there is help to be got in order to be able to cope with it.

In a study from 2003 done by a Swedish researcher, it was found that 74 % of the rock musicians had some form of hearing impairment.

It’s not good to have loud music because there are tiny hairs in the cochlea. If they break, your hearing can be damaged.

The medical definition of tinnitus is: Sound that is heard all the time but which does not come from any outer sound source.

You should put loud speakers high up on a shelf so that the people that are dancing don’t get the sound straight into their ears. The sound level gets less the further you are from the loud speaker.

In a study from 2003, it was shown that in nearly half of the discos in Sweden the sound level was too high. The same problem existed in many premises used for training sports.

A banger or a rocket can cause hearing loss if you stand too close. A number of people have damaged their hearing in this way.

Research shows that the sound level at a disco is often raised in the course of an evening.

Several studies show that musicians prefer loud sounds even if they are worried about their hearing at the same time.

There is special music hearing protection that muffles the loud. The sound can be reduced by 9, 15 or 25 decibels. The advantage of music hearing protection is that all tones are muffled without spoiling the sound quality, which most other kinds of hearing protection do. Therefore the music quality is like the one you get in reality but just a little softer.

You can get help to cope with your tinnitus by practising thinking of something else besides the disturbing sound. This method might work rather well, but it can take a long time to change to this way of thinking. Experts in hearing care centres can provide such help.

Worry and stress (even unhappy love) might make your tinnitus worse.

Auditory experts sometimes use something called a sound simulator when helping people with severe permanent tinnitus. The impaired person wears an apparatus that makes sound so you don’t only hear the noise from tinnitus. This helps the brain to concentrate on other sounds than the frustrating tinnitus sound.
If they use an apparatus of this kind 8 hours a day, it can take 1-2 years for many impaired persons to learn to live with a difficult form of tinnitus.

We are born with approximately 20 000 hair cells and if they are damaged, they can never grow again. It is the hair cells in the inner ear that transform vibrations into electric impulses. These impulses are then sent on to the brain via the auditory nerve.

You can get life-long tinnitus after listening to loud music in MP3 players.

It doesn’t matter whether you like the music you listen to or not. You can get tinnitus in any case.

Children and young people that listen to far too loud music in their MP 3 players are mostly unconscious of it. Besides, they don’t believe they themselves will ever suffer from hearing impairment. *(Research shows that this way of thinking is very common and a risky way of thinking).*

The most common way of thinking among young people is: Loud music is only risky for others but not for me.

In groups of young people there are those that unconsciously think “being young and strong is the same as standing high sound levels”. In order to feel accepted in such a group you won’t use hearing protection even if there is a need for it.

The following statements are purely pupils’ opinions and lack scientific underpinnings:

The one who don’t want high sound levels at a disco can go home.

One way of protecting your hearing is to raise the volume of the ’cool’ songs and lower the volume of the soft ones. *(Comment: This is inappropriate).*

You can always rely on the disc jockey making sure that the sound levels will not be so high as to be harmful.

You can turn down the base in your CD player or in your hi-fi and then it’s not so risky to have a loud volume. *(Comment: The treble sounds are more dangerous than the bass sounds since speech is in this range. Thus thinking in line with the opinion above is very risky).*

If you don’t agree about the volume at a party or at a disco you should vote. Then the decision will be a good and fair one that nobody can complain about. *(Comment: Should a democratic standpoint in your own class be more important than health issues? As far as sound levels are concerned, there are democratically passed laws based on knowledge of what is harmful. The results from the National evaluation of the compulsory school in Sweden (2003) showed that many pupils put democracy before health).*

Those who are bothered by tinnitus at a disco should go home or take a walk with a mate to feel better. Then come back if he or she feels better. All the others that want to lower the volume can manage high sound levels if they aren’t bothered by tinnitus. Otherwise they can go home as well. That is why I think it is unfair to say: “Lower the volume!” If I were one of those that like high sound levels, then it would be a crashing bore if they lowered them.

All the talk about high sound levels is exaggerated. I often listen to loud music and **I** haven’t got any hearing impairment. (*Comment: The statement challenges pupils’ ideas of myself as not being vulnerable to loud sounds).*

The following statements can be interpreted in different ways:

A disc jockey can hire sound equipment that can damage a person's hearing in a short period of time. Some people are of the opinion that the people who hire equipment like this should have a "sound (driving) licence"! *(Comment: This statement is based on the opinion of people, and their opinions are based on scientific knowledge).*

Adults should take responsibility and look after the sound volume at discos in school so that the sound level does not get too high. *(Someone has an opinion but this opinion might be based on scientific knowledge of sound levels).*

If I were at a disco I would lower the sound volume if it was too loud cause I want to take care of both myself and others. Those who listen to loud music risk getting tinnitus, which is rather common nowadays. *(This seems like an opinion, but this statement can also be interpreted to mean that this person knows that sound levels can damage your hearing).*

Those who are sensitive to loud sounds can carry earplugs with them whenever they go to a hockey game, handball match or a musical event. Then we would get rid of the problem of having to check sound levels. *(There are persons that have got hearing impairments at these types of events. In that way the statement is based on scientific knowledge. This is also the case with using earplugs when the noise is too loud. But if you say that you don't need to control the sound level, it's an opinion.*

It's better that some people think that the music is too low rather than some people getting a pain in their ears. (*Someone has an opinion and this opinion might be based on scientific knowledge about hearing impairment).)*

It’s up to me to decide

Here are a number of suggestions for how you can think or what you can do in different situations. Be totally honest and think carefully about what you choose to do. Put an ‘X’ in the box that you think fits best.

	Yes, this is what I would choose to do	Yes, this is maybe what I would choose to do	Don’t know	No, I don’t think I would choose to do this	No, I would not choose to do this
If I thought the sound level at a disco was too high, I would tell the person responsible for changing it.					
I think it is embarrassing to tell the person responsible to lower the sound level, so I don’t say anything.					
If we have voted about the sound level and raising it wins, I think it is ok to raise it although I really want to lower the volume. Democracy is more important than your health.					
I am going to use earplugs at concerts if the sound level is too high.					
I want to use ear plugs at concerts really, but it’s embarrassing. That’s why I don’t use them.					
I lower the sound level in the ear plugs that belong to e.g. my MP3 player if I think it is too high, even though I actually like to have it high.					
I seldom think that my hearing can be damaged by high sound levels. That’s why I don’t care.					
I don’t do anything about the sound volume even though I think that my friends’ hearing can be damaged when the volume is loud.					

The sound level at the disco – Verbal introduction

THE SCHOOL DISCO

Lucy filled a bowl with the last bag of crisps and threw away the empty bag.
- Done at last, she thought and added loudly: The rest of them will come in 20 minutes.
She looked around the school dining hall. All the tables had been taken away and the chairs put aside, along the walls. Several bowls of candy, pop corn, crisps and bottles with soft drinks were placed on the tables. Lucy felt her mouth watering and couldn't resist having some delicious crisps. There was a small table they'd left in the corner. It was for the DJ to use when playing records. She and the others in the prep group had done an excellent job! They had had a vote on who should be the DJ. Finally the pupils' council had suggested that it ought to be someone from the ninth year and that it should be voted on. Patrick had won. He was pretty popular, and several girls in the school were secretly in love with him. Perhaps that was the reason why he had received so many votes…?

Jane combed her hair a last time, set up her fringe with a pin and smiled in the mirror. She loved dancing and enjoyed going to discos very much! Only it was nerve-wrecking dancing cheek to cheek, especially if it was someone that you were in a little in love with.
– Jaaaane, we have to go now! Otherwise you will be too late for the disco! Jane's mother called out from the kitchen and Jane bounced down the stairs to the hall and put her jacket on.

Pete was upset and kicked angrily away a piece of stone. He and his mother had just had a big row. Pete wanted to wear his favourite jeans at the disco, but his mother wouldn't let him as they had a big hole on them.
– Stupid, daft mum, he mumbled. What does it matter if I have a tiny hole on one of the knees that hardly shows?
It all ended with Pete sneaking out through the terrace door wearing his favourite jeans without his mother noticing. He felt the joy of victory to a certain extent but was also upset and angry.

The disco would start at eight and lots of people showed up at the same time. Many had dressed up a little which suddenly made the school mates seem a little more exciting than usual. Full of expectations, they were talking and laughing, in the overly crowded cloakroom where they left their jackets. Minutes before, the prep group had been covering the windows, turned off the lights and put on the disco lamps that they had borrowed. Patrick had turned on the music at a low volume and the dining hall looked very different from usual. Now the disco could really start and Patrick put on a cool song and raised the volume. Some songs on, the dancing started seriously and almost everyone was on the dance floor. Pete, who was still in a bad mood, sat on a chair eating crisps. He wasn't the least bit interested in dancing and didn't have much fun. In contrast, Jane and Lucy were into the dancing and were having a great time.

After a while Jane thought the music was too loud. She felt it almost hurt her ears and so she went to the cloakroom to take some air and to rest a little. When she felt her ears buzzing she got a bit worried. Lucy continued dancing and enjoyed moving her body to the really good music. She gave the thumbs-up sign to Patrick who was standing fixing his records.

– Everything had turned out so well, she thought and felt a little proud of herself, that she'd been part of the preparations for the disco.

Her thoughts were interrupted by the sudden lowering of the music volume and she looked towards Patrick. Jane was standing talking next to him.

– Turn up the music! Lucy shouted.

Nothing happened so Lucy went to the DJ's table.

– Don't you hear me, or…? She wondered and wrinkled her forehead.

– Jane said she thought it was too loud, Patrick responded.

– It was not, Lucy muttered angrily. It was just right! By the way your ears get used to it after a while!

Pete, who was still sitting down with his crisps, overheard them and went over. He smiled to himself and said teasingly:

– It has been too soft the whole time – without a high volume there is no disco you know! If you can't stand it you might as well go home!

Some agreed with Pete. Patrick scratched his neck, sighed quietly, and carefully raised the volume again.

– Only nerds want a high volume, John said and pulled out a new CD for Patrick. You should go out and scream instead. You can't even talk in here with that volume!

Patrick looked bewildered and felt unsure of what to do. Suddenly he lowered the volume and said with a smile on his face.

– Lets vote about raising or lowering the volume! How many want the music to be louder?

– Hold on! Why don't we keep it in between, so that it'll be just right for everyone, someone interrupted.

– It won't work, as someone thinks just right is too low. And someone else thinks just right is too loud, there is no such thing as just right!

– We still have to decide whether we should lower or raise the volume. Either we raise it or we lower it. How many want to lower it?

Twelve hands shot up.

– And how many want to…

Patrick was interrupted by Maves, who had just entered.

– If we want a democratic decision we might as well toss a coin. Lucy thought enough was enough and burst out impatiently.

– Is there nobody who can lend some earplugs to the ones who have "tinus"? Or else you will have to hold your ears! Like this!

Demonstratively she put her fingers into her ears and shook her head.

– It's called tinnitus...which you know nothing about...right? Jane wondered.

– Loud sound is not dangerous when you like the music I've heard, Lucy said.

– You are completely wrong, all music can hurt your ear! John put in.

– Turn up the sound! Pete shouted.

– Turn it down! John shouted.

The sound level at the disco – Pupil's sheet

People are constantly having to make a lot of choices. It may concern how many sweets to buy, which film to see, when to do homework etc. In order to be able to make good decisions when you are dealing with important questions, it is easier to be aware of the arguments for and against such choices.

Perhaps you've been at a disco and wondered about the volume of the music. Perhaps you've been thinking about what volume to choose when you are listening to music on your own. Or perhaps you haven't given this any thought.

Imagine that you are at a disco where the same problem that you just have heard about arises. You do not agree about which volume is most appropriate. Some want to raise it and some want to lower it. What should you do? What do you think and why?

My choice is to (put a cross):

Raise the volume ☐ Lower the volume ☐ Not do anything at all ☐

Arguments for my choice are:………………………………………………………...

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Arguments against my choice are:…………………………………………………

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Below is what I will add after the group discussion (underline scientifically based arguments).

New arguments supporting my choice are: …………………………………………

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New arguments against my choice are::…………………………………………………

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My final choice following the group discussion is to (put a cross):

Raise the volume ☐ Lower the volume ☐ Not do anything at all ☐

What do the pupils think?

This is how real pupils have argued in support of raising the volume at a disco. What do you think of these? Put a cross in the box you think is the most appropriate.

Arguments supporting a higher volume	***Yes, I agree***	***Yes, I agree to some extent***	***I do not know***	***Well, I do hardly agree***	***No, I do not agree at all***
1. You should keep the volume high, it's not cool to turn it down.					
2. You can hear the beat better, it's more fun, you let go, it's more exciting…					
3. The sound should be loud (125dB) because if it isn't it will seem like a party for retired people.					
4. If the sound is too soft you can hear others talking. And if you start singing the others may hear and start laughing.					
5. It's easier to dance and to keep time.					
6. Without a high volume it's not a real disco.					
7. Everyone should have the right to have her/his own way.					
8. My ears are fine as I can stand high volumes.					

This is how real pupils who are in favour of lowering the volume at a disco have expressed their thoughts. What do you think? Put a cross in the most appropriate box.

Arguments against high volume.	*Yes, I agree*	*Yes, I agree to some extent*	*I do not know*	*Well, I do hardly agree*	*No, I do not agree at all*
9. It's better to lower the volume and not risk one’s life so to speak. Or else one could end up having a vacuum cleaner at 75 dB inside your ears 24 hours a day.					
10. Loud music may damage your ears, and we shouldn't vote about such a thing. Because health is more important than music.					
11. The sound volume is a problem for some pupils. So if there are some who don’t feel well, we cannot just ignore it but do the best to see to it that everyone is fine. Everybody should feel that the level of the sound is okay.					
12. One shouldn't have to shout to a friend at a distance of only 30 cm.					
13. Lowering the music volume cuts the risks of future ear pains. A high music volume does more than hurt the ears, it also causes tinnitus. And it may also harm your vocal cords as you have to speak in such a loud voice. Damaging your hearing may cause a lot of problems in future.					
14. One should take into consideration that it’s a school disco, and not a pub or a bar. At a school disco everyone should be able to attend without damaging their hearing.					