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Spontaneous reasoning on the propagation of sound.
L.Maurines
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The results of a preliminary enquiry regarding pupils' conceptions on propagation of sound are presented. About six hundred sixteen years'old french children have answered before any lessons about waves to paper and pencil questionnaires. The same tendencies towards a mechanistic and single-notion based reasoning appear as those put forward for the propagation of a signal on a string.The signal is a material object created and set in motion by the source. It materializes a "supply" given to it by the source. This supply, a mixture of force, energy, speed, is the basis of the spontaneous reasoning. It leads to a link between the propagation velocity and what happens at a given point of the medium: this velocity depends on the source, on the signal amplitude and can decrease with time. The medium is a passive support even useless: sound can propagate in the vacuum.

SPONTANEOUS REASONING ON THE PROPAGATION OF SOUND

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INTRODUCTION

This paper reports on research still in hand regarding pupils' and students' conceptions of sound. General ways of reasoning of all kinds of populations are analysed and described in a synthetic and organized model. It aims at supporting discussions on teaching goals and at helping to elaborate pedagogical means adapted to the difficulties pointed out.

This research follows up an investigation on pupils' and students' conceptions of the propagation of a transverse signal on a string (Maurines 1986,1992). It is intended to examine whether the tendencies towards a mechanistic and single-notion based reasoning, first brought out for the "bump" on the string, also appear in the case of invisible signals moving faster. In the situations investigated, these tendencies will be shown to occur. First, the problems explored in this research on the propagation of signals, and the methods used are presented. Then, some results on the propagation of a signal on a string and their interpretation are given. Finally, the case of the propagation of sound is discussed.

PROBLEMATIC, METHODS, SAMPLES

This research focuses on concepts which, in France, are taught for the first time in the scientific fifth form, and on their understanding by pupils and students at this level or above.

In the French syllabus, waves are introduced by a lesson on the propagation of a signal. The approach used at this level consists mostly of a macroscopic and qualitative description of the phenomenon:

-experiments showing all kinds of signals (on a string, a spring, water, sound, light...) are demonstrated. The material mediums used, such as ropes, are always slightly dissipative and dispersive so that a visible signal, like a "bump" on a rope, damps down during propagation and disappears.

-these experiments, especially the propagation of a transverse signal on a rope, are studied graphically. This study concerns only "ideal" one dimensional mediums in which a signal has the same shape throughout propagation. The graphs of the two possible descriptions are used (appendix 1) : the space description gives the state of the medium at a given instant t (e.g., photograph of a bump on a string) and the time description gives the state of the medium as a function of time at a given point x (e.g.,recording of the movement of a point on the string). The relation L=VT is given.

At this level, one might expect students:

-to understand the roles played by the source (the hand which holds one end of the rope, the voice which calls...), the medium, the friction

-to know what each variable (the propagation velocity V, the time interval during which a signal is observed at a given point of the medium T, the signal length L, the signal amplitude H ....) depends on and how they are linked together

-to draw the graphs of the space-time description correctly.

At the university level, students are expected to master the mathematical framework of the wave equation and its solutions (functions of two variables of type f(x-Vt)).

After preliminary enquiries (interviews and a first set of questionnaires), the research on the signal on the string has focused on three types of problems:

1)For students, what does the propagation velocity V depend on? What does the signal length L depend on? What does the transverse motion time of a given point of a string T depend on?

2)the ways students cope with multivariable situations

3)the difficulties raised by the space-time description.

A set of paper and pencil questionnaires was developed in order to examine these problems. As usual in this type of enquiry, most of the questions are qualitative since they clearly bring out difficulties that normal exercises avoid or hide.

1300 students were questioned:

-700 had received no lessons about waves. They have been designated by W_0. They came from French secondary schools (fourth forms, scientific fifth forms, technical sixth forms).

The experiment showing the propagation of a signal on a string was demonstrated before they were asked to answer the questionnaire.

-600 had received lessons about waves. They have been designated by W_1. They came from French scientific forms (fifth or sixth), from the first two years of a scientific university of Paris (physics) or of Gembloux in Belgium (agronomy), from the first year of a French Grande Ecole which trains students to teach physics (third year after baccalaureat).

Their answers and comments were first analysed following the framework presented above. Then a more synthetic description of students' main trends of reasoning was elaborated.

The research on the sound has been conducted in the same way. About ten questionnaires have been elaborated. They are close to those built for the string and explored the first problem dealing with the three physical quantities V,L,T.

780 students were questioned:

-600 had received no lessons about waves. They came from French secondary schools (third and fourth forms, scientific fifth forms). No experiment was demonstrated before they were asked to answer the questionnaire.

-180 had received lessons about waves. They came from French scientific forms (fifth or sixth), from the first two years of two scientific universities of Paris (physics).

For the sake of brevity, only results regarding the two physical quantities V and T are discussed here. In the case of the sound, they are presented with the text of each question and the percentage of answers are given in tables (appendices 2-8). In the case of the string, percentages of wrong answers are given. Further information can be found in Maurines (1992). For both phenomena, the main types of comments are illustrated with examples. For each of the groups described above (W_0 and W_1), the percentage of answers and the justifications were so similar that no distinction can be made between the different subgroups. The reasonings put forward are tendencies which can be observed by teachers in their classes before any lessons on waves. They are not those of a particular learner.After teaching they can subsist at a certain extent depending on the situation.

PROPAGATION OF A SIGNAL ON A STRING

The students will be shown to explain the propagation of a signal on a string by focusing on the visible travelling shape. This"bump" is considered as a material object created and set in motion by the source (the hand which holds one end of the rope).

Signal velocity and source

In a linear and slightly dispersive one dimensional medium, each point of the signal shape (e.g the front, the peak...) has the same propagation velocity so that the signal damps down during propagation but keeps the same length. This velocity is a constant, characteristic of the propagation medium.

For students this is not the case. When they are asked whether a given point of a rope can move earlier, a majority of them (W_0, 60%, N=42 ; W_1, 75%, N=16) answer that there is a way of moving the hand so that the signal travels more quickly. Most of the corresponding justifications mention the force used by the hand to create the signal: the stronger the force, the greater the propagation velocity:

"the bump will move faster if the shake is sharp" (underlined by the author)

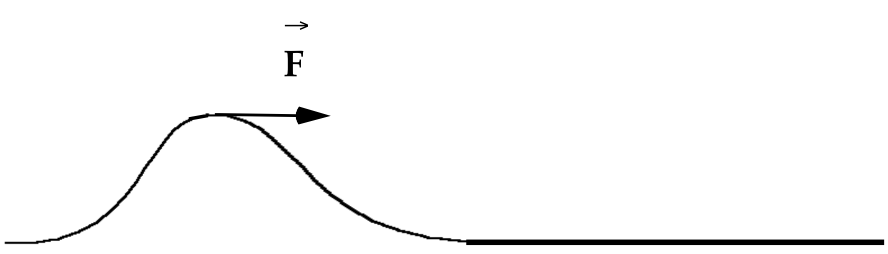
The cause (the shake given by the hand) and the effect (the bump and its motion) are confused: indeed, the "force" used by the hand to create the signal seems stored in the bump and to be its"motor":

"the speed depends on the force given by the hand"

"if the intensity of the force which is propagated is stronger, so the signal will spread more quickly too"

Some drawings given with the justifications confirm this assumption. The "force" represented is not applied to every point of the medium as in theory but on the signal shape as a whole:

"We can say that there is a bump which is moving because of the force $\vec{F}$ "



The force is localized only on the bump and has the same direction as the propagation velocity. The velocity and the force seem to have been combined.

What students call "force" is in fact something that has been given to the rope by the source at the start, something moving on and staying in the bump. It is a mixture of force, energy, speed...This hybrid notion has been called "signal supply", because the signal stores it.

Signal velocity and signal shape

This supply is not only put into motion by the source but moulded by it on the rope as if it was a material object. The signal shape is its materialization. This can be seen with a question asking students to compare the velocities of three signals with different shapes. Whereas the velocities are the same, many students (W_0, 87%,N=93 ; W_1, 41%, N=27) answer that they are different. Here also the justifications that mention force (in fact the supply) are numerous. They link the signal amplitude to the force of the hand at the start and therefore to the propagation velocity:

"it depends on the force with which the movement has been given. It can be seen according to the shape height. It reflects the force given by the child to get this result"

Signal velocity and propagation

The supply can change during the propagation. It happens for example when there are frictions. This can be seen with a question relating to the velocity of a bump which disappears before reaching the other end of the rope. Most of the students (W_0,68%, N=56 ; W_1, 55%, N=42) mention a decrease of the velocity. Here also, the justifications that mention force are numerous. They again point out that the force of the hand at the start seems stored in the bump and that it is materialized in the signal amplitude. When this amplitude decreases, this "force" (in fact the supply) and consequently the propagation velocity decrease simultaneously:

"the height decreases as the action of the hand is getting weaker"

"if the bump disappears, it is because the force which caused it disappears as well. During that time, the speed decreases"

Outcomes of a single-notion based reasoning

Students seem to understand the being of the bump and its motion as resulting from only one thing : the supply. Several outcomes are derived. In particular:

1)spontaneous laws of the bump motion

The bump moves according to the laws of "dynamics": the signal velocity depends on the initial conditions like for a ball when it is thrown and can decrease with time like for a solid submitted to friction. The spontaneous reasonings previously detailed are close to those put forward by L.Viennot (1979) and E.Saltiel (1980) in the spontaneous mechanics of the solid. The comments given by students for the motion of a signal and of a ball when it is thrown may be analysed by the same notion of supply: it is put into motion by the source, remains in the "object", can decrease with time and finally determines the propagation velocity.

2)irrelevant connections between the propagation velocity V,the signal amplitude H and the observation time interval T

In an ideal medium, each point of the string moves during the same time T which is also the hand motion time T_0. It is also the case in a sligtly dissipative medium: the signal propagates with the same velocity V and keeps the same length L, so that T given by the relation L=VT is a constant. T is not affected by a change of medium. For many students, this is not the case:

-it depends on the propagation velocity. Indeed, two marks set on two different ropes are said not to move during the same time when two signals obtained by similar hand movements are propagated : the time that a mark set on the string with the highest velocity moves is shorter (W_1, 48%, N=46). In the justifications, the transverse speed of a point of the medium seems to be mistaken for the propagation velocity:

"the time that R_2 moves is shorter since the bump travels more quickly in the second case"

"mark R_1 oscillates with a linear speed v. Mark R_2 oscillates with a linear speed v'=2v as the wave velocity is twice as big on the second string"

-it depends on the signal amplitude. Two marks set on the same rope are said not to move during the same time when a damping bump whose length is constant is propagated (W_1, 28%, N=32). The corresponding justifications point out that the transverse motion time is not linked to the signal length (which is constant) but to the signal amplitude (which decreases):

"as the bump is moving forward, its height decreases and its velocity also"

3)role of the medium

The medium plays very little part in this reasoning. It is only a passive support since

-the propagation of a signal does not result from an interaction between a point of the string and its surroundings through the internal field of force but from the force "stored in the bump"

-the signal shape does not result from the propagation of a transverse perturbation but seem to be moulded on the rope by the supply. The medium seems like a carpet under which a mouse is moving.

PROPAGATION OF A SOUND SIGNAL

The results obtained for the sound will be shown to be explained in the same way.

Sound velocity and source

In an "ideal three dimensional medium, a sound signal, whatever its amplitude, propagates radially with the same speed in each direction. The signal is attenuated throughout propagation but the speed is a constant, characteristic of the medium.

For students, this is not the case. When they are asked to compare the velocities of two sound signals emitted by sources of different amplitudes (appendix 2), many of them (W_0, 40%, N=62) ; W_1, 21%, N=34) answer that the observer does not start hearing the two sounds at the same instant : the source of the greatest amplitude is said to be heard first. The justifications point out that the sound amplitude is linked to the sound velocity:

"she hears Peter first because the sound is higher and is thrown more quickly"

"she hears Peter first because as he is singing louder, the sound gets more quickly to her ear"

"Mary hears Peter first. The speed of the sound emitted by Peter is greater because the sound intensity is higher. The sound "A" of Peter will reach Mary's ear earlier."

These justifications show clearly that the voice does the same thing as the hand which holds one end of the rope : the louder the voice, the quicker the sound and the stronger the force used by the hand, the quicker the bump.

Sound velocity and signal amplitude

The link between the signal amplitude and the propagation velocity appears again on the results of a questionnaire dealing with the comparison of two sounds emitted by similar sources, one sound propagating in free air and the other in a tube (appendix 3). When guided by a cylindrical tube of diameter d, a sound wave (characterized in free air by the velocity c and the wavelength λ) can propagate according to different modes. Each mode, except the fundamental one, has a particular velocity, always smaller than the velocity c in the free air. If the diameter of the tube is small enough , the sound wave is propagated according to the fundamental mode of velocity c and without attenuation.

At the first question relating to the sound intensity, most of the students (W_0, 89% , N=28) answer that the sound guided by the tube is louder. 92% of the answers have been justified and mention that the sound is "wedged" (72% of answers), there are no "losses" (20%), the sound is not impeded as in the air by obstacles, an opposition.....(28%).

At the second question relating to the sound velocity, a majority of students (W_0, 79%, N=28) answer that the guided sound is not heard at the same instant that the sound propagating in the air. Most of them (54% on the whole population) say that the velocity of the guided sound is greater. The justifications are similar to those given for the intensity:

"John receives more "sound". He hears it first because the sound reaches him earlier thanks to the tube which guides the waves directly avoiding losses"

"the sound intensity is not the same, it is greater. In this situation, nothing impedes the sound propagation, because the sound is alone. John starts hearing Peter earlier because nothing brakes or disturbes the sound motion from Peter to John"

The number of students does not allow a more precise analysis of the nature of the justifications and their number. Nevertheless, a correlation between the answers at the two questions points out a preferential link of type : "the louder the sound, the greater its velocity" (43% of answers) .

Sound velocity and propagation

The previous results can be compared to those obtained for the string: the propagation velocity depends on the source and on the signal amplitude. To account of these links, the same type of hybrid notion can be introduced as the basis of the students' reasonings. The supply, a mixture of energy, intensity, speed is given by the source to the medium and is materialised in the "sound particle". It can change during the propagation (e.g. in a three dimensions medium) or not (e.g. in a tube). When it changes, the signal amplitude and the sound velocity change simultaneously and in the same way. This can be seen with a question asking to compare what is heard at two different distances from the source (appendix 4).

At the first question, a majority of students (W_0, 80%, N=25 ; W_1, 97%, N=34) answer that the sound is not heard at the same instant by the two observers, showing consequently that the sound velocity has a finite value.

At the second question, the times of propagation on the two same distances are said to be different (W_0, 32%, N=25 ; W_1, 15%, N=34). Some justifications clearly point out that the sound velocity and the sound amplitude decrease simultaneously along the way:

"because the sound is reducing more and more and so goes slower as an earthquake"

"the sound slows down and so will not take as much time to go from Mary to John as from Peter to Mary"

"the sound takes a longer time to go from Mary to John than from Peter to Mary because the wave is attenuated"

Discussion

1) It can be seen that on that particular point of the constancy of the velocity, the wrong answers are more numerous for the string than for the sound. Two explanations may be proposed: a first one relating to everyday life (signals on strings are unusual while sounds are not!...) , another one relating to the manner in which the questions are presented. The research on the string, as other ones in different fields (Viennot, 1988; Rozier and Viennot, 1991), has revealed that students take into account only one variable at a time and that this preferential variable depends on the question. For the string, two velocities are asked to be compared. For the sound, it is two propagation times on two identical distances. When they are asked to compare these times, many students who say that they are similar do not mention the constancy of the velocity but focus only on the distances (cf. the tables of the appendices 2 and 4). A question dealing with the sound velocities might have given other results.

2)As in the case of the propagation of a signal on a string, the medium plays very little part. In the particular case of the sound, it may be unnecessary.

The questionnaire in appendix 5 investigates what students think about the propagation of sound in the space vacuum. Whereas many students (W_0, 40%, N=62) answer that a disaster happening on the moon cannot be heard by an astronaut in orbit around it, few of them explain it by the lack of air (13% of the population):

"no, because without"air", sound cannot get to our ears and on the moon, there is not enough air, even none at all"

"the astronaut cannot hear the sound, because there is no air and only the air conducts the sound"

Most of the students answering that the disaster can be heard by the astronaut mention the distance between him and the moon: it is short enough. The results for the second question confirm that students focus only on that point: for a larger number of them, the disaster cannot be heard on the earth. The justifications that mention the distance, now too great, are more numerous:

"we will not hear it on the earth, because the distance between the moon and the earth is too great. The astronaut will perhaps hear it, but how far is he in orbit?"

3) If the two kinds of signal move according the same spontaneous laws of dynamics, the sound signal seems moreover carried by material particles. This has been already put forward for another kind of signal that is propagated in a fluid medium: when ripples travels on water, this water seems to move with them so that they push corks laid on it(Maurines, 1986). The questionnaire in appendix 6 brings it out. The propagations of

sounds emitted by similar sources in various different types of "mediums" (vacuum, solid (steel), liquid (water), gas (air)) are asked to be compared.

The results given in the first table by students who had received no lessons on waves show that for many of them, sound can propagate in water. The great number of such answers does not mean that the medium is understood as the support of the propagation of an energy. Many justifications reveal that the medium can move in a combined movement (sound seems carried by a stream) or that the medium must contain a gas ,air or oxygen (sound seems carried by the molecules of this gas):

"air : yes, it is like a blast

water : yes, because when water moves, it can be heard,

steel: no, because steel does not make noise, does not move

vacuum: no, because there is nothing"

"air : yes, air conduct sound towards the microphone

water : yes, there is oxygen

vacuum: no, there is no air to conduct the sound

steel: yes, the air conduct the sound"

The first table in appendix 6 points again out that for a significant amount of students who had received no lessons on waves, sound can propagate in vacuum.On the other end, for many of them sound cannot propagate in a solid. The results and the justifications seem to reveal that the denser the medium, the more difficult the propagation . As it is exactly the same for the motion of a solid, this is consistent with the fact that sound can be carried by material particles:

"yes, for vacuum: sound does not encounter opposition"

"yes, except the dense steel, because sound cannot move through the full tube and be recorded. It is the same for the water."

"yes for the air, the vacuum, because there is no insulator as in the water "

"except for the steel, because it is a dense metal through which air and water and consequently sound cannot go

The results obtained for students who had just received lessons on waves, point out two more difficulties. If all of them say that sound cannot propagate in the vacuum, many of them answer that it is the same in a solid. The justifications given at this level focus on the molecules and on the fact that they can move or not:

"steel and vacuum: no sound is recorded. The sound propagates only in mediums where molecules can move. In the vacuum, there are no molecules and in the steel the molecules are fixed."

Some justifications given for water suggest that,as for the students having received no lessons on waves, sound can be carried by material particles:

"vacuum : no because there is no stream to carry the sound to the microphone

steel : no because the sound cannot go through the steel

water recording is possible because the stream and the air of the water take the sound up to the microphone"

The results given in the second table in appendix 6 confirm that for both populations, propagation is more especially difficult when the medium is dense. Whereas most of the students answer that the sound velocities depend on the medium, they class them in the reverse order: sound propagates more quickly in vacuum than in water or in steel:

"it depends on the tube. It will take a longer time in the steel tube than in the tube in which a vacuum has been made."

"no because one tube can be filled and another not. In that case, the sound will move more quickly : vacuum, air water, steel (order given for the propagation times)"

"the sound velocity depends on the propagation medium. It is braked by he collisions with the more or less numerous molecules of the medium : water,air,vacuum (order given for the velocities)"

"no ,the air molecules are much more flexible than the water molecules. The sound is quicker in the air : air,water (order given for the propagation times)

4)As in the case of the propagation of a signal on a string, irrelevant connections are made between the signal velocity, the signal amplitude and the observation time interval. In the first questionnaires, the sound velocity is said to depend on the source and on the signal amplitude. In other situations, the observation time interval is linked to the signal amplitude or depends on the medium.

The link between H and T is illustrated here by the three first questionnaires (appendices 2-4). Appendix 7 gives the results and shows that for many students, the preferential link is "T increases with H". A deeper analysis of the nature of the justifications and of their number cannot be made. Several questions are worth being studied thoroughly : in particular,does the link between H and T reveal that students answer on the time of the motion of the vibrating source (the stronger the shake given to a bell, the longer it moves and consequently the longer it can be heard) and not on the observation time interval of a given signal? does the link between H and T result from the way that the ear receives sounds?

The link between T and the medium is illustrated by the questionnaire on the four tubes. Appendix 8 gives the results and some examples. Some of them clearly point out that the observation time interval is confused with the propagation time. It is exactly the same for the signal on the string. Some others suggest that students focus on the signal attenuation: the denser is the medium, the greater the signal attenuation and so the shorter the observation time interval.

5) The mechanistic model and the trend towards a single-notion based reasoning described here give meaning and coherence to students'answers on propagation of sound. Some of its components can be found in younger children, others are extremely resistant to teaching. Watt and Russell (1990) have noted that "sound transmission is not an idea which is expressed by many young children (7-10 years'old)....When sound travel is mentioned, there is a prevalent idea that sound needs an unobstructed path along which to travel". Linder and Erickson (1989)have brought out four different conceptions of sound in tertiary physics students. In one of these conceptions,"the sound is an entity that is carried by individual molecules through a medium" and in another, "the sound is a travelling bounded substance with impetus, usually in the form of flowing air".

Moreover, it is worth noting that scientists have had to get over the same difficulties that students have nowadays, e.g. ; in the late eighteenth century, Gassendi and Nollet made experiments on sound. They respectively showed that its velocity did not depend on its intensity and its frequency.

CONCLUSION

The tendencies towards a mechanistic and a single-notion based reasoning first put forward for a visible signal (a "bump" on a string) do not seem to depend on the visual properties of such a signal since they occur also for sound. They certainly result from everyday life. Other research in other physical fields (electricity, J.L.Closset; mechanics, L.Viennot, E.Saltiel and J.L. Malgrange; thermodynamics, S.Rozier and L.Viennot) brings out similar tendencies.

Pedagogical implications have been derived from the research on the string. Many of them could be proposed for sound. In particular, to help students be aware of their spontaneous reasoning, qualitative questions, such as those elaborated here, could be used. These could help them realize that some parameters they have considered are irrelevant. Moreover, an explicit comparison between the movements of a solid and a signal could be made while teaching in order to make students understand which laws characterize each of these.

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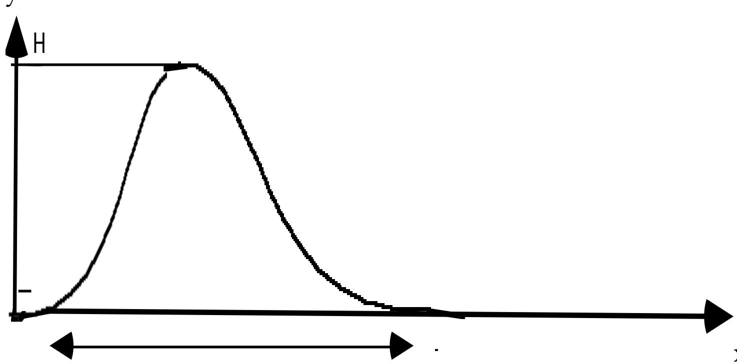
Appendix 1

The space-time description of the propagation of a signal

space description (e.g., the photograph of a bump on a string)

y at t



x

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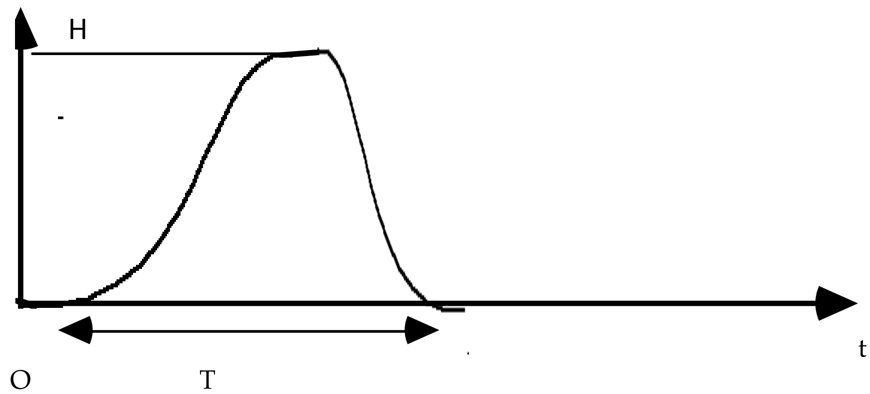
time description (e.g., recording of the movement of a point of the string)

y at x



L,H, T designate respectively the signal length, the signal amplitude, the time interval during which a signal is observed at a given point of a medium (also called, the observation time interval)

Appendix 2

The sound velocity depends on the source amplitude

Text of the questionnaire:
Peter, Mary and John are along a road in a straight line in the open country. Peter and John are at one hundred meters from Mary.

Peter Mary John

Peter and John are looking at Mary and start singing at the same instant. They both sing the note A for one second but Peter sings louder than John.

question 1: Does Mary start hearing Peter and John at the same instant?
Yes: why?
No: who is heard first? Why?

question 2: Does Mary hear Peter and John during the same length of time ?
Yes: why?
No: who is heard for a longer time ? Why?

Results to the first question on the sound velocity:

	correct answer yes "t="	wrong answer no "t ≠ "	no answer
W_0, N=62 third form	42%	40% V increases with H :**39**%	18%
W_1, N=34 scientific fifth form	76% *j* : V= 38%*	21% V increases with H: **21**%	3%

the percentages are always given on the whole population
**j means justifications: they explicitly mention that V does not depend on the source amplitude*

Appendix 3

The sound velocity depends on the signal amplitude

Text of the questionnaire:
Peter and John are at five meters from each other. Peter calls John faintly by his first name, so faintly that John barely hears him .
Peter calls John again in the same way but this time he takes a long tube through which he speaks:

Peter speaks John

:questions: Compare what is heard by John in this situation with what is heard when there is no tube. Specify in particular:
-1)whether the sound intensity is the same as before or whether it is greater or smaller.
-2)whether John starts hearing Peter at the same instant as before or whether it is earlier or later.

-3)whether John hears Peter during the same time as before or whether it is for a longer or a shorter time.
Justify each answer and draw what happens to the sound.

Results to the first question on sound intensities:

	correct answer intensities are different	wrong answer intensities are similar
W_0, N=28 scientific fifth form	89%	11%

Results to the second question on propagation velocities:

	wrong answer no "t ≠"	correct answer yes "t ="
W_0, N=28 scientific fifth form	**79%** $V_2 > V_1$: **54%** $V_2 < V_1$:25%	11%

Appendix 4

The sound velocity decreases during propagation in a three dimensional medium

Text of the questionnaire:

Peter, Mary and John are along a road in a straight line in the open country. Peter and John are at one hundred meters from Mary.

Peter	Mary	John

Peter sings the note A for one second.

question1: do Mary and John start hearing the sound at the same instant?
yes: why?
No: why?

If you have answered "no" to the previous question, answer the following ones:
question 2: does the sound take the same time going from Peter to Mary as Mary to John?
yes: why?
no: why?
question 3: do Mary and John hear Peter for the same time?
yes: why?
no: why? Who hears Peter for a longer time? Why?

Results to the first question on the instants when the sound is heard first :

	correct answer "t≠"	wrong answer "t="	no answer
W_0, N=25 third form	80%	12%	8%
W_1, N=34 scientific fifth form	97%	3%	0%

Results to the second question on the times of propagation on the two same distances:

	correct answer yes "t ="	wrong answer no "t ≠"	no answer
W_0, N=25 third form	48% *j : d= 24%,* *V= 0%*	**32%**	20%
W_1, N=34 scientific fifth form	76% *j : d= 32%* *V= 3%* *d= andV= 41%*	**15%**	9%

Appendix 5

Sound can propagate in the space vacuum

Text of the questionnaire:
If a disaster would happen on the moon (for example: an earthquake), could it be heard by an astronaut in orbit around it?Why?
Could anybody hear it on the earth? Why?

Results to the question on the astronaut, A:

	A does not hear	A hears
W_0, N=62 third form	40%	**35%**

13% of students (on the whole population) note that A does not hear the disaster because without air there is no sound

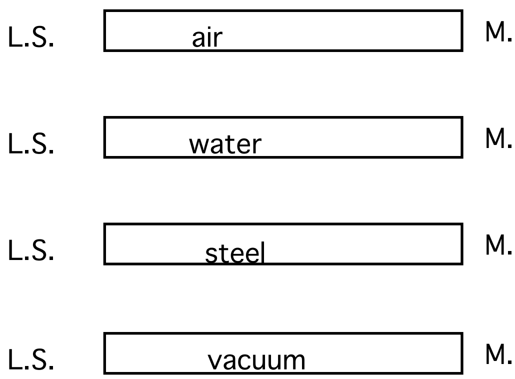
Results to the question on somebody on the earth, E:

	E does not hear	E hears
W_0, N=62 third form	**65%**	6%

Appendix 6

The denser the medium, the more difficult the propagation

Text of the questionnaire:
Four similar tubes are considered.
the first one is filled with air ; the second one is filled with water ; the third one is filled with steel ; in the fourth one, a vacuum has been made : there is nothing.
At one end of each tube, a loudspeaker (L.S.) is set and at the other end there is a microphone (M.) connected to a tape recorder. All of the loudspeakers, microphones and tape recorders are similar. All the loudspeakers start producing the note "A" at the same instant and stop at the same instant.



questions :
1) Which microphone does record a sound and which does not? Explain for each tube why.

For the microphones which are recorded, answer the following questions:
2) do they start recording a sound at the same instant?
yes: why?
no : why? class the microphones according to increasing arrival time and justify your answer.
3) do they record a sound for the same length of time?
yes : why?
no : why? class the microphones according to increasing recording time and justify your answer.

Results to the question on propagation

W_0, N= 108 third and fourth form *W_1, N= 34* *scientific fifth form*	a sound is recorded	no sound is recorded
vacuum	**44%** *0%*	45% *100%*
air	91% *100%*	6% *0%*
water	73% *100%*	**22%** *0%*
steel	30% *56%*	**61%** *35%*

Results to the question on propagation velocities

	"t="	"t≠"	no answer
W_0, N=108 third and fourth form	6%	**76%** *j : d ↑, V ↑ , 10%* *d ↓,V ↑ : 35%*	18%
W_1, N=34 scientific fifth form	3%	**94%** *j : d ↑, V ↑ 50%* *d ↓ V ↑ : 44%*	3%

d designates the medium density

Appendix 7

Irrelevant connections between the sound amplitude and the time interval during which a signal is observed at a given point of the medium

Results to the questions on the observation time intervals

appendix 2: two sounds emitted by two sources of different amplitudes

	wrong answer "T≠"	correct answer "T="	no answer
W_0, N=62 third form	45% T increases with H: **32%**	34%	21%
W_1, N= 34 scientific fifth form	29% T increases with H: **26%**	62%	9%

examples of justifications to T ≠ :

"Peter, because he sings louder. There is a resonance which makes Peter's voice lasting a longer time "

"she hears Peter for a longer time because the sound amplitude is greater and therefore the sound takes a longer time to disappear"

appendix 3: two sounds emitted by similar sources, one travelling in free air, the other in a tube

	wrong answer "T≠"	correct answer "T="	no answer
W_0, N=28 scientific fifth form	54% T increases with H: **36%**	21%	25%

example of justification to T≠ :

"John hears Peter for a longer time because the sound is submitted to vibrations and is intensified"

"He hears him for a shorter time because the sound reaches him directly without being slowed down at all"

appendix 4: propagation of a sound in free air

	wrong answer "T≠"	correct answer "T="	no answer
W_0, N=25 third form	68% T decreases with H **40%**	24%	8%
W_1, N=34 scientific fifth form	32% T decreases with H : **21%**	59%	9%

examples of justifications to T≠ :

"Mary hears for a longer time because the sound is attenuated and gets shorter."
"Mary hears for a longer time because she is the second and the sound is all fresh."
"Mary because the sound slows down. When John receives it, all will not be heard."
"no, the sound is scattered. There are more air molecules moved at the start. John hears for a shorter time than Mary."

Appendix 8

The time interval during which a signal is observed at a given point of the medium depends on the medium

appendix 6 : propagation in four different "mediums"

Results to the question on the observation time intervals

	wrong answer "T≠"	correct answer "T="	no answer
W_0, N=108 third and fourth form	54% *j : d ↑, T↑ 16% d ↓, T↑ 13%*	13%	33%
W_1, N=34 scientific fifth form	38% *j : d ↑, T↑12% d ↓, T↑ 21%*	53%	9%

Examples of justifications to T≠ :

" the microphones do not record for the same time . Depending on the mediums, the wave is submitted to more or less resistance and is attenuated"
"because the denser the medium , the shorter the time of recording: steel, water, air"
" no, 1) air 2) water 3) steel . The obstacles put on the way are more important in steel and water than in air because of the increasing opacity"
" t=d÷c, the speed depends on the medium. The distance is constant (tubes of same length). Consequently the recording times are different . The greater c, the smaller t ,so the order is : steel , water , air"