Classification of sound conceptions

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Abstract. Experience and other studies show that students come to our Science Centres with pre-existing ideas of how the world works (often called prior-, naïve- or mis-conceptions). When confronted with conflicting ideas from science they are forced to make a “border crossing” [1] from the familiar territory of their cherished beliefs into the “unknown country” of science. How difficult this crossing is and how comfortable a student feels to remain in this new country depends on many factors both internal and external to the student. The challenge for our Science Centres is to assist students to cross these borders more easily and to remain in their new country without feeling threatened. An example will be given of student prior conceptions with regard to sound and waves: a brief literature survey will outline pre-existent conceptions noted around the world. The 4 level framework [2] is used to classify these conceptions and modify them in the light of data gathered. Student responses to a questionnaire provide multiple mode (MCQ, written and drawings) feedback into this process. The result is a modified table of local students’ prior conceptions with regard to sound and waves. This is a useful resource when designing (and improving) science shows, exhibits and other programme materials in this area. While the specific example of sound and waves will be the focus of this presentation, suggestions will be made of how this resource can be used in other subject areas.

1. Review of Research into Student Conceptions of Sound (Summary and comments)

Most of the literature on this topic starts with the comment that little work has been done on students’ conceptions of sound [3], [4], or that even in higher level Physics courses, sound is often treated superficially as a simple example of wave-physics [5]. The studies all continue to assert that sound is not a straightforward topic, based on findings of clear gaps in students’ conceptual understanding of the subject material [6]. This review was undertaken using Pfundt and Duit’s [7] Database of student and teacher conceptions and science education, and further searches, which revealed only a few relevant papers.

Linder [5], on summarising the findings of Linder and Erickson [8], reported the following types of understanding of sound expressed by students: Firstly, sound is sometimes seen as an entity carried by individual molecules as they move through a medium. This entity is transferred from one molecule to another through the medium. For others, sound is a traveling bounded substance with impetus, usually

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represented in the form of flowing air. Another understanding was that sound is a bounded substance in the form of some traveling pattern. Finally, for many students, sound is linked to the concept of waves as part of a mathematical physics modelling system (but students' wave conceptualization is often divorced from their conceptualization of sound).

Hrepic et al [6] expanded on Linder's idea of the "entity model" with the notion of blend models. They identified the entity model as the usual starting point for naïve students (as would be expected in the present study), and the wave model as the scientifically accepted, or community consensus model. In addition to these two main models he enumerated models which were conceptual blends of these two, incorporating ideas from both of them. His studies showed that most students begin with an entity model of sound, but after instruction move closer to the wave model, but often finishing somewhere in between in a blend model. Linder [5] also discusses at length the confusion caused by representing longitudinal sound waves with transverse sinusoidal waves, and the problems associated with the "water-wave analogy", which is inappropriate at best, incorrect and profoundly misleading . From my very first pilot tests this factor came through very strongly, so was worth a detailed follow-up. He stresses later [9] that students' conceptions can be classified into two perspectives: a mental model (inside the head)-based perspective and an experientially-based one. My experience has shown that sophisticated, urban students tend towards more abstract mental model perspectives, while rural students living simpler lives often maintain a perspective based on their life experiences. This was tested especially in the written answers and drawings.

In a later study, Linder [9] identified three conceptualizations of the factors which university students believe affect the speed of sound, namely: a sound-resistance factor based on the physical size or density of the molecules; a separation factor based on molecular separation as a function of medium density and a compressibility factor based on a (confused) understanding of the elasticity of the medium. Wittman et al. [4] found similar problems with conceptualizations of wave-speed, whereby students believed that the force used to create a wave would determine its speed. In other studies Watt and Russel [10] found that students perceived sound as an invisible object with dimensions which required some space in order to move, echoing Linder's finding of sound as an entity. Similarly, Wittman et al [4] encountered student problems when they focused purely on the object-like properties of sound waves, rather than other properties relating to their propagation. Boyes and Stannistreet [11] uncovered an unusual belief – especially in younger students - in a reverse pathway whereby sound travels from the hearer to the source, rather than source to hearer. We have never encountered that particular notion in many years of teaching Physics, so were interested to see if it surfaced in the present study.

Eshach and Schwartz [3] used the 11 substance schema of Reiner et al [12] to investigate whether students would use these properties to explain sound phenomena. They found that Reiner et al.'s [12] properties were not all applicable, but that some of them did apply. They too cautioned teachers to be careful when describing sound as waves because of the confusion caused between longitudinal, transverse and water waves, echoing Linder's findings and my anecdotal experience. Houle and Barnett [13], in an interesting study using Urban Bird Communication to teach sound topics, found three main student conceptions, that: sound travels in a sinusoidal wave fashion (as mentioned above and by Linder), sound is a material or a substance and sound is a vibration (the "shaking model" of Hrepic et al [6]). Caleon and Subramaniam [14] identified eleven student conceptions of sound, eight of which had featured in at least two previous studies. Huey-Por Chang et al. [15] found similarly that students attributed sound leaving a container carried by the air which escaped through small holes in the container-wall. In addition students in Caleon and Subramaniam's [14] study asserted that sound, unlike light, cannot be refracted and that wave speed is dependent on wave properties such as frequency or amplitude, with a resulting confusion as to whether pitch is associated with amplitude or frequency. Again many of their students imagined sound as propagating like a (transverse) sine-wave.

My anecdotal experience from teaching and performing this show for many years is that students do indeed confuse frequency and amplitude (and pitch and volume), so in the present study questions were designed to test this.

Calik [16] compared different conceptual change pedagogies and their effectiveness and found that a combination of different methods (e.g. the use of analogies, computer animations and conceptual change text) was most effective in producing conceptual change in sound-related topics. Finally, Hapkiewicz [17] compiled a list of 17 Student Conceptions of sound ("Sound Misconceptions") in the Michigan Science Teachers' Association newsletter, based on teaching experience, which formed the main basis for my list.

2. Synthesis and Classification of student difficulties with sound

The goal of this study was to perform a comprehensive synthesis and classification of students' difficulties with the phenomenon of sound based on both the Hapkiewicz list [17] and other relevant literature. The initial synthesis was taken mostly from the literature with some input from teaching experience. This was then modified in the light of the data *we* gathered and reflected in the final table, table 1. The four-level framework [2] was used to classify the conceptions at different levels, according to the insight one has from research or experience into the nature of the difficulty. Those difficulties firmly established by multiple studies with different groups are classified with a 4 at the top level as ***established***. These were confidently used in devising questions and distracters. Those shown in a single study or in limited studies as only ***partially established*** were classified as 3, and those merely suspected from anecdotal information mentioned in single studies (and which *we* have personally not encountered), or from personal experience (teaching science *or presenting* this show for 20 years) were classified at level 2, as ***suspected***. It is expected that this study will produce some as yet ***unanticipated*** conceptions, which *we* will then add at level 1. Finally the difficulties will be reclassified in the light of the results and data, possibly resulting in some of them moving up the list as being more firmly established.

A simple study of 117 Grade 9 students from three different schools (urban, township and rural) was conducted using pre and post tests administered before and after a science show on sound and waves at the Unizulu Science Centre. Students answered the same 10 multiple choice questions before and after the show and then more comprehensive questions after, including written explanations and drawings. The questions were carefully structured to cover all the difficulties in the table below and data analysed to probe for evidence of students displaying these difficulties. Having done the data analysis of the mixed-mode student questionnaires, table 1 was established: with the following columns:

OR LEV – the initial 4 level classification of the difficulty based on experience and literature survey alone

FIN LEV – the revised 4-level classification amended in the light of data

LIT REF – the number of different literature references mentioning this difficulty

SEEN IN DATA: the prevalence of this difficulty in my student data, ranked from 0 (not present) to 5 (present across all groups)

The student difficulties are numbered from 1 through 19 and will hereafter be referred to as "d 1" etc.

Table 1: Summary of student difficulties evident: level, literature references and prevalence.

NO.	DIFFICULTY	OR LEV	FIN LEV	LIT REF	SEEN IN DATA
1	Sound travels as a transverse sine wave	4	4	8	4
2	Sound is a microscopic entity either carried by or transferred between molecules	4	(4)	4	0
3	Sound is a macroscopic entity with impetus like flowing air or a traveling pattern	4	(4)	5	0
4	Speed of sound-wave is affected by: force, sound-resistance, molecule separation	4	(4)	5	0
5	Sound can be trapped in a container if the air is trapped-needs holes to escape	4	4	4	3
6	Sound can travel through a vacuum and therefore through space	4	4	4	3
7	Sound waves cannot be refracted or bent like light	3	(3)	2	0
8	Confusion between volume and pitch (and amplitude and frequency) and their units	3	4	2	5
9	Sound only travels if air is present (therefore can't travel through liquids or solids)	3	4	2	5
10	A human has many different vocal cords to produce different sounds	2	(2)	1	0
11	Ultrasounds are very loud sounds	2	(2)	1	0
12	Sound travels from the hearer to the source (Reverse sound)	2	(2)	1	0
13	Music has low volume (small amplitude) & noise has high volume (large amplitude)	2	2		3
14	Longer objects vibrate faster, or produce higher notes	2	2		1
15	The sound box on a musical instrument is to make the sound clearer	2	2		1
16	Vibrations and waves are the same thing	2	2		3
17	Sound travels as electromagnetic Waves	1	2		3
18	Sound is unaffected by solid obstacles, passing right through them	1	2		4
19	Sound waves turn towards a hearer	1	2		5

In general it is apparent from table 1 that the difficulties experienced by South African students were not the same as those found overseas. We did not experience any students displaying difficulties d2, d3 or d4, but these are deeper level explanations which would be more likely to come out in interviews than in the simple tests we used. Similarly, we didn't experience d7 either, but again we are not sure if it would have come out in our simple tests. d8 and d9 came out consistently across all school groups and one should consider reclassifying these at level 4 (as they also come from the literature). From all the data, we found no evidence of d10, 11 or 12, and indeed have never found any evidence of these while doing this show, so would not suggest raising them to a level 3. None of d13 – d16 was found in all the groups and we would not want to elevate these to level 3 without finding some more evidence of their regular occurrence. The new student difficulties d17 – d19 were fairly consistent across all the schools (although slightly less so for the rural group) and in future studies we would certainly raise them to a level 2. These suggested changes to the level are reflected in the fourth column in table 1, but could certainly be revised following further studies. The above discussions allowed table 1 to be modified into a condensed table which better shows local students difficulties with sound (but space does not allow it to be displayed). This table would reflect the final level we came to, rather than the original level and would omit difficulties not encountered locally (those with the final level in parentheses)

3. Conclusion

In conclusion this study yielded some interesting insights into local student difficulties in sound. Starting with a difficulties table drawn from the literature, this was refined and focussed on a particular group of South African students. Our students' difficulties were not unlike those in the literature, although it was interesting that a few difficulties in the table above were not found in this group. It was also interesting to discover strong evidence of 3 new difficulties not found in the literature and to add these as d 17, 18 and 19. The final, refined table will be very useful in designing and evaluating science shows on sound. Indeed a similar method could be employed for any section of the Physics curriculum and could be adapted to guide teaching at school or tertiary level. This research was limited to the evaluation of a single science show in one subject area. Much work has been done in attempting to evaluate the impact of Science Centres in general (for example Perrson [18]) but this is a much more complex issue and beyond the scope of this study.

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