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Learning abstract concepts such as sound often involves an ontological shift since to conceptualize sound transmission as a process of motion demands abandoning sound transmission as a transfer of matter. Thus, for students to be able to grasp and use a generalized model of sound transmission poses great challenges for them. This study involved 199 students aged 10-14. Their views about sound transmission were investigated before and after teaching by comparing their written answers about sound transfer in different media. The teaching was built on a research-based teaching-learning sequence (TLS), which was developed within a framework of Design Research. The analysis involved interpreting students' underlying theories of sound transmission, including the different conceptual categories that were found in their answers. The results indicated a shift in students' understandings from the use of a theory of matter before the intervention to embracing a theory of process afterwards. The described pattern was found in all groups of students irrespective of age. Thus, teaching about sound and sound transmission is fruitful already at the ages of 10-11. However, the older the students, the more advanced is their understanding of the process of motion. In conclusion, the use of a TLS about sound, hearing and auditory health promotes students' conceptualization of sound transmission as a process in all grades. The results also imply some crucial points in teaching and learning about the scientific content of sound.

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Introduction

According to Reiner, Slotta, Chi and Resnick (2000), students tend to attribute properties or behaviours of material substances to abstract concepts such as force, light, heat and electricity. Sound and sound propagation can also be considered abstract concepts, because in a similar way to them are often attributed material properties. Learning such concepts requires

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1
2 the students to reconstruct their ideas related to matter into process views, and such
3 reconstruction involves conceptual change. Ideas of conceptual change were used by Hewson
4 (1981) and Posner, Strike, Hewson and Hertzog (1982), and they suggested a conceptual shift
5
6 when students were confronted with new experiences that did not fit in with previous ideas.
7
8 According to Treagust and Duit (2008), since the 1980s the meaning of conceptual change
9
10 has been widened from a focus on science concepts to considering epistemological as well as
11
12 ontological and affective domains. During this period, there have been discussions about
13
14 whether misconceptions are fragmented or coherent, but Chi (2005) questioned this debate
15
16 and called for a greater focus on explaining why some misconceptions may be more
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18 entrenched than others.
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22 Conceptions might be restructured in different ways due to their initial status (Chi, 2008;
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24 Chi, Slotta & De Leeuw, 1994). Incomplete conceptions are developed by adding new
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26 components in order to fill the gap, (enrichment), whereas conceptions that are ontologically
27
28 miscategorised are robust and difficult to revise because they have to be re-structured into a
29
30 new ontological category, (radical conceptual change). In order to develop the meaning of a
31
32 concept from a matter-based view to a process view, where the focus of the concept changes
33
34 from transportation of matter to transmission of motion, the students need to re-assign the
35
36 concept from one ontological category to another (Carey, 1991; Chi et, al., 1994). Vosniadou,
37
38 Vamvakoussi and Skopeliti (2008) asserted that the kind of conceptual changes that involve
39
40 ontological-category shifts require more radical changes, and that is why these concepts are
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42 more difficult to learn.

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44 In addition to the conflicting matter versus process category, there is a conflict within the
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46 process category, i.e. between direct processes versus emergent processes (Chi, 2008).
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48 Emergent processes are described by Eshach and Schwartz (2006) as 'interactions of large
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50 numbers of smaller pieces that somehow combine in different ways to create the large-scale
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1
2 pattern' (p. 1495). One of their examples is waves, where the motion of the wave is very
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4 different from the motion of the constituent parts. In direct processes, the behaviours of the
5
6 various constituent components are quite distinct and they are a direct cause of the global
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8 pattern of flow, such as its direction and speed (Chi, 2008). Often the emergent process, the
9
10 large-scale pattern, is mixed-up by the students with the direct processes, the motion of the
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12 constituent parts; assigning the characteristics of the large-scale pattern to the constituent
13
14 parts. In order 'to correct such a misconception requires a re-representation or a conceptual
15
16 shift across ontological kinds' (Chi, 2005, p. 161). Consequently, developing learners' ideas
17
18 from thinking of direct process to emergent process is another radical step.

19
20 This paper analyses students' conceptual understanding of sound and sound transmission
21
22 before, immediately after and one year after teachers' use of a research-based teaching-
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24 learning sequence. The teaching-learning sequence was designed with the overall aim to
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26 investigate 10-14 year old students' learning of sound, hearing and auditory health.

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27 28 **Learning about sound**

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30 The research literature contains a number of studies in which different methods have been
31
32 used to investigate pre-school to university level students' learning about sound. The focus of
33
34 these studies varies: some deal solely with conceptual understanding, while others look at the
35
36 relation between the design of teaching, conceptual understanding and/or epistemic
37
38 development.

39 40 ***The origin of sound***

41
42 Watt and Russel (1990) reported that school children aged 6-10 often attributed the
43
44 production of sound by an object to the properties or impact of that object, and whether sound
45
46 caused vibrations or vibrations caused sound seemed to depend upon the context. Similar
47
48 results were found in the study by Asoko, Leach and Scott (1991; 1992) in which the 200
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1 participants, aged 4–16, were asked to make sounds in different ways and explain how the
 2 sound arose. Asoko et al. showed that in certain situations, such as sounds from colliding
 3 stones or from a horn, it became difficult for the individuals to explain the production of
 4 sound. In conclusion, the researchers stated that children/students, even older ones, did not
 5 possess any general theory for the origin of sound that was applicable in new situations.
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12 *Sound transmission*

13 Several researchers have reported that students, [ranging from 6 years to university age](#), tend to
 14 attribute material properties to sound. In these studies, various ways of describing the material
 15 properties of sound are identified; at a micro level where sound is a material entity or small
 16 things that are moved, or at a macro level where sound is a discrete object-like substance,
 17 such as air or wind, which is transported. Seeing sound as something material results in
 18 believing that sound can easily pass through a vacuum and that sound needs a free passage
 19 through materials. Therefore, sound cannot pass through solids unless there are visible holes,
 20 like spaces under doors, cracks, keyholes or microscopic holes. [Another idea is](#) that sound can
 21 pass through a material if the ‘sound material’ is harder, thus referring to properties of the
 22 materials i.e. the relative strengths of the materials. In this case, the material sound is able to
 23 experience friction, and consequently the sound speed is slower the denser the medium.
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37 Many researchers have investigated the learners’ ideas of sound transmission in
 38 connection with teaching interventions. Houle and Barnett (2008) found that half of the
 39 students [in grade 8](#) held a matter-based view before the teaching intervention and there was
 40 no significant change afterwards. Many of the students conceived sound as molecules instead
 41 of conceptualizing sound as energy transfer by means of molecules. The belief that sound is
 42 pushable was also identified and this idea increased after the intervention. Similarly, Caleon
 43 and Subramaniam (2010a) reported on results after a teaching intervention in which more
 44 than half of the students [in grade 10](#) considered that sound propagates because sound
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Deleted: Watt and Russel (1990) and Asoko et al. (1991, 1992) in the studies mentioned above; Mazen and Lautrey (2003) from their interviews of 89 French children aged 6-10; Chang et al., (2007) in questionnaires from 3 639 students in grade 6 from Taiwan; Lautrey and Mazens (2004) from interviews of 83 8-year-old French children; Barman, Barman and Miller (1996) from their study of different teaching strategies in two groups of a total of 34 American students in grade 5; Eshach and Schwartz (2006) from an interview study of 10 Israeli students’ preconceptions from grade 8; Houle and Barnett (2008) from a study of approximately 100 students in 8th grade before and after teaching; Maurines (1993) and Viennot (2001) in questionnaires from 550 French students in grade 9 and 10 before and after teaching; Fazio, Guastella, Sperandio-Mineo and Tarantino (2008) in a study of 75 students’ learning aged 16-17 in a science orientated school; Caleon and Subramaniam (2009a) from 243 well-achieving grade-10-students from Singapore after they had been taught about the nature and propagation of waves; Caleon and Subramaniam (2009b) from 598 grade 9 and 10 students from Singapore after a teaching intervention; Linder (1992, 1993), Linder and Erickson (1989) and Wittman, Steinberg and Redish (2003) from their research on university students in physics.

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2 transports the particles of the medium away from the source. Further, Maurines (1993) and
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4 Viennot (2001) reported that many [grade 9 and 10](#) students answered that sound is transmitted
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6 in vacuum but not in solids. After teaching, one third retained the idea that sounds propagates
7
8 faster in vacuum than in water and steel. However, the majority knew that sound could not be
9
10 recorded in a vacuum, but still many believed that sound propagated faster in liquids than
11
12 solids. Their explanations were based on whether the molecules could move or not. In
13
14 comparison, slightly more than one tenth of the [grade 10](#) students in the study by Caleon and
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16 Subramaniam (2010a) believed after the intervention that sound travels slower in solids than
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18 gases because the former is denser than the latter. However, half of the students expressed the
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20 opposite; they held a more scientific view. The idea, that the denser the medium is the more
21
22 difficult for sound to pass through, is also in accordance with [the university students'](#)
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24 [reasoning reported by Linder \(1993\)](#). It is as though the molecules in a medium are obstacles,
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26 either because they are too big or too close.

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28 Fazio, [Guastella, Sperandeo-Mineo and Tarantino](#) (2008) also reported on the
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30 conceptualization of the medium when assessing [16-17 year old science-orientated](#) students'
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32 learning by comparing their mental models, i.e. internal representations that they form and use
33
34 while interacting with the environment, from pre- and post-test [results](#). The analysis of the
35
36 results suggested that half of the students [who](#) considered the medium [through](#) which sound
37
38 passes to be passive (metal/water obstructs, hinders sound propagation) maintained this
39
40 reasoning at the post-test. However, half of those students with the preconception that closer
41
42 particles involve faster propagation (closer atoms/molecules transfer sound in a faster way)
43
44 shifted to a scientific model including considerations about elastic and inertial properties.
45
46 Thus, Fazio et al. concluded that students who are able to represent mechanisms of
47
48 propagation through interactions between molecules, or atoms, can modify their reasoning
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50 and arrive at the correct scientific solution as a result of teaching. According to Fazio et al.,
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2 students' learning advances, 'via some intermediate or *transitional states*, from initial,
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4 scientifically more or less incorrect, views to scientific views' (p. 1518).
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6 Confusion about the role of air was found in several studies. Watt and Russel (1990) noted
7
8 that some students, aged 6-10, stated that sound can be transmitted through air, but what they
9
10 meant by air was often unclear. Moreover, many students from French secondary schools who
11
12 believed that sound can be transmitted through water, explained that water must contain gas,
13
14 air or oxygen (Maurines, 1993). Thus, Maurines argued that these students did not understand
15
16 the mechanism for transmission in water. The presence of air as a prerequisite for the
17
18 propagation of sound even if other media are present was also emphasized in other studies
19
20 representing students in grade 8 (Eshach & Schwartz, 2006) and students in grade 10 (Caleon
21
22 & Subramaniam, 2010a). In addition, Houle and Barnett (2008) reported that some students in
23
24 grade 8 stated that sound is air molecules. In conclusion, there seem to be confusion about the
25
26 different media and its constituents, as well as the role of air as medium or as being sound.
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28 Sound may also be conceptualized as something immaterial or abstract (Lautrey &
29
30 Mazens, 2004; Linder & Erickson, 1989; Mazens & Lautrey, 2003). Mazens and Lautrey
31
32 (2003) showed that one-third of 6-10 year old students' explanations referred to arguments
33
34 pertaining to the immaterial nature of sound. Beyond that the children/students used words
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36 referring to resonance and vibration phenomena, even though the scientific explanation was
37
38 not known. The term vibration began to emerge in second grade and was described by a third
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40 of students in grade 4.
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42 *Representations of sound transmission*

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44 Representations are important for learning science (Lemke, 2003; Norris & Phillips, 2003;
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46 Prain & Tytler, 2007; Prain, Tytler & Peterson, 2009). Sound and sound propagation can be
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48 represented and expressed in different terms. Frequently used terms in connection with
49
50 descriptions of sound by 6-10 year old students were vibrating, echo, travel and sound waves
51
52

(Watt & Russel, 1990). In accordance several studies report that the term vibration is used with quite different meanings than the scientific way of conceptualizing the term. These studies represent results from younger students (Barman, Barman & Miller, 1996; Chang et al., 2007; Houle & Barnett, 2008; Lautrey & Mazens, 2004; Mazens & Lautrey, 2003) as well as results from older students at university level (Linder, 1993; Linder & Erickson, 1989). In addition, sound and sound propagation were illustrated with the help of musical notes, bubbles, lines, lightning, waves, words, arrows, shadows and whirls by 6-10 year old students (Watt & Russel, 1990) and students in grade 8 (Eshach & Schwartz, 2006).

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Deleted: (Barman, Barman & Miller, 1996; Chang et al., 2007; Houle & Barnett, 2008; Lautrey & Mazens, 2004; Linder, 1993; Linder & Erickson, 1989; Mazens & Lautrey, 2003).

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The term sound wave seems difficult to conceptualize for many learners, irrespective of age (Caleon & Subramaniam, 2010a, 2010b; Eshach & Schwartz, 2006; Barman et al., 1996; Linder, 1992; Wittman, Steinberg & Redish, 2003). As described in previous sections, many learners' understand sound as something material and this interpretation also occurs concerning the concept of sound waves. In the study by Wittman et al. university students regularly treated sound waves as objects that were capable of pushing things along in the direction of their motion, for example kicking the medium in their path or guiding the medium along a sinusoidal path. In addition, it was suggested that the object-like sound waves collide with each other. Besides, the students had great difficulty in distinguishing between the propagation of the sound wave and the motion of the medium through which it travelled. As a consequence, new instructional materials were developed and tested, which contributed to increased understanding, although the students' use of object-like reasoning still remained.

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Generalizing sound propagation through different media is a challenge, and learners make use of different representations of the propagating sound mechanism depending on the medium in which the sound propagates. As an example, in the study by Eshach and Schwartz (2006), all the grade 8 students at some point in their interview described a wave pattern for the propagation of sound, but when they were asked to relate this explanation to their other

1
2 explanations, they were confused. In accordance, several researchers argue that there is a need
3
4 for the students to construct a general theory for sound propagation (Asoko et al., 1991, 1992;
5
6 Eshach & Schwartz, 2006; Linder, 1992, 1993; Linder & Erickson, 1989).
7

8 9 *Teaching and learning about sound and sound propagation*

10
11 In an overview, Driver, Squires, Rushworth and Wood-Robinsson (1994) stated that a
12
13 prerequisite for students' understanding when building scientific knowledge about sound
14
15 propagation is that they understand what air is, i.e. that air is something and that vacuum is
16
17 the absence of this something. Otherwise the students may not develop the idea that a medium
18
19 is required for sound transmission. Furthermore, the students need to understand that sound is
20
21 vibrations in matter, and that these vibrations are transmitted to the matter next to it.
22
23 Therefore, Driver et al. concluded that students who work on the basis of a particle model of
24
25 matter have a better chance to understand that sound propagates by means of vibrations
26
27 transmitted via particles. Similarly, Eshach and Schwartz (2006) recommended teachers to
28
29 dedicate efforts in scaffolding students' understanding of the medium.
30

31
32 In addition, Eshach and Schwartz (2006) emphasized the use of language and non-verbal
33
34 representations in science classrooms. As mentioned before, there are difficulties in using the
35
36 term sound waves, and many researchers (Eshach & Schwartz, 2006; Hrepic, 2002; Linder &
37
38 Erickson, 1989; Wittman et al., 2003) have stressed the importance of discussing the everyday
39
40 meaning of wave compared to the scientific meaning, the mathematical abstraction, of the
41
42 term. As a consequence, the students' ability to differentiate sound waves from water waves
43
44 would increase. There are varieties of other non-verbal representations that should also be
45
46 considered, contrasted and explained in order to facilitate the students' scientific
47
48 understanding of sound. In facilitating this understanding, discussions about the limits of
49
50 those representations are fruitful. Analogies are quite common in teaching about sound, in
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52 lessons as well as in school-science textbooks, and sometimes they might preserve everyday
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2 conceptions or cause misconceptions (Leite & Afonso, 2001; Linder, 1992). These
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4 researchers argued, besides the use of water waves as an analogy, that the use of slinky
5
6 springs may cause problems in understanding. In a study of Portuguese textbooks and factual
7
8 material intended for students aged 13-15, Leite and Afonso concluded that most illustrations
9
10 of sound propagation supported common misconceptions. Only four illustrations out of 41
11
12 were believed to facilitate students' understanding of sound, and they demonstrated sound
13
14 propagation at the particle level. The use of slinky springs was also criticized by Houle and
15
16 Barnett (2008) in their discussion about the reasons why the students' interpretation of sound
17
18 as pushable increased as a result of the intervention.

19
20 Finally, Chu, Treagust and Chandrasegaran (2008) claimed that the most important factor
21
22 for students' learning of conceptions relating to sound and wave motion in an introductory
23
24 course at the university level was that the physics' content was related to the students'
25
26 everyday life experiences, whereas the extent of the students' previous physics knowledge did
27
28 not necessarily influence their learning.

29
30 In summary, the research presented above identifies content aspects that are important to
31
32 consider when designing teaching and learning about sound in compulsory school as well as
33
34 in higher education.

35 36 **Aim and research questions**

37
38 The overall aim of the research project is to examine to what extent a research-based
39
40 teaching-learning sequence (TLS) might improve students' understanding of the properties of
41
42 sound, the function of the ear and hearing, and how to maintain auditory health. This paper
43
44 contributes to the overall aim by addressing the following questions:

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46
47
48 What are 10 to 14-year old students' understandings of sound and sound transmission before
49
50 and after a research-based teaching intervention about sound, hearing and auditory health?
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4 To what extent do students use a generalized theory about sound and sound transmission in
5
6 their understandings before and after the intervention?
7

8 9 **Research design**

10
11 The educational design used in this study is derived from traditions within design research,
12
13 which has been a continuous endeavour since the classical article about design experiments
14
15 by Brown (1992). Brown's research focused on the theory-practice gap, which was also what
16
17 Linjse (2000) emphasized in order to develop content-specific didactic knowledge. There are
18
19 other examples of approaches to design-based research (Leach & Scott, 2002; Lijnse, 1994,
20
21 1995; Kattman, Duit, Gropengieber & Komorek, 1996; Kelly, 2003; Méheut & Psillos, 2004;
22
23 Tiberghien, 2000), and the design used in this study is based on Design and Validation of
24
25 Teaching-Learning Sequences (Andersson & Bach, 2005; Andersson & Wallin, 2006).
26
27 According to this framework there are some general theoretical considerations regarding
28
29 students' learning. Firstly, the framework is based on a constructivist view of the learner.
30
31 Secondly, the teacher is considered as the bearer of the scientific knowledge and is well
32
33 acquainted with common alternative ideas of the teaching content. The teacher's introduction
34
35 of concepts and systematic planning of situations for the use of concepts is crucial. Thirdly,
36
37 students should be given opportunities to conceptualize the school scientific content by means
38
39 of talking and writing science, individual and group reports, true dialogue, cross-discussion
40
41 and small-group work. Moreover, the framework emphasizes formative assessment that
42
43 should be done consciously and systematically. Finally, considerations concerning students'
44
45 interest and motivation are of importance. These general guidelines are combined with
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47 aspects about the nature of science limited to school science and content-specific aspects
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49 limited to the given topic.
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2 On the basis of the presented framework a research-based teaching-learning sequence was
3 designed for the school scientific area of sound, hearing and auditory health. The sequence
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6 was elaborated in the form of a flexible teachers' guide, and it was regarded as an instrument
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8 for teachers' further knowledge building. Teachers, with students from grade 2-9, made use of
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10 the guide as a tool for designing their own lessons, selecting goals and choosing activities and
11
12 problems for students to solve. In this way the TLS was tested, results from practice were
13
14 collected and evaluated, the teachers' guide was refined and this process was repeated several
15
16 times. The results in this study are based on research from the final cycle.

17
18 Briefly, the guide used by the teachers in this study, dealt with the following content:
19
20 auditory health and attitudes; sound and hearing throughout history; matter and a particle
21
22 theory for teaching; sound and sound transmission; the function of the ear and hearing;
23
24 animals, sound and hearing; students' conceptions about sound and hearing including
25
26 previous research; national curricula and syllabuses; ideas for teaching goals; formative
27
28 assessment; suggestions for teaching and finally an appendix consisting of resource-materials
29
30 for copying (West, 2008).

31 32 **Methods**

33
34 The approach was to explore the students' conceptions and learning about sound when
35
36 teachers implemented the TLS in practice. Students were given a pre-, a post- and a delayed
37
38 post-test one year after the teaching intervention. On each occasion, there was a test with
39
40 questions related to the school scientific learning goals. The first author visited a selection of
41
42 lessons, observed the lessons, wrote extensive field notes, and videotaped a number of lessons
43
44 and group exercises. The data from the teachers' diaries, students' notebooks and notes from
45
46 the author's visits were used as sources to get a reliable picture of the intervention in the
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48 different classrooms. In addition, the teachers were individually interviewed before and after
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50 the intervention.
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The teachers

Seven teachers participated in the study. There were three from grade 4, usually teaching all subjects, and four from grades 7 and 8, usually teaching all science subjects: biology, physics, chemistry and technology. They continuously documented their lessons in diaries on an Internet platform where a lot of collaboration took place; teachers discussed and gave feedback to each other. The first author also took part in these discussions. All the teachers except one had previously participated once in the iterative process. Moreover, two of teachers in grade 4 previously had participated in science education courses for in-service teachers.

The students

A total of 199 students participated in the study: 48 aged 10-11 in grade 4 (24 girls and 24 boys), 71 aged 12-13 in grade 7 (28 girls and 43 boys) and 80 aged 13-14 in grade 8 (38 girls and 42 boys). The students in grade 4 were from one school, but students from the other grades were from three different schools. The students in grade 4 are considered as one class though there were three teachers; they planned together, and they sometimes taught their students in three groups but there were also occasions when they taught their students in other arrangements. However, the students in grade 7 consisted of three separate classes taught by two teachers from two different schools, and in grade 8 there were two teachers teaching in three classes from the same school. The schools are situated on the west coast of Sweden. The students had not previously been taught about sound, despite [the fact that](#) there are goals for learning about sound in grade 5 in the national curricula.

The teaching intervention

The teachers formulated goals for students' learning in accordance with the national curricula using the ideas and proposals in the 'Teachers Guide' (West, 2008). Goals set up by the teachers concerning learning about sound were:

- 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
- be able to carry out simple systematic observations, measurements and experiments and also be able to compare his/her predictions with results
- gain insight into and be able to discuss the importance of a good sound environment
- know that sound is vibrations that are transmitted through the medium, not something material (e.g. sound particles).

These goals guided the content of the lessons, but depending on the individual teacher and the students' questions they were treated at somewhat different depth. The total time used for the teaching intervention about sound, hearing and auditory health was around 15-20 hours including the time for the tests. Time used for the content of sound was approximately 10 hours in grade 4, 6-9 hours in grade 7 and 7-12 hours in grade 8.

The content about sound dealt with in all the classes was the following: sound arises when objects vibrate; sound is transmitted via particles in matter in air (gases), liquids and solids; ways of representing sound transmission including discussions of the meaning of sound waves; properties of sound like pitch and sound volume; measuring sound levels by using sound-level meters in different places including personal music players; and how to construct a good sound environment considering absorption and reflection of sound in different materials. Additionally, in grades 7 and 8 the speed of sound was included. The content was dealt with in different ways, orally as well as in writing and there were experiments, group

1
2 work, small group discussions as well as teachers' teaching in the whole class. In this way, all
3
4 the students have also taken part in group discussions consisting of arguments about sound
5
6 levels at discos, discussing what are scientific claims and/or opinions, and in some cases
7
8 clarifying their own values concerning these questions. All the teachers have continuously
9
10 used formative assessment as a tool for teaching and students' learning.

11
12 As was mentioned above, ways of representing sound transmission including discussions
13
14 of the meaning of sound waves was explicitly treated during the lessons. Most students
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16 discussed in pairs how the sound passing from one person to another person could be drawn:
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18 'Draw as many examples as possible of ways the sound can be illustrated'. The students'
19
20 different ideas were summarized on the whiteboard (as an example, see Figure 1), and the
21
22 advantages and disadvantages of drawing sound in these different ways were discussed. In
23
24 this context, sound waves were explained as being a mathematical model that natural
25
26 scientists and mathematicians have chosen to use when talking about and illustrating how
27
28 vibrations are transmitted.

29
30
31 [Insert figure 1 about here]

32
33 **Figure 1.** A picture of the whiteboard, demonstrating the students' different ideas of
34
35 drawing sound, from one of the lessons in a class in grade 8. The Swedish word 'susning'
36
37 means whistling, and 'hej' is hello.

38
39
40 Additional information about the underlying ideas, including pedagogical principles, in
41
42 the intervention is available in the English version of the 'Teacher's Guide' on the Internet
43
44 (West, 2008).
45
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Tests

The students answered questions about the production of sound and the transmission of sound through air, water, wood and vacuum (Appendix 1). Of course, there are limitations of only using paper and pencil tests, but by using answers from several questions from the same student this problem is reduced. There was no time limit for doing the tests. The tests were given in two versions on the pre- and post-tests occasions; A1 and B1 were given in grade 4, and A2 and B2 in grade 7 and 8; these versions were given to half the students in each grade. The delayed post-test was only given in one version to all the students. The distribution of questions according to the different tests is shown in Table 1.

[Insert table 1 about here]

Analysis

Students' answers from pre-, post- and delayed post-tests are explored in the following sections. First, a classification is made of the answers in order to construct an instrument for analysis and thereafter the results from this analysis are presented.

I. General classification of answers

The classification is influenced by results from previous research, [presented in the section 'learning about sound'](#), in connection with students' drawings and/or written answers. In order to analyse the students' generic conceptions of sound propagation and not only situated conceptions, each student's collection of the four answers to the questions concerning different media was used as a unit of analysis. In other words, this was an attempt to capture the student's underlying theoretical framework for explaining sound and sound transmission. In the students' collections of answers, there were signs of material reasoning and/or signs of process reasoning, but there were also answers where no such theoretical framework was

1
2 obvious. Henceforth each student's collection of four answers will be designated as the full
3
4 answer.

5
6
7 *No signs of theoretical reasoning about sound and the transmission of sound*

8
9 If there are no signs of either material or process reasoning about sound and the transfer of
10
11 sound, the student's full answer is categorized as lacking theoretical reasoning. In addition,
12
13 answers such as 'took a chance', 'do not know' or 'electromagnetic radiation', are also
14
15 considered as lacking theory.

16
17
18 *Signs of material reasoning about sound and the transmission of sound*

19
20 Signs of material reasoning about sound and sound transmission are considered to comprise
21
22 one or more of the following:

- 23
24 • Sound can pass through vacuum, and/or sound cannot pass through water (liquids)
25
26 and/or wood (solids).
27
28 • Sound can pass through water because there are bubbles, air or oxygen. Sound can
29
30 pass through wood because there is air, air particles, oxygen, small holes or narrow
31
32 openings in/inside the wood.
33
34 • Referring to density and/or relative strength of materials, i.e. that sound experiences
35
36 friction and as a result, the speed of sound slows down in water or wood. However,
37
38 changes in the sound level when passing water or wood are not considered.
39
40 • Sound waves knock atoms/molecules/particles.
41
42 • Vibrations (on their own) knock atoms/molecules/particles.
43

44
45 *Signs of process reasoning about sound and the transmission of sound*

46
47 Signs of process reasoning about sound and sound transmission are considered to comprise
48
49 one or more of the following ideas:
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- Ideas of vibrations in connection with the transmission of sound, i.e. vibrations in a context that can be interpreted as a process. Vibrations in an object (e.g. flute, bee or ear drum) are not considered in themselves.
- Vibrations from an object knocking atoms/molecules/particles, which subsequently knock other atoms/molecules/particles.
- Atoms/molecules/particles vibrate and this causes other atoms/molecules/particles nearby to vibrate.

II. Classification of the theoretical pattern

In order to analyse the theoretical pattern at a fine grain level, all four answers (full answer) from each student are further categorized within a framework designated 'generalized sound theory framework'. The framework is derived from previous research and developed in detail based on the students' reasoning in this study. The different categories/models of description represent qualitatively different ways that students use to describe sound and sound transmission. The categorisation, in principle, reflects going from a simple full answer without any theory to a more and more advanced full answer and finally to a full answer based on process ideas (Table 2).

[Insert table 2 about here]

Theory 0: No properties of sound or sound transmission.

Full answers without any or irrelevant explanations, or explanations without scientific content, and/or explanations based on students' own experience. However, there are full answers comprising scientific term/terms but where there are no signs of clarification of the term/terms. Example:

1
2 In air (the bee): 'Sound waves'. In water (the motorboat): 'I have done it myself'. In wood
3
4 (the door): 'Can't explain but I have heard it'. In vacuum (the room): 'I think that the
5
6 sound is sent further by the air.' (Boy, grade 7, delayed post-test)
7

8
9 There are full answers with signs of ideas of the importance of a medium (including correct
10
11 answers to yes/no questions concerning water, wood and vacuum) but there is a lack of ideas
12
13 of the nature of sound or sound transmission. Example:

14
15 In air (flute note): 'There are sound waves.' In water (swimmers): 'Yes, it makes sound
16
17 waves that reach land.' In wood (door): 'Yes, sound can be transmitted through wood.' In
18
19 vacuum (room): 'No, there is no air.' (Girl, grade 4, delayed post-test).
20

21 *Theory 1: Sound as something material, an object or a substance. No signs of processes.*
22

23
24 There are different ideas related to matter in the full answers. Firstly, there are full answers
25
26 consisting of descriptions that sound cannot pass through liquids or solids, i.e. sound is
27
28 containable. Example:

29
30 In air (flute note): 'Sound waves are formed from the flute to the brain.' In water
31
32 (swimmers): 'No, the water hinders the sound to go through.' In wood (door): 'No, I do
33
34 not think that sound can travel through doors. But through narrow openings in the door.'
35
36 In vacuum (room): 'No, nothing stops the sound from going through.' (Boy, grade 4,
37
38 delayed post-test).
39
40

41
42 Secondly, there are full answers referring to properties of the materials, i.e. the relative
43
44 strength of liquids and solids. Example:

45
46 In air (flute note): 'When Linda blows there are immediately sound waves travelling
47
48 throughout the room. Sound waves are really vibrations in air which travel at different
49
50 speeds.' In water (motorboat): 'Yes a little, but the matter is denser than in the air so it is
51
52

1
2 more difficult for the sound waves to pass through. Yes one can hear something, but often
3
4 just mumbling.' In wood (door): 'Wood is not very dense matter and therefore the sound
5
6 waves do penetrate more easily, but anyway one hears less than if there hadn't been any
7
8 door. The door is not compact. There are narrow openings along the sides.' In vacuum
9
10 (room): 'No, where there is no air sound waves don't come through.' (Girl, grade 8,
11
12 delayed post-test).

13
14 Thirdly, there are full answers that use air as a compelling reason for sound transmission in all
15
16 media. Example:

17
18 In air (bee): 'It's the small things that are called sound waves, they are moving in the air.
19
20 They travel from bee to my (your) ear.' In water (motorboat): 'Yes, there is a little oxygen
21
22 (air) in the water that makes it possible to hear the sound.' In wood (door): 'Yes I think it
23
24 is not quite compact so there are small holes that the air (with sound waves) can pass
25
26 through.' In vacuum (room): 'No, the sound waves cannot reach the other side of the room
27
28 if there is no air to move in.' (Girl, grade 8, pre-test).

29
30 Finally, there are full answers consisting of a mix of these ideas related to matter, which vary
31
32 depending upon the context, and/or other ideas indicating that sound is something material.

33
34 Example:

35
36 In air (bee): 'It may have to do with the air. The bee flaps its' wings in the air which might
37
38 create a sound.' In water (motorboat): 'Yes, the sound continues through the water, but is
39
40 weakened because of the density of water.' In wood (door): 'No, I think not, but the sound
41
42 can get around the door (cracks, holes, etc.) and then continue.' In vacuum (room): 'Yes,
43
44 because otherwise you cannot hear sounds from space.' (Boy, grade 8, pre-test).

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Theory 2: Sound as something material and as a process.

Full answers consisting of ideas of matter of the nature of sound but also signs of processes.

Example:

In air (flute note): 'When Jane blows she starts vibrations that begin to move in the air by the atoms pushing on each other right up to your ear. How much or little they vibrate determines how you hear the sound.' In water (motorboat): 'Yes, there are atoms in the water like there are in the air that can push the sound forward. But there are so many obstacles it probably has greater difficulty passing through.' In wood (door): 'Yes, there are atoms in the wood too. But it is harder to hear because the wood slows down the sound frequencies.' In vacuum (room): 'No, there are no atoms that can push on each other and carry the sound or vibrations any further.'

Theory 3: Sound as a process. No signs of sound as transportation of matter.

There are full answers where the propagation of sound is described as a process and no ideas about transportation of matter are found in any of the constituent answers. Many of these full answers describe the transmission of sound as a sequential process of motion caused by interactions of particles/molecules. Firstly, there are full answers expressing ideas of transmission as a process but the nature of sound is indefinable. Example:

In air (flute note): 'The sound goes in the air to Peter's ear'. In water (swimmers): 'There are also vibrations in the water and the sound can go by vibrations.' In wood (door): 'Wood is solid material and there are molecules and the sound can travel through it.' In a vacuum (room): 'Sound travels in the air and in a vacuum there is no air.' (Girl, grade 4, delayed post-test).

1
2 Secondly, there are a number of explanations based explicitly on ideas of processes in some
3
4 media and the nature of sound is seen as immaterial. Example:

5
6 In air (flute note): 'It creates vibrations when Jane blows. These vibrations make the
7
8 atoms push each other to reach your ear'. In water (swimmers): 'The vibrations (sound)
9
10 can travel well in water'. In wood (door): 'Sufficiently strong sound can.' In a vacuum
11
12 (room): 'The vibrations (sound waves) cannot travel in a vacuum (room).' (Boy, grade 8,
13
14 post-test).

15
16 Finally, there are full answers based explicitly on ideas of processes in most media, i.e.
17
18 explicitly generalizing the transmission of sound. Example:

19
20 In air (bee): 'When the bee flies it vibrates (its wings) and the vibrations make the
21
22 molecules in the air push against each other. Then the vibrations are transferred in the air
23
24 and finally they reach our ears.' In water (motorboat): 'Yes, the motor boat vibrates, and
25
26 therefore it produces sound and because part of the motor boat is underwater vibrations
27
28 are transmitted in the water too.' In wood (door): 'Yes, there are molecules in the wood so
29
30 they push against each other and the vibrations reach our ears and we perceive a sound.'
31
32 In a vacuum (room): 'No, there is no air and consequently no air molecules that can
33
34 "push" against each other and therefore the sound won't be transferred.' (Girl, grade 8,
35
36 post-test).

37 38 ***Generalizability, validity and reliability***

39
40 This study sheds light on what the students can learn from this intervention. According to
41
42 Bassey (1981), it is not possible to make open generalizations, but it 'is the extent to which
43
44 the details are sufficient and appropriate for a teacher working in a similar situation to relate
45
46 his decision making to that described' that is important (Bassey, 1981, p. 85). In this way, the
47
48 results are useful for other educational designers as well as teachers.
49
50

1
2 The same content, i.e. sound transmission through air, water, wood and vacuum, was
3
4 tested to make valid comparisons between the pre- and post- results. Two questions were
5
6 identical in all tests (wood and vacuum). Two questions differed between different tests; they
7
8 dealt with the same content (transmission in air and water, respectively) but they were placed
9
10 in other contexts. It could be claimed that the students have learnt to deal with the specific
11
12 content in cases with the same questions. However, the delayed post-test was given one year
13
14 after the teaching was completed and therefore the memory bias from previous tests is
15
16 considered to be small.

17
18 In order to estimate the reliability of the results, the authors and another researcher
19
20 separately and independently scored a sample of answers. According to the general
21
22 classification system and the 'generalized sound theory framework', the goal was to
23
24 categorize the underlying theory for sound and sound transmission (Theory 0, 1, 2 and 3) that
25
26 was visible in the full answers. A random sample of 150 full answers was chosen. The first
27
28 author categorized all these answers and the two other researchers categorized 75 answers
29
30 each. The inter-rater reliability was 64% and 66%, respectively. In cases where our views
31
32 differed, the first author analyzed the differences, improved the general classification system
33
34 and the 'generalized sound theory framework', and once more the answers were categorized.
35
36 The second time the inter-rater reliability was 80% and 85%, respectively. In cases where our
37
38 views differed, we discussed each case until we agreed.

39
40 Finally, the drop-out of students in the different tests was low. In grade 4, 94% of the
41
42 students took part in all the tests and in grades 7 and 8 these figures were 92% and 93%,
43
44 respectively.

45 46 **Results from the analysis**

47
48 The students' full answers concerning knowledge and learning about sound and sound
49
50 transmission were analysed by using the classification framework developed.
51
52

1
2 *A. Students' conceptions and learning about sound and sound transmission*
3

4 The distribution of the underlying theories from the students' full answers at the different tests
5 (pre-, post- and delayed post-test which was given one year after the intervention) is reported
6 in Figure 2.
7
8
9

10
11
12 [Insert figure 2 about here]
13
14

15
16 **Figure 2.** The distribution of the students' full answers classified in the
17 different theories: T0, T1, T2 and T3. Pre-test (n=193), post-test (n=192) and
18 delayed post-test (n=188).
19
20
21

22
23 Before the intervention, the full answers from most students showed matter-based ideas (T1)
24 and in the remaining answers almost no underlying theories were identified (T0). However,
25 after the teaching intervention half of the students used process reasoning (T3) and a quarter
26 used a combination of both process and material reasoning (T2). One year later the most
27 common idea once more was the matter-based one, but a quarter still based their statements
28 on process reasoning (T3). There are no significant gender differences in any of the tests
29 (Pearson Chi-square tests, 2-sided; $p > 0.05$).
30
31
32
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36

37 In order to examine a detailed picture of the results from the different grades, and also to
38 undertake an in-depth analysis of the distribution of the underlying theories and their adherent
39 categories presented in Table 2, these results are summarized in Table 3.
40
41
42
43
44

45 [Insert table 3 about here]
46
47

48 At the pre-test the matter-based reasoning was the most common in all grades (T1). This
49 reasoning consisted mainly of a mix of different matter-based views, i.e. students utilized two
50
51
52

1
2 or more ways of matter-based reasoning according to different media. When the students
3
4 made use of the same matter-based reasoning in different contexts, the containable and air
5
6 categories were found. Categorized as lack of theory (T0), slightly more than a tenth of
7
8 students in all grades showed awareness of the need for a medium. Some based parts of their
9
10 argumentation only on their own experiences, while others used scientific terms like sound
11
12 wave or vibration but without showing any understanding of the terms.

13
14 However, in the post-test, explanations based on ideas about processes were the most
15
16 common in all grades (T3). The older the students the more they had constructed a
17
18 generalized theory of sound and sound transmission in all the media occurring in the test (air,
19
20 water and wood), and this same theory was also used to explain why sound is not transferred
21
22 through a vacuum (Table 3, process/all media). A quarter of the students in all grades
23
24 displayed matter-based ideas in one context and process ideas in other contexts (T2), but this
25
26 theory was very seldom found in the pre-test.

27
28 The delayed post-test was performed one year after the intervention was completed. The
29
30 use of a general theory for sound and sound transmission had decreased in all grades,
31
32 although about 10% of the students still applied this theory. However, twice as many students
33
34 in grade 4 than in the other grades applied T3. Although their reasoning is simpler than the
35
36 older students this might seem confusing and will be further considered in the discussion
37
38 section. Concerning the matter-based ideas (T1), the proportion of students considering air
39
40 necessary for sound transmission in all media increased somewhat after the teaching
41
42 intervention.

43
44 To conclude, when comparing the results from the pre- and the delayed post-test; very few
45
46 students show signs of process reasoning before the intervention. However, one year later
47
48 20% to 40% of students make use of process reasoning (T3), or use process reasoning in some
49
50 context and matter-based reasoning in other context/context (T2).

B. Students' learning about process reasoning in different classes

In order to explore students' learning about sound transmission at class level, students' use of any form of process reasoning when answering the tests will be explored (T2+T3). The results are presented in Figure 3.

[Insert figure 3 about here]

Figure 3. The distribution of different classes of students' full answers comprising any form of process ideas (T2+T3). The numbers of students presented are the numbers of students that participated in the pre-test.

Figure 3 shows differences between classes in the students' learning of process reasoning. There are no significant differences between the classes in grade 8, but there are significant differences between the classes in grade 7 (Mann-Whitney's test, 2-sided, post-test $p < 0.05$ and delayed post-test $p < 0.05$). Grade 4 performed significantly better than the two lowest classes in grade 7 (post-test $p < 0.05$ and delayed post-test $p < 0.001$), and grade 8 significantly better at the post-test than grade 4 ($p < 0.05$).

C. Teaching and learning in different classes

All teachers emphasized formative assessment for learning. For example they formulated questions now and then to assess the students' understanding in relation to the goals for the lesson by using students' written answers in note books. The questions formulated were often linked to students' everyday life, but the content was placed in another context than the one just dealt with. But the teachers followed-up the assessment in different ways. One teacher reflected over students' learning more generally, others explicitly transformed the results from the assessments, either by giving encouraging comments to

1
2 the individual students in the note book after every occasion and/or carefully adapting the
3
4 next lesson to the students' understanding.
5

6 The comments in the note books often confirmed the students' learning but also
7
8 varied somewhat. One teacher gave direct responses by clarifying or further explaining a
9
10 concept, whereas other teachers more frequently asked for clarifications. However, these
11
12 questions were not so often answered by the students.
13

14 **Discussion and implications**

15
16 The main purpose of the present paper has been to investigate students' understandings and
17
18 learning about sound and sound transmission from a teaching intervention based on a
19
20 teaching-learning sequence about sound, hearing and auditory health. Students' use of matter-
21
22 based ideas decreased after the intervention in the present study. A majority, 63% of all
23
24 students, were categorized as holding matter-based views and mainly a mix of various ideas
25
26 about sound transmission in air, water, wood and/or a vacuum in the pre-test, 15% in the post-
27
28 test and 38% in the delayed post-test one year later. In comparison, Houle and Barnett (2008)
29
30 found 53% ($n \approx 100$) of the students in grade 8 as holding a matter-based view of sound
31
32 transmission in the pre-test and 42% in the post-test. On the other hand, Houle and Barnett
33
34 merely investigated sound transmission through air. In the present study grade-8-students (n
35
36 =77) expressed matter-based ideas in some media at the pre-test (69%), post-test (9%) and
37
38 delayed post-test (34%), respectively. Accordingly, the matter-based view of sound
39
40 transmission in air decreased more in the present study.
41

42 Matter-based ideas might be expressed in different ways in the same media. Students'
43
44 ideas about sound transmission through solids were investigated by Mazens and Lautrey
45
46 (2003), who observed that 26% ($n=30$) in fourth grade explained such transmission by
47
48 referring to holes, and 15% referred to properties of the material, i.e. the relative strength.
49
50 These students had not had any formal teaching about sound, and therefore their results can be
51
52

1
2 compared to the results from the pre-test in grade 4 in the present study in which 17% (n=47)
3
4 of students referred to holes or narrow openings for transmission through wood in a door.
5
6 However, they sometimes wrote about keyholes and chinks, but 6% explicitly mentioned
7
8 microscopic openings in the wood. Some students involved relative strength; 4% considered
9
10 sound can pass wood because of these properties, but no one used this idea in explaining why
11
12 sound cannot pass through wood.

13
14 Students' ways of expressing the need for air in different media for sound transmission
15
16 increased as a result of the intervention. This was seen in all grades; in the pre-test up to 5%
17
18 of students held the idea and one year after the intervention, 6-11% of the students expressed
19
20 this idea. Similarly, Chang et al. (2007) discovered that 5% of students in grade 6 answered
21
22 that sound was carried by air when it passes through the wall of a sealed container. The idea
23
24 that water must contain gas, air or oxygen is also found in other studies (Eshach & Schwartz,
25
26 2006; Maurines, 1993). Moreover, Houle and Barnett (2008) reported 5% of students [in grade](#)
27
28 [8](#) considered that sound travels on or is carried by the air molecules both before and after the
29
30 teaching intervention. Likewise, Caleon and Subramaniam (2010a) reported that 74% of
31
32 students [in grade 10](#) agreed in the post-test with the statement 'without air, sound cannot
33
34 propagate, even if other media are present'. Caleon and Subramaniam concluded that this was
35
36 the most strongly held alternative conception among those students. Similarly, the present
37
38 study found that students' generalization of the idea that there is a need for air/oxygen when
39
40 explaining sound transmission through different media was nearly the same or increased after
41
42 the intervention. One conjecture may be that the teaching started with how vibrations are
43
44 transmitted through particles/molecules in the air, and as a consequence the students could
45
46 have extrapolated this to water and wood. This in spite of the fact that they had done
47
48 experiments with sound transmission through other media and discussed the prerequisite for
49
50 sound transmission with the help of particles in the media referred to.

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Learning a generalized theory for sound transmission

This study elucidates the challenges students meet when they have to conceptualize and develop a generalized theory of process reasoning for sound transmission. Before the intervention there was hardly any process reasoning at all, but in the post-test there was process reasoning (Table 3, the sum of T2 and T3) among a high proportion of students in all grades, and one year later up to half of them used this reasoning. Moreover, a number of students' answers indicated they had constructed a generalized theory for sound and sound transmission in all the media at hand in the tests. In the post test 45% of students in grade 8, 23% in grade 7 and 13% in grade 4, were found in this category (Table 3: T3, process/all media). One year later, the use of the generalized theory had decreased in all grades, and about 10% the students still applied this theory. If it is argued that students' awareness of process reasoning is beneficial for their understanding of sound transmission, this is a promising result. But if the emphasis is on the importance of students' understanding of the generalized theory of sound transmission, the results suggest the need for repeated ontological discussions concerning the nature of sound and sound transmission (Bruner, 1977).

Learning in different classes

As mentioned above, the older the students were, the more established the generalized theory was after the teaching intervention. Surprisingly, a relative high proportion of the younger students, i.e. grade 4, showed some form of process reasoning (T2+T3) especially compared to two of classes of older students, i.e. grade 7 (Figure 3). As all the teachers considered their classes normal this seems to be a contradictory result. Thus, there are other factors than age that are important for students' learning. One such factor might be the teachers' way of using formative assessment and feedback. The collected data shows that teachers in the five best achieving classes followed-up the students' answers explicitly, either by giving encouraging comments to the individual students in his/her note book after every occasion and/or carefully

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adapting the next lesson to the students' understanding. The follow-up in the least achieving classes was less systematic, and besides there was a substitute teacher not focusing formative assessment at some occasions. The impact of formative assessment and the way of giving feedback are emphasized by many researchers (Black & Wiliam, 1998; Black, Harrison, Lee, Marshall & Wiliam, 2003; Hattie & Timperley, 2007; Shute, 2008; Treagust, Jacobowitz, Gallagher & Parker, 2001). Therefore the way of performing formative assessment might be one reliable explanation of the differences. Another factor might be the goals set up for teaching and learning because the teachers in the best achieving classes more often specified goals for learning according to the different lessons (Millar, Leach, Osborne & Ratcliffe, 2006). This was not done in the same extent in the other two classes, and beyond that loose ends according to the goals set up were now and then not tied up. Finally, in the better achieving classes the teachers had previously explicitly taught about the particle theory for matter, and this was not done in the least achieving classes. Also students in grade 4 had worked with a sequence dealing with a particle theory for air. Ideas for such a sequence were part of the in-service course in science education which two of teachers in grade 4 had attended a few years before this study. Certainly, teaching and learning is a complex process and no one sole factor may cause the learning results (Andersson & Bach, 2005).

Learning about sound transmission

The scientific model for sound transmission includes considerations about elastic and inertial properties, and these properties are as a rule not included in the syllabuses in compulsory school. When students in the present study express their ideas about sound transmission as a process they mainly base their reasoning on transmission by adjacency. According to Fazio et al. (2008) students in upper-secondary school who are able to represent mechanisms of propagation through interactions between molecules, or atoms, can modify their reasoning and arrive to the correct scientific solution as a result of teaching. Consequently, students who

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1
2 in the present study describe sound transmission as a process of adjacency might benefit from
3
4 this when there is a need for learning the scientific model. Whether students who define
5
6 transmission as consisting of a mix of ideas related to matter and ideas about processes by
7
8 adjacency are also favoured, we do not know. However, the results suggest that students
9
10 develop their understanding of sound and sound transmission via intermediate models that can
11
12 also consist of such a mix (Table 3, T2). Probably, the mixed model would also be useful as a
13
14 starting-point when there is a need to learn the scientific model.

15
16 In contrast, Chu et al. (2008) did not emphasize students' preconceptions as a key
17
18 component in learning the scientific model [at university level](#). They argued that the most
19
20 important factor for students' development of conceptions relating to sound and wave motion
21
22 was that the physics' content was related to the students' everyday-life experiences.

23
24 The intervention in the present study embraced students' everyday-life experiences as
25
26 well as sound transmission as a process of adjacency. Therefore, the intervention might be
27
28 beneficial to students' learning about the concept of sound. Furthermore, understanding this
29
30 concept makes it easier for students to develop an understanding of other general concepts
31
32 such as pressure and waves, and to learn other complex scientific concepts (Chi, 2005; Eshach
33
34 & Schwartz, 2006).

35 36 *Limitations of the present study*

37
38 In the present study, there might be some limitations influencing the results. Since students'
39
40 written answers were used as a basis for analysis, their interpretations of the questions used in
41
42 this study and their own use of language were crucial. As a consequence, the weakness of one
43
44 question and the student's conceptualization of this question might delimit the categorisation
45
46 of the collection of all answers from one and the same student. For example, using sound
47
48 from colliding stones might be difficult for students to capture (Asoko et al., 1991, 1992).
49
50 Furthermore, in utilizing a door for explaining whether sound can pass through wood or not,
51
52

1
2 can promote students to use everyday experience instead of using their scientific
3
4 understanding. They might also be stimulated to explain sound transmission *only* by help of
5
6 keyholes and chinks even if there were none in the illustration. As a matter of fact, in many
7
8 cases it was the answer to the question about the door which contributed to a material
9
10 categorisation.

11
12 On the other hand, there are also advantages in using a collection of answers when making
13
14 categorisations, because unclear points in one answer can be clarified in another answer. Such
15
16 examples are students who write that sound waves or vibrations move from one object to
17
18 another without describing the nature of sound waves/vibrations, but in answers to other
19
20 questions clarify their ideas about the nature of sound waves/vibrations.

21
22 One of the goals for learning was that sound is produced when objects vibrate. Therefore,
23
24 vibrations have been focused on in the teaching, which might result in some students only
25
26 writing about vibrations without any signs of elucidating the meaning of vibrations when
27
28 explaining transmission, although this understanding exists. On the contrary, there has been
29
30 another goal; sound needs matter (solid, liquid or gas) in order to be transmitted. Therefore,
31
32 the use of 'vibration' without signs of clarifications were categorised as 'scientific term' in
33
34 order to separate use of term from interpretations of the term. This is in accordance with other
35
36 studies that describe how the term vibration is used in quite different meanings (Barman et al.,
37
38 1996; Chang et al., 2007; Houle & Barnett, 2008; Lautrey & Mazens, 2004; Linder, 1993;
39
40 Linder & Erickson, 1989; Mazens & Lautrey, 2003).

41
42 Moreover, since students written answers are the foundation for the categorisation, there is
43
44 a limitation for younger students from a linguistic point of view.

45
46 Finally, the study can only show what students' have learnt from the approach presented,
47
48 but cannot say anything about whether it is better or worse than other approaches.

Deleted:

Implications for teaching

The results illuminate the capacity of 10-11 year old students to learn about sound and sound transmission. They have learnt almost as much as the older students, aged 13-14, with one exception; the older the students were, the more they indicated the use of a generalized understanding of sound transmission in all media in their answers (Table 3, Process/all media). A similar pattern was found concerning the same students' learning about hearing (West, 2010).

As a consequence, teaching science as early as at the ages of 10-11 seems to be fruitful. The results suggest that additional teaching at older ages, in order to stimulate students' more advanced learning concerning causal links and generalized understanding, would enhance students' conceptualization of sound. In addition, other studies (Lindahl, 2003; Martin et al. 2008; Osborne & Dillon, 2008) indicate that students are more interested in learning science at earlier ages. Osborne and Dillon (2008) pleaded for increased quality of science education before the age of 14, and the results from this study confirm that this effort would be worthwhile.

In comparison, the TIMSS study carried out in 2007 (Martin et al., 2008) demonstrated that teaching about sound and hearing is not common. On average, 33% of the students in grade 4 from all countries had been taught about the production of sound through vibrations, and 60% of all grade 8 students had been taught about the properties of sound.

Conceptual change

The results from the present study indicate that the development of students' generalized understanding of the nature and transmission of sound comprises different theories: from no theory and/or an ontological theory of matter to an ontological theory of processes and, in between, a mix of these categories. The change between these theories seems to be gradual where the attributes of these ontological theories coexist, albeit in different contexts.

1
2 Concerning sound and sound transmission, this picture supports the interpretations from
3
4 Lautrey and Mazens (2004). In addition, these intermediate models are in accordance with the
5
6 idea of synthetic models described by Vosniadou (1994) and Vosniadou and Brewer (1992)
7
8 where these models are seen as intermediate solutions consisting of alternative conceptions at
9
10 different levels, and this is a result of the inconsistency between students' everyday
11
12 conceptions and scientific conceptions. Teaching and learning the nature of sound and sound
13
14 transmission is about a dynamic concept which includes enlargement of existing knowledge
15
16 as well as shifting the foundations of that knowledge, i.e. ontological shifts which seem to be
17
18 gradual and challenging to capture for students (Carey, 1991; Chi, 2008; Chi et al., 1994).

19
20 Table 4 demonstrates how students' scientific knowledge about sound can be elaborated
21
22 via intermediate scientific models. The intermediate models are regarded as school scientific
23
24 models appropriate for students' understanding and everyday life.

25
26
27
28 [Insert table 4 about here]
29

30
31 Certain steps in Table 4 are expected to be particularly difficult for students to conceptualize
32
33 because they embrace ontological-category shifts and such shifts provide challenges for
34
35 students to deal with (Chi, 2005; Vosniadou et al., 2008). As shown in the table, students'
36
37 initial conceptions concerning sound are principally matter-based. According to Chi (2005), a
38
39 characteristic of such conceptions is that they are held across grade levels, something that was
40
41 confirmed in the present study. Further, Chi mentioned that those conceptions are also held
42
43 across historical periods, and this was confirmed from historical overviews concerning ideas
44
45 about sound and sound transmission (Blood, 2009; Caleon & Subramaniam, 2007; Eshach &
46
47 Schwartz, 2006; Hunt, 1978). In summary, these results emphasize there are great challenges
48
49 for teaching and learning the concept of sound.
50

1
2 In order to deal with matter-based conceptions, the use of formative assessment as a
3 sequential process may be crucial for capturing the students' conceptualization of what has
4 been taught, and the more complex the scientific content, the more essential this form of
5 assessment is to students' learning. However, in giving feedback for learning, the teacher's
6 own conceptualization of the scientific concept is crucial, and research shows that teachers
7 might themselves have alternative conceptions about sound (Linder & Erickson, 1989;
8 Treagust & Duit, 2008). Since the teacher is one of the most important factors influencing
9 students' learning (Hattie, 2009; Vygotsky, 1978), teaching-learning materials will contribute
10 to teachers' as well as students' learning. As a consequence, designing research-based
11 material for teacher's further knowledge-building such as the 'Teacher's Guide' (West, 2008)
12 used in this research can be one way of improving teachers' knowledge.
13

14
15 Finally, as shown by Schreiner and Sjøberg (2007) traditional school sciences, particularly
16 physics, do not succeed in further inspiring and interesting students, and therefore the
17 researchers argued that school science should face the students' values and concerns. Since
18 students are interested in the human dimensions of science and technology, and school
19 science related to health and environmental issues (Baram-Tsabari & Yarden, 2005; Schreiner
20 & Sjøberg, 2007) it might be fruitful to connect the physics content to these areas. Moreover,
21 Aikenhead (2006), and Osborne and Dillon (2008) emphasized a student-oriented point of
22 view aimed at citizens acting as critically consumers of science and technology in their
23 everyday life. As a conclusion, teaching sound in compulsory school associated with hearing
24 and auditory health might be mutually fruitful in several ways. Especially in an era of
25 increasing risks for music-induced hearing impairment among young people connected to
26 loud music listening via personal music players (i.e. Bulbul, Bayar Muluk, Çakir & Tufan,
27 2009; Daniel, 2007; SCENIHR, 2008; Vogel, Brug, Hosli, van der Ploeg & Raat, 2008; Zhao,
28 Manchaiah, French & Price, 2010).
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APPENDIX

The flute note

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

[Insert figure

Flute note

Steve is thinking and wonders:

about here]

- I know that the sound goes from the flute to my ears. But what's going? What is happening between the flute and my ears when Jane plays and I hear?

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.

[Insert figure

Bee about

- Lucky you saw the bee! Steve exclaims.

here]

- 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?

Under the water (swimmers)

Kate and Pete are swimming in Stone Lake. Kate dives to the bottom followed by Pete immediately afterwards. 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.

[Insert figure Swimmers about

here]

Yes, I think so because

No, I don't think so because

Is it possible to hear sound under water? (motorboat)

Tony is sitting on the jetty and is just about to jump into 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. Imagine that it can emit such a loud sound!

[Insert figure

Motorboat about

here]

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

June is eavesdropping (door)

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?

[Insert figure Door
about here]

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

Yes No

Explain how you thought

Can we record music on the moon? (room)

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 tape-recorder. 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 tape-recorder in a room without any air. This would then be exactly like on the moon.

[Insert figure Room about here]

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? (astronaut) (modified from Maurines, 1993)

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

[Insert figure Astronaut
about here]

Yes

No

Explain how you thought.

Table 1. Questions used in the present study. A and B refer to different versions of the tests. (Pre-test = Pre, post-test = Post and delayed post-test = Del).

Sound trans- mission	Question	Grade 4					Grade 7 o 8				
		Pre <i>A1</i>	Pre <i>B1</i>	Post <i>A1</i>	Post <i>B1</i>	Del	Pre <i>A2</i>	Pre <i>B2</i>	Post <i>A2</i>	Post <i>B2</i>	Del
Air	<i>Flute note</i>	x	x	x	x	x	x	-	x	-	x
	<i>Bee</i>	-	-	-	-	-	-	x	-	x	-
Water	<i>Swimmers</i>	x	-	x	-	x	x	-	x	-	-
	<i>Motorboat</i>	-	x	-	x	-	-	x	-	x	x
Wood	<i>Door</i>	x	x	x	x	x	x	x	x	x	x
Vacuum	<i>Room</i>	-	x	-	x	x	x	x	x	x	x
	<i>Astronaut</i>	x	-	x	-	-	-	-	-	-	-

Table 2. Generalized sound theory framework. Theoretical categories, concerning students' ideas of the nature of sound and sound transmission, found in the full answer from each student. Theory 0 refers to lack of theory, theory 1 to properties of matter, theory 2 to properties of matter and process and theory 3 to properties of process.

Theory	Properties of sound and sound transmission	Models/ categories	Main characteristics of the nature of sound and how sound is transferred
Theory 0	No properties	<i>Category:</i> No content	No explanation, explanation without experience or scientific content
		<i>Category:</i> Experiences	Explanation based on experiences
		<i>Category:</i> Scientific terms	Use of scientific term/terms but no signs of clarifications of the term/terms
		<i>Category:</i> Experiences and scientific terms	Explanation based on experiences AND use of scientific term/terms.
		<i>Category:</i> Medium	Signs of ideas about the importance of a medium (including correct answers of yes/no to questions concerning transmission in water, wood and vacuum) BUT no ideas about the nature of sound or sound transmission. Scientific terms may be used.
Theory 1	Sound as something material, an object or as a substance. No signs of process.	Model 1: Containable - able to be contained by something	Sound cannot pass through either water/liquids or wood/solids. However, sound can pass wood/solids if there are visible or non visible holes. Sound can travel in vacuum.
		Model 2: Properties of the materials	Relative strength of materials. The denser the medium the more resistance and the harder the transmission of sound and/or the slower the speed of sound, i.e. sound experiences friction. Signs of this idea are visible both in water/liquids AND in wood/solids. Changes in the sound levels are NOT considered. Sound can/cannot travel in vacuum.
		Model 3: Air is necessary	Air as an explanation for transmission in all media (air, water/liquids AND wood/solids). Sound can pass <u>through</u> wood/solids <u>only</u> because there are air/oxygen or small holes/openings AND sound can pass through water/liquids <u>only</u> because there are air/oxygen/bubbles. Sound cannot travel in vacuum.
		Model 4: Other material ideas or a mix of ideas from models 1-3.	Indications of sound as something material, but unclear or different explanations. A mixture of ideas from models 1-3 is also included here. Sound can/cannot travel in vacuum.

Theory	Properties of sound and sound transmission	Models/ categories	Main characteristics of the nature of sound and how sound is transferred
<i>Theory 2</i>	Sound as something material <u>and</u> as a process	Model 5: The mixed material and process model	Mix of matter and process. Signs of processes but <u>also</u> material ideas about the nature of sound (theory 1). For example, use of the terms vibrate/vibrations which indicate an idea of process in connection with ideas from theory 1.
<i>Theory 3</i>	Signs of sound propagation as a process but the nature of sound is unclear.	Model 6: Ideas about transmission as a process	The nature of sound is indefinable, but there are ideas about processes when explaining the transmission of sound.
	Sound propagation as a process and the nature of sound is immaterial	Model 7: Explicit transmission in some media	Explanations based explicitly on ideas of processes in <u>some</u> media (air, water/liquids or wood/solids but not in a vacuum). 1-2 examples are a necessity. No answer may be incompatible with process ideas.
		Model 8: Explicit transmission in all media	Explicitly generalized model. Explanations based explicitly on ideas of processes in <u>most</u> media (air, liquids and solids but not vacuum). 3-4 examples are a necessity. No answer may be incompatible with process ideas.

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Table 3. The distribution (%) of theories and their adherent categories for sound and sound transmission in different grades. (Pre-test = Pre, post-test = Post and delayed post-test = Del).

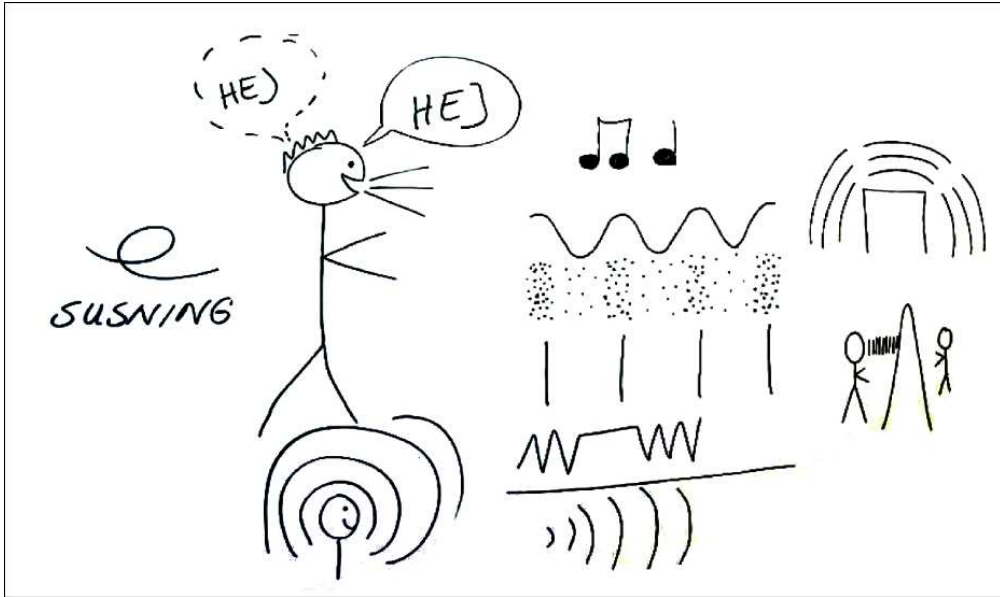
Category/Theory	Grade								
	4			7			8		
	Pre n=47	Post n=46	Del n=48	Pre n=69	Post n=69	Del n=66	Pre n=77	Post n=77	Del n=74
<i>No content</i>	11	0	4	12	1	1	5	0	0
<i>Experience</i>	8	0	2	14	0	3	3	0	1
<i>Scientific term</i>	0	0	4	3	2	5	9	0	2
<i>Medium</i>	13	17	4	14	10	20	10	1	4
T 0	32	17	14	43	13	29	27	1	7
<i>Containable</i>	0	0	2	0	0	0	3	0	0
<i>Rel strength</i>	0	0	2	0	0	1	0	0	1
<i>Air</i>	2	7	6	4	6	12	5	4	11
<i>Material mix</i>	64	2	23	51	20	32	61	5	22
T 1	66	9	33	55	26	45	69	9	34
T 2	2	24	12	1	23	6	3	25	38
<i>Process/signs</i>	0	24	25	0	10	9	1	9	5
<i>Process/some media</i>	0	13	9	0	5	2	0	10	5
<i>Process/all media</i>	0	13	6	0	23	9	0	45	11
T 3	0	50	40	0	38	20	1	64	21

Table 4. Crucial points in teaching and learning the scientific content of sound.

<i>Explanations</i>	<i>Additives</i>	<i>Level of learning</i>
Initial explanations:		
Sound is not anything that is transferred, or <u>is</u> an object or a discrete substance such as wind or air that is transported.		Enrichment
	Air (gaseous substances), liquids and solids are composed of particles. These particles are of different kinds, i.e. there are no ‘air-particles’ in liquids and solids.	Ontological shift
Intermediate model/school scientific model:		
Sound is vibrations (energy) that are transferred, and they are transferred through all matter via particles. The closer the particles the faster the transfer of sound.	Sound transmission is a direct process (process by adjacency).	
Sound transmission can be represented in different ways.		Ontological shift
Intermediate model/alternative school scientific model:		
Sound propagation is a large-scale process <u>whose motion differs from the motion of the constituent particles.</u>	Sound transmission is an emergent process.	Enrichment
Scientific model:		
Sound propagation is influenced by elastic and inertial properties.	Sound transmission as a complex emergent process.	

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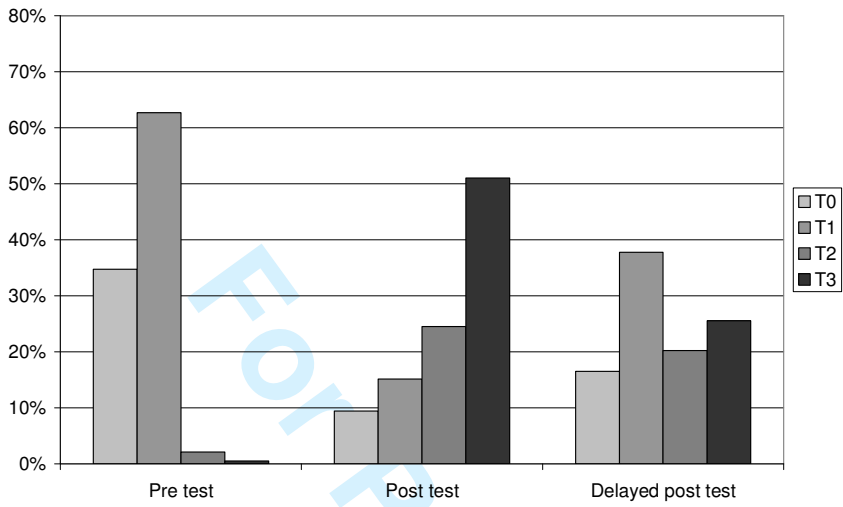
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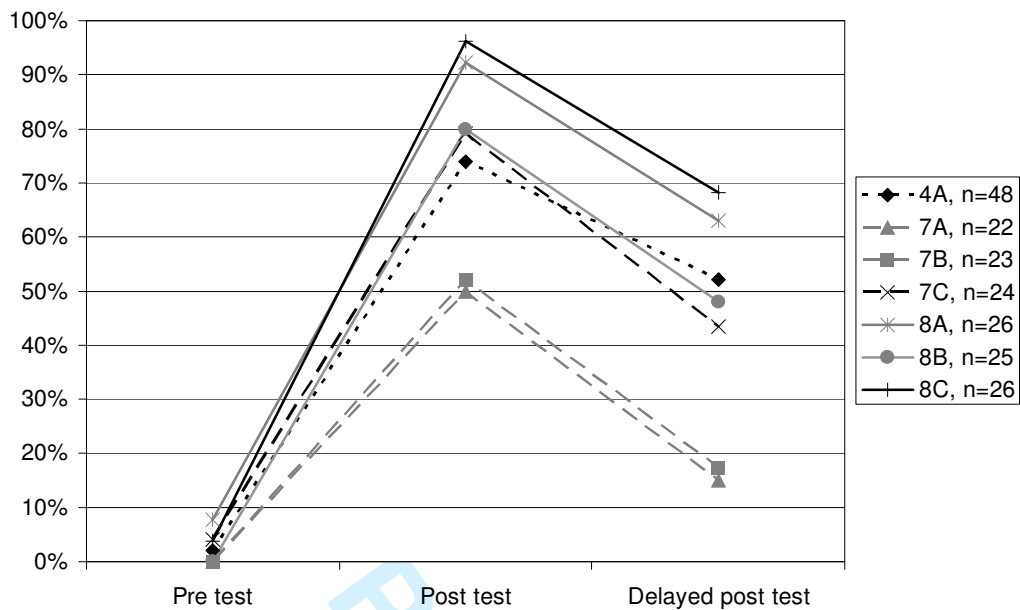


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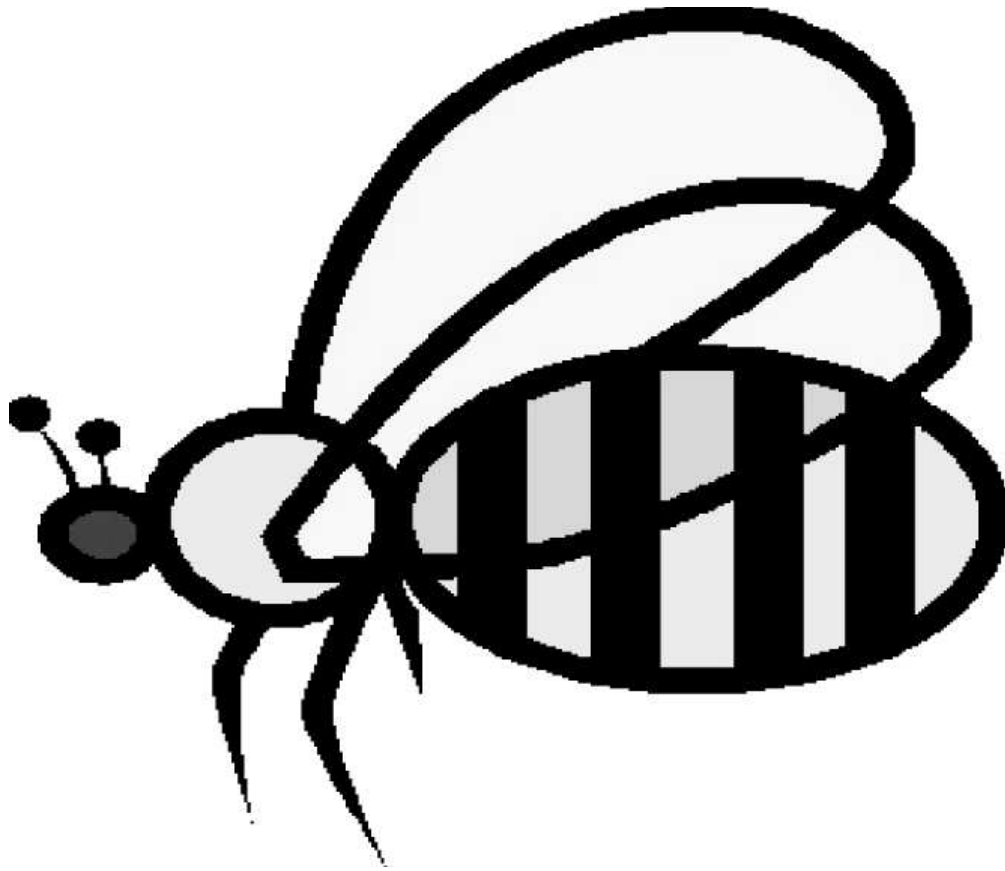
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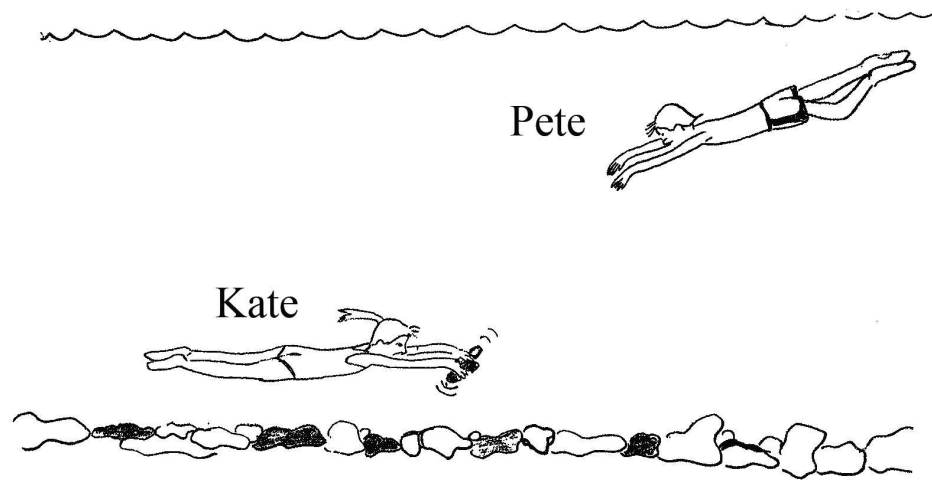


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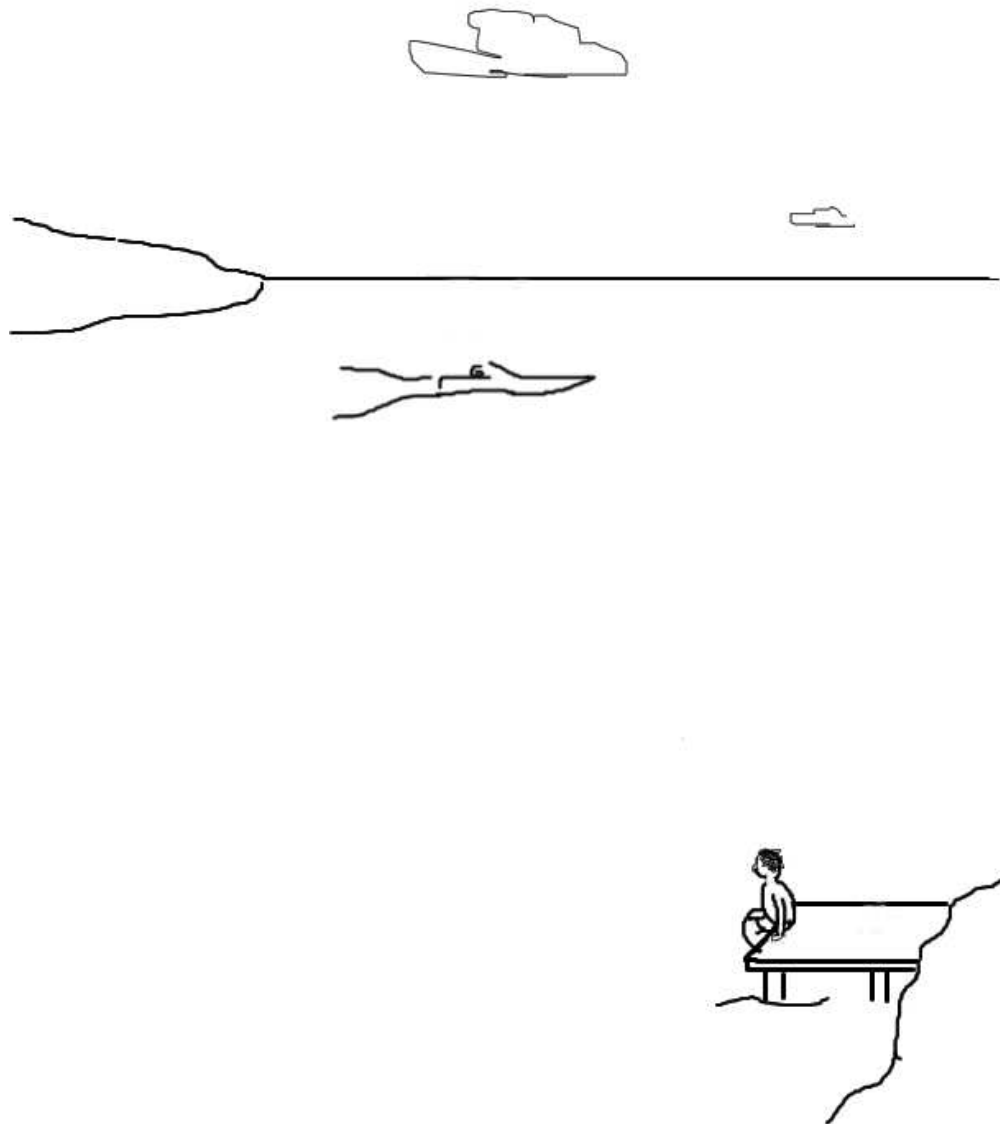
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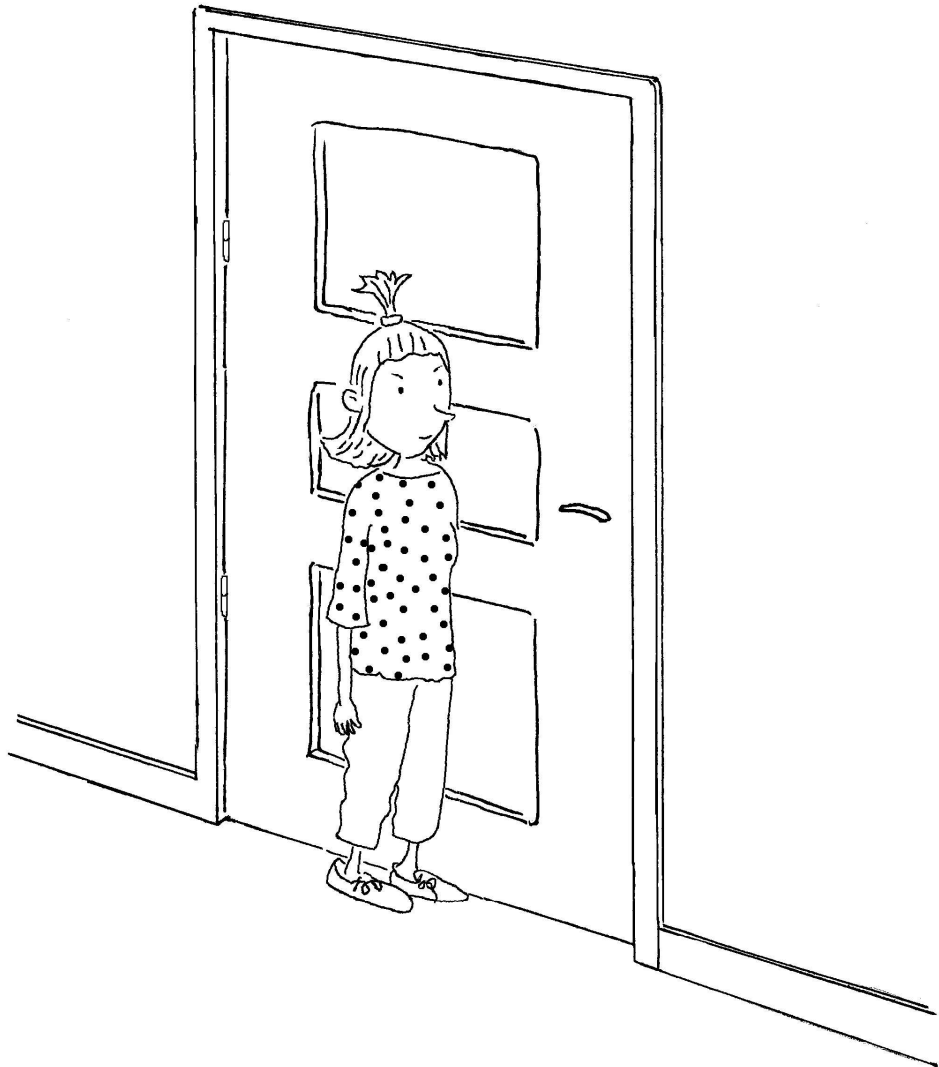
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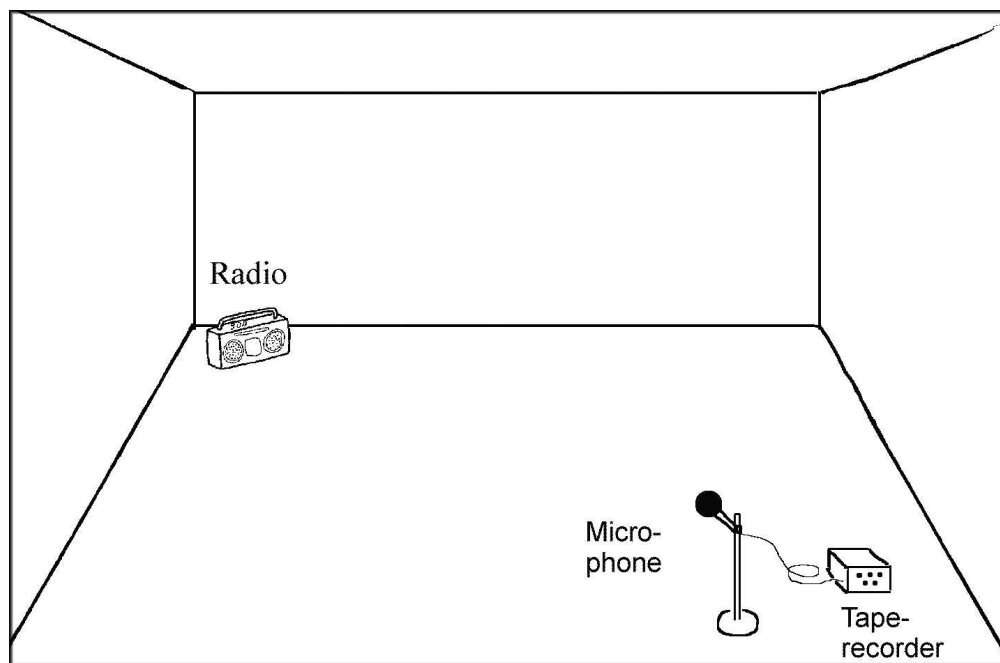
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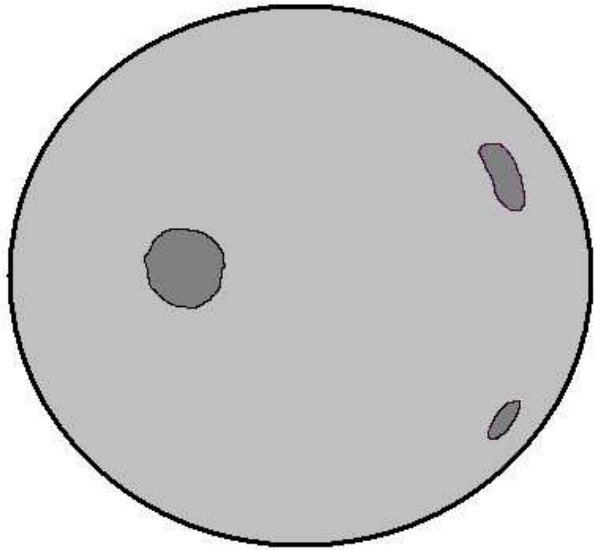


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