PUPIL RESEARCHER INITIATIVE

Sound Judgement

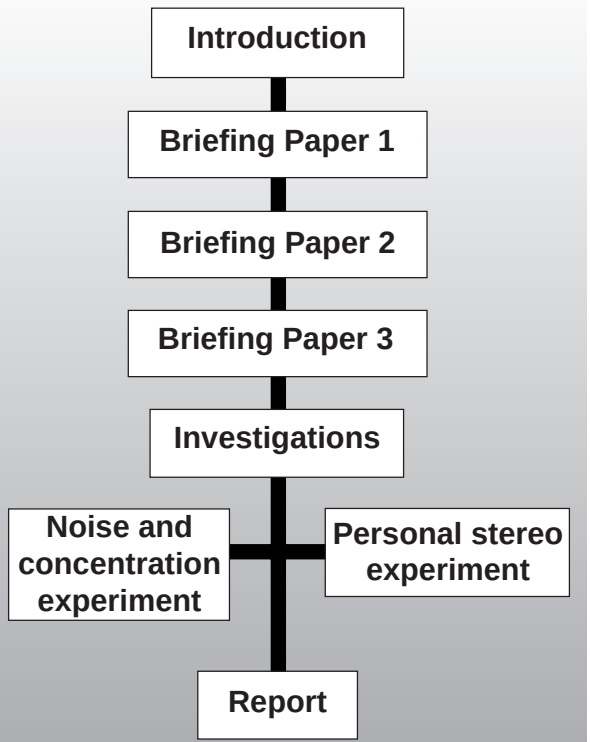
Pupil Research Brief

Teachers' Notes

Syllabus Coverage *Subject Knowledge and Understanding*

- ❏ sounds are produced when objects vibrate
- ❏ the greater the size of vibration (amplitude) the louder the sound
- ❏ the number of complete vibrations each second is called the frequency (hertz, Hz)
- ❏ you should know how to compare amplitudes and frequencies as they would appear on an oscilloscope trace
- ❏ sounds bounce back (reflect) from hard surfaces (echoes are sound reflections)
- ❏ sound travels through solids, liquids and gases as longitudinal waves

Route through the Brief



Introduction

In this Brief pupils will carry out simple investigations into the acoustics of classrooms in their school. Pupils are supplied with Briefing papers on the working of the human ear and on the causes of hearing loss. They carry out experiments on one or more classrooms to determine the background noise level and reverberation time, and they take part in a speech intelligibility test for these rooms. They write a report on their findings and make recommendations for improvements to the classrooms tested. There is also an opportunity for pupils to devise an experiment to assess the effect that noise has on concentration and memory. Pupils can also determine the sound intensity level of personal stereos.

The investigations presented in the Brief are based on research being carried out by scientists in the *Department of Building Engineering and Surveying* at *Heriot-Watt University, Edinburgh*, with support from the Engineering and Physical Sciences Research Council (EPSRC). Pilot studies done by this team and studies carried out in other countries around the world have shown it is likely that a large number of classrooms either have too high a background noise level, or are too reverberant, or both.

Experimental and investigative skills

- planning experimental procedures
- obtaining evidence
- analysing evidence and drawing conclusions
- evaluating evidence

Pupil Research Brief

Teachers' Notes continued

Prior knowledge

Before attempting this Brief pupils should know already that sound travels in waves and requires a medium for transmission. It is envisaged that frequency, amplitude, longitudinal waves and oscilloscope traces will be taught by the teacher during the course of the Brief.

Running the Brief

Pupil grouping

Pupils could work in a number of groupings during this Brief. Suggestions are :

Introduction	-	Whole class, teacher introduces the topic and sets the context for the activities
Briefing paper 1	-	Whole class, teacher uses a slinky spring to demonstrate sound waves and an oscilloscope with a signal generator and loudspeaker to demonstrate pitch and loudness
Briefing paper 2	-	Whole class, teacher uses a tape recorder to give an idea of how hearing aids work
Briefing paper 3	-	Depending on equipment available, pupils work in small groups on the investigations. Alternatively, each investigation could be given to different groups. Teacher carries out the Fairbanks Test
Effect of noise on learning	-	Individuals or in pairs. Teacher collates suggestions during whole class session and makes a final decision using the suggestions. Pupils in groups to carry out experiments, the size of the group depending on the experimental procedure selected
Personal stereos test	-	Whole class, with individual pupils testing their own personal stereos
Communication	-	individual reports of findings and recommendations for improving classroom acoustics

Timing

This Brief is likely to take at least 3 hours to teach, depending on the extent of the testing of classrooms and other spaces within the school. Writing the final report can be set as a homework exercise.

Activities and investigation details

The teacher should issue pupils with the **Study Guide**, which provides them with a summary of what they should produce as they work through the Brief. It can also act as a checklist for pupils to monitor their own progress.

The teacher should issue pupils with **Briefing Paper 1**. This contains simple information about how sounds pass into the ear and reach the cochlea via the ossicles. The teacher could work through this with pupils, using a slinky spring to demonstrate the way longitudinal waves travel. The teacher could also use a signal generator attached to a loudspeaker and connected to a cathode ray oscilloscope to demonstrate frequency and amplitude. Pupils could also test their own hearing range as the teacher turns up the frequency on the signal generator from below 20Hz to above 20kHz. Pupils should make brief notes summarising this information.

Next, the teacher should issue **Briefing Paper 2**. This contains information on the causes of hearing loss. Hearing loss may be classified as:

- *conductive,* where the cause lies in the external ear canal or the middle ear
- *sensory,* when the cochlea is affected, and
- *neural,* when the problem lies with the nervous system transmitting the signals from the cochlea to the brain.

It is usual to describe these last two types of hearing loss as senso-neural, because of the difficulty in determining the exact cause of hearing loss.

The teacher should have discreetly set up a tape recorder during a previous practical lesson to record

Teachers' Notes continued

some of the sounds being made, in order to demonstrate to pupils some of the problems and drawbacks of using hearing aids. These devices do not restore hearing to its normal state. A hearing aid amplifies speech and all other sounds as well. So, if the background noise is high, the speech or sounds the hearing aid user wishes to hear could be lost. A tape recorder also picks up a lot of unwanted noise, and so to some extent it can imitate the effect of a hearing aid.

NOTE: the Briefing Papers are written in fairly simple language in order to be accessible to lower-achieving pupils. Additional material is supplied under the heading *Background Information* in these Teachers' Notes, and it is hoped that the teacher will use this material to supplement the Briefing Papers, so as to provide higher-achieving pupils with more challenging work.

The teacher should issue pupils with **Briefing Paper 3**. This explains the main factors that affect speech intelligibility in classrooms. They are a simplified version of the investigations actually conducted by researchers at Heriot-Watt University. The teacher should issue the **classroom survey** data collection sheets (found at the end of these Teachers' Notes) for pupils to record their results. Further copies can be obtained from

http://www.hw.ac.uk/bdgWWW/home.htm

The data collected by pupils would be useful to the experts at Heriot-Watt University and they would be pleased to receive this information. You could send completed forms to:

David J MacKenzie
Department of Building Engineering and Surveying
Heriot-Watt University
Riccarton
Edinburgh
EH14 4AS.

If the equipment is available, the reverberation time of the room can be measured. Strictly speaking reverberation time is the time taken for the intensity of a sound to fall by 60dB, and it is usually measured using a sound source of 500 Hz. However, a rough estimate of a room's reverberation time can be made using a datalogger able to sample small time intervals, attached to a sound sensor. A sharp, loud sound is used, and the reverberation time can be taken as the time interval between the maximum sound level and the point where the sound intensity graph levels off.
If it is possible, these tests should be conducted in other rooms, such as an ordinary classroom, a craft workshop, a gymnasium, an art room and the school hall. Having carried out this survey, pupils should discuss in pairs or small groups possible ways of improving the acoustics in the rooms tested. They should write a report of the work they have done. Further work that can be done involves the effects of loud noises on human beings. It is generally agreed that excessive background noise can influence the achievement and behaviour of pupils. Noise adversely affects higher mental thought processes such as those used in problem-solving, as well as short-term and long-term memory. Pupils can be asked to devise an experiment to test the effect of noise on problem-solving or on memory. One possibility would be to give pupils a seven digit number to memorise. Half the class would do this in silence and the rest would listen to personal stereos. They should be given, say, one minute to memorise and 5 minutes to remember without the number in front of them. They should then write down the number. Those pupils who had retained the information should be counted from each group. Pupils should be given time to devise their own procedures. The teacher should collect these and decide which experiments to use.
Another investigation would be to measure the sound intensity of personal stereos. Pupils can set the volume of their own stereos at their usual level and measure the sound level coming out of the earpieces. It is likely that some pupils will be listening to music at a level above 90dB, the highest recommended level for safety.

The Fairbanks Test

This is a simple speech intelligibility test devised in the late 1950s by Grant Fairbanks, and published in the *Journal of the Acoustical Society of America*. The test uses five sets of 50 monosyllabic words, carefully chosen from the most common words in use. These words are presented in Table 2 at the end of these notes. As can be seen, the words in each set differ in only the first letter with the word in the corresponding position in the other sets. These words are put into sentences that have no real meaning, and the teacher should read these sentences in a normal voice, not placing any emphasis on the test words. Pupils have an answer sheet with the 50 words in order on it, but with the first letter missing. As the teacher reads out the sentences which include the test words pupils should fill in the missing letters on their sheet. The teacher now marks the answer sheets, and the percentage of correct answers will be a rough measure of how clearly speech can be discerned in the room. For a different room the same sentences can be used, but with the test words being replaced by the words from another set.
The sentences could be anything, but the signal that the test word is coming up should be the same each

time. An example of the sorts of sentences that can be used is given at the end of these notes. Pupils will need to be told what to do, and so **the first two sentences in this given example contain words that do not appear in the sets of test words.**

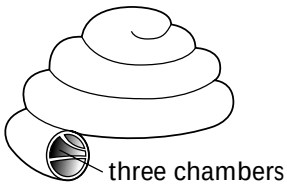


Figure 1. The cochlea

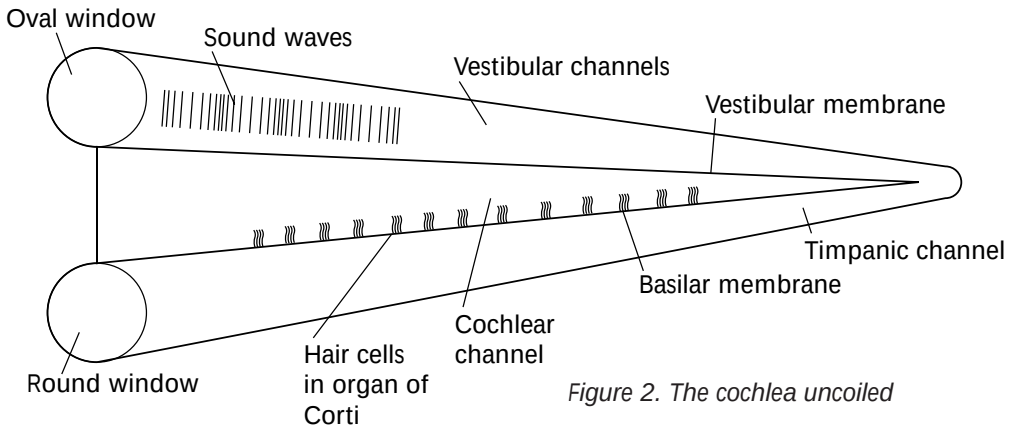


Figure 2. The cochlea uncoiled

Technical details

Equipment needed will include:

slinky spring
signal generator and loudspeaker
cathode ray oscilloscope
sound intensity meter
tape recorder
personal stereos
datalogger and sound sensor

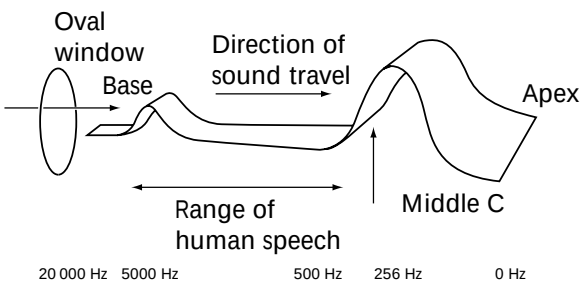


Figure 3. The basilar membrane

Background information

The functioning of the ear

Sound entering the ear passes down a tube roughly 2.4cm long (the ear canal or external auditory meatus) and sets a thin membrane called the eardrum vibrating. The 3 bones that connect the eardrum to the cochlea are known collectively as the ossicles. These bones act as levers and they amplify the sound vibrations that enter the ear. The stirrup bone pushes against the entrance to the cochlea, the oval window, with 22 times greater pressure than that felt at the eardrum. Figure 1 shows a diagram of the cochlea, which in reality is about the size of a pea. Figure 2 shows a diagram of the inside of the cochlea, uncoiled. The cochlea is filled with a fluid, and the base of the central cavity, the basilar membrane, is flexible. It is lined with hairs which are sensor cells that detect the motion of the membrane. When the stirrup bone pushes the oval window waves are sent through the liquid inside the cochlea.

These pressure waves in the fluid send snake-like waves of motion down the basilar membrane. The membrane is narrower and slightly stiffer at the end closest to the oval window (the base) and wider and looser at the other end (the apex). High-pitched sounds affect the membrane nearer the apex the most. This is shown in Figure 3. So, each part of the basilar membrane responds to only a very narrow range of pitches. The height of the wave as it travels along the membrane depends on the loudness of the sound. When the membrane moves the hair cells bend and generate tiny electrical pulses that are sent down the auditory nerve to the brain as speech, music or whatever the sound is that went into the ear.

Teachers' Notes continued

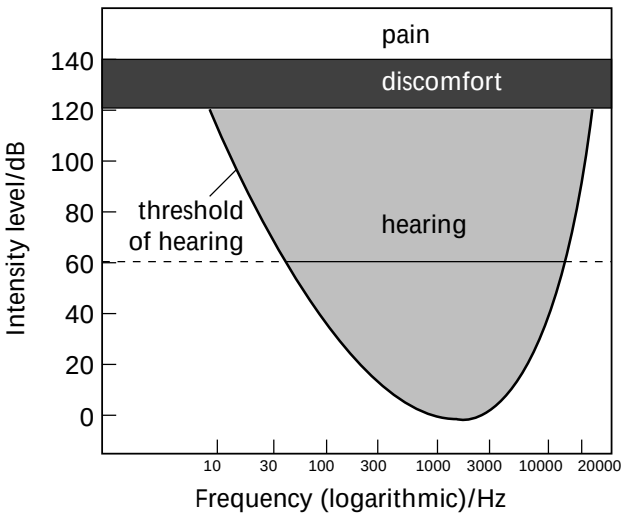


Figure 4. Human hearing range and sound intensity

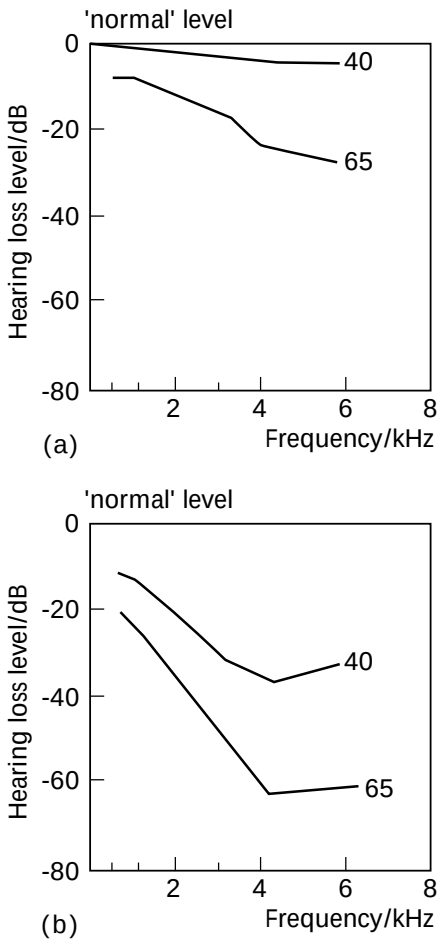


Figure 5. Hearing loss with age (a) 40 year old man (b) 65 year old man

The ear is an immensely sensitive organ. The quietest sound that is detectable by human beings is caused by a change in air pressure of only 2×10^{-5} Pa. Since normal air pressure is around 1×10^{5} Pa, this is an extremely small fluctuation in pressure. Humans can hear sounds with pitches between 20 Hz and 20 000 Hz (20 kHz), as can be seen in Figure 4, but as we get older the range gets smaller, and we lose particularly the top end frequencies. We don't hear all sounds equally well. The ear is more sensitive to sounds with pitches between 2000 Hz to 5000 Hz. So, a note of 300 Hz at, say, 80 dB will not seem to be as loud as one of 3000 Hz at the same decibel level. This is why some sound level meters have a switch marked dB(A) which makes the instrument respond to sound levels in the same way that we do. Noise affects the sensitivity of our hearing. If we are exposed to loud sounds for a prolonged period we become tolerant to the noise.

Two tiny muscles within the middle ear can undergo a reflex action stimulated by loud noise. This causes them to contract. One muscle pulls on the eardrum, and the other on the stirrup bone. This reduces the amount that the ossicle can move and is known as a *temporary threshold shift*.

Afterwards we remain slightly deaf for a time, but our hearing recovers. The louder the noise and the longer the exposure to it the more time it takes to get our normal hearing back. If we are exposed to loud noises for long periods day after day, our hearing will be damaged permanently. This is the result of a *permanent threshold shift*. A ringing in the ear which may occur after expsure to loud noise is called *tinnitus.* This usually disappears after a day or so. Tinnitus can be permanent, and can have other causes. Sometimes the sounds heard by tinnitus sufferers can be quite bizzare (not just ringing) and can cause severe stress. The Czech composer Smetana suffered tinnitus in middle age, and this eventually led to his mental collapse.

Figure 5 shows hearing loss with age. Graph (a) shows graphs for a person aged 40 and one aged 65. As previously stated, almost all people experience some hearing loss as they get older. Graph (b) shows the hearing loss for a 40 year old and a 65 year old who have been exposed to the equivalent of 96 dB of noise for 8 hours a day, 5 days a week since their 18th birthdays.

There is severe loss of sensitivity to frequencies above 3000 Hz (3 kHz) in both the 40 year old and 65 year old. This causes problems in understanding some important elements of speech and can spoil the enjoyment of music.

NOTE: the decibel scale is not a linear scale, like the scale on a ruler. The sound level doubles for roughly every 3dB rise so, a noise of 43 dB is twice as loud as a noise of 40 dB.

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Teachers' Notes Continued

In the UK there are recommended exposure times for various noise levels encountered in the work place. They are presented in Table 1 below. In the USA workers are not allowed by law to be exposed to noise levels above 115dB, even momentarily.

Table 1. Recommended exposure times for noise levels in the workplace

Sound level (dB)	90	93	96	99	102	105
Maximum exposure time (hours per day)	8	4	2	1	0.5	0.25

Workers generally do not experience the same noise level constantly throughout the working day. Sounds fluctuate in intensity. So, there is something called the *equivalent continuous sound level*, Leq. This is that sound level which, if constant for a defined period, would give an equivalent exposure to that received. The defined period is usually 8 hours in dBA. Leq[8h] should never rise above 90dB.

Assessment issues for *Experimental and Investigative Science* (National Curriculum for England and Wales)

P	Planning	O	Obtaining evidence
A	Analysing evidence	E	Evaluating evidence

This Brief contains one main investigation, divided into a number of sections. One of the aims of the investigation is to produce standardised data to enable the comparison of the acoustic properties of one room with another. This means that the method is quite prescriptive, and therefore the investigation is not suitable for assessment of **Skill Area P.** The collection of the data may be divided across different groups in the class, with the teacher putting the whole picture together, although it would be possible for each group to collect all the required data themselves. This must be taken into account when looking at **Skill Area O.** The amount of guidance given in the Brief on the method for the investigation could limit the marks to the middle range, but high marks are possible if some of the guidance about the appropriate number and range of measurements is not given to the pupils. However, this may reduce the comparability of the results. High marks should be possible for **Skill Areas A** and **E.**

Assessment issues for *Experimental and Investigative Science* (Northern Ireland Curriculum)

P	Planning	O	Obtaining evidence
I	Interpreting and Evaluating		

(See notes for England and Wales about **Skill Area P** and **O**). High marks should be possible for **Skill Area I.**

Scottish syllabus coverage

Standard Grade Physics - *Telecommunications* and *Health Physics*

Further pupil research opportunities

The *Background information for teachers* article (at the end of these Teachers' Motes, entitled *Can Mozart make maths add up?* from *New Scientist* describes how three teams of students listened to 10 minutes of a Mozart sonata or minimalist music or silence before carrying out a simple task involving predicting patterns of shapes cut out of folded paper. The results showed that those who listened to Mozart did significantly better than the other two teams. Pupils could repeat the experiment and extend it to other types of music. Will listening to *indie* music help them in the task more than *heavy metal* or *dance* music? They could also carry out different tasks involving other skills to see if listening to music beforehand enhances a whole range of abilities or not.

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Teachers' Notes Continued

Examples of sentences used for the Fairbanks Test
The same sentences could be used for other tests, but with the next set of words used in place of the ones in bold type.

Note: The first two sentences (underlined) are to give pupils a 'dry run' before starting the test.

Bricks are bricks also write down **dog** now. Table is broad also write down **toy** now. The river was narrow also write down **hot** now. They crossed the road also write down **pay** now. Then and there also write down **top** now Three hundred pounds also write down **peel** now. The cow lay still also write down **wake** now. Paper and fire also write down **law** now. It is a success also write down **vile** now. Stone and timber also write down **neat** now.
The fire engine also write down **look** now. The tourist stopped also write down **fill** now. The shops are closed also write down **tire** now. Guns guard the coast also write down **male** now. The dive fell short also write down **sent** now. Kick the ball also write down **moon** now. Trees in the wood also write down **kick** now. The bright light shines also write down **same** now. Rain is forecast also write down **wide** now. The clock struck also write down **rip** now. Houses are buildings also write down **sore** now. Castle on a hill also write down **bang** now. Bricks for rubble also write down **men** now. The set of china also write down **park** now. The stray cat sat also write down **coil** now. Green kittens followed also write down **big** now. Raced down the road also write down **rage** now. The river was narrow also write down **cast** now. They crossed the road also write down **gain** now. Then and there also write down **nest** now. Three hundred pounds also write down **gun** now. The cow lay still also write down **heal** now. Paper and fire also write down **sin** now. It is success also write down **bust** now. Stone and timber also write down **fine** now. The fire engine also write down **mink** now. The tourist stopped also write down **sold** now. The shops are closed also write down **hit** now. Guns guard the coast also write down **led** now. The dive fell short also write down **tend** now. Kick the ball also write down **rid** now. Trees in the wood also write down **back** now. The bright light shines also write down **tail** now. Rain is forecast also write down **fight** now. The clock struck also write down **torn** now. Houses are buildings also write down **rod** now. Castle on a hill also write down **dock** now. Bricks for rubble also write down **bump** now. The set of china also write down **date** now. The stray cat sat also write down **well** now. Green kittens followed also write down **set** now. Raced down the road also write down **luck** now.

	RT-1	RT-2	RT-3	RT-4	RT-5
1	hot	got	not	pot	lot
2	pay	may	day	way	say
3	top	hop	pop	mop	cop
4	peel	reel	feel	heel	keel
5	wake	take	make	cake	lake
6	law	saw	jaw	paw	raw
7	vile	mile	file	tile	pile
8	neat	seat	beat	heat	meat
9	look	cook	hook	took	book
10	fill	kill	will	till	bill
11	tire	hire	sire	fire	wire
12	male	tale	sale	pale	bale
13	sent	rent	went	bent	tent
14	moon	noon	goon	boon	soon
15	kick	sick	lick	tick	pick
16	same	fame	name	came	game
17	wide	tide	side	ride	hide
18	rip	dip	lip	hip	tip
19	sore	bore	tore	more	wore
20	bang	hang	sang	gang	rang
21	men	den	hen	pen	ten
22	park	bark	lark	mark	dark
23	coil	foil	boil	soil	toil
24	big	wig	dig	fig	pig
25	rage	cage	page	sage	wage
26	cast	past	fast	last	mast
27	gain	pain	main	rain	vain
28	nest	west	test	best	rest
29	gun	nun	run	sun	fun
30	heal	deal	seal	zeal	meal
31	sin	win	tin	din	pin
32	bust	just	must	rust	dust
33	fine	mine	wine	nine	line
34	mink	link	pink	wink	sink
35	sold	told	hold	cold	gold
36	hit	sit	wit	fit	bit
37	led	bed	red	wed	fed
38	tend	send	bend	lend	mend
39	rid	bid	kid	did	hid
40	back	lack	pack	jack	sack
41	tail	sail	mail	nail	fail
42	fight	light	right	might	night
43	torn	worn	born	horn	corn
44	rod	god	cod	sod	nod
45	dock	mock	cock	lock	rock
46	bump	pump	lump	dump	jump
47	date	rate	gate	late	hate
48	well	fell	tell	bell	sell
49	set	let	get	yet	met
50	luck	tuck	duck	suck	buck

Pupil Research Brief

Sound Judgement - pupil answer sheet

Fairbanks Test

1	___	ot	**26**	___	ast
2	___	ay	**27**	___	ain
3	___	op	**28**	___	est
4	___	eel	**29**	___	un
5	___	ake	**30**	___	eal
6	___	aw	**31**	___	in
7	___	ile	**32**	___	ust
8	___	eat	**33**	___	ine
9	___	ook	**34**	___	**i**nk
10	___	ill	**35**	___	old
11	___	ire	**36**	___	it
12	___	ale	**37**	___	ed
13	___	ent	**38**	___	end
14	___	oon	**39**	___	id
15	___	ick	**40**	___	ack
16	___	ame	**41**	___	ail
17	___	ide	**42**	___	ight
18	___	ip	**43**	___	orn
19	___	ore	**44**	___	od
20	___	ang	**45**	___	ock
21	___	en	**46**	___	ump
22	___	ark	**47**	___	ate
23	___	oil	**48**	___	ell
24	___	ig	**49**	___	et
25	___	age	**50**	___	uck

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Sound Judgement - classroom survey: *impressions*

Name	Year/Class/Form
School Address	
Room being studied	Date
What is your personal opinion of the classroom you have chosen in terms of noise	noisy / in-between / quiet
Do you find the noise level in the classroom acceptable?	yes / sometimes / no
What are the main sources of noise, if any, that are created outside the classroom itself, e.g. road traffic?	
Does the noise level change in the classroom when you open: a window a door?	yes / sometimes / no yes / sometimes / no
How would you describe how the noise affects you in the classroom?	
At what time of day is the noise more noticeable?	
Can you hear clearly what the teacher is saying to you?	
Can you hear clearly what other pupils are saying to you during small group discussions?	
Describe your overall impression of the classroom.	
Please return completed forms to: David J. Mackenzie, Heriot-Watt University, Department of Building Engineering and Surveying, Riccarton, Edinburgh, EH14 4AS Telephone: 0131 449 5111 Ext. 4620 Fax: 0131 451 3161	

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Sound Judgement - classroom survey: *measurements*

Name						Year/Class/Form				
School Address										
Room being studied						Date				
Plan of room					Length (m)		Width (m)			
					Height (m)		Volume (m^3)			
					Windows	No.	Area	m^2		
					Doors	No.	Area	m^2		
					Materials on the room's surfaces Wall Ceiling Floor Objects in room					
Noise levels in the room - measured in dB(A)										
Measurement	1	2	3	4	5	6	7	8	9	10	Mean
Empty room: windows and doors closed											
Empty room: windows open and doors closed											
Empty room: windows closed and doors open											
Pupils in room: quiet											
Pupils in room: talking to each other											
Pupils in room: teacher talking, pupils quiet											
Please return completed forms to: David J. Mackenzie, Heriot-Watt University, Department of Building Engineering and Surveying, Riccarton, Edinburgh, EH14 4AS Telephone: 0131 449 5111 Ext. 4620 Fax: 0131 451 3161											

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Sound Judgement - classroom survey: *hot spots*

Name	Year/Class/Form
School Address	
Room being studied	Date

1. Draw an accurate plan of the classroom in the space below.
2. Draw all the desks, chairs and other furiniture.
3. Show where the chalkboard/whiteboard is.
4. Place the loudspeaker in front of the chalkboard/whiteboard, and using white noise adjust the level to get 67.5 dB(A) at 1m in front of the speaker.
5. Using a sound level meter set to dB(A), measire the resulting sound level at ear height at each desk within the classroom (do not stand in between the speaker and the sound level meter).
6. Identify areas in the classroom which may be louder or quieter and work out why this is so.

Please return completed forms to: David J. Mackenzie, Heriot-Watt University, Department of Building Engineering and Surveying, Riccarton, Edinburgh, EH14 4AS
Telephone: 0131 449 5111 Ext. 4620 Fax: 0131 451 3161