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A Visual and Intuitive Approach to Teaching and Learning Concepts in Wave Theory

Dr. Daniel Raviv, Florida Atlantic University
Adam Ginton, NA

Adam Ginton recieved his B.S. in Physics at the Georgia Institute of Technology. Prior to that he attended Dreyfoos School of the Arts as a communications major. He anticipates becoming involved in education and eventually going to graduate school.

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Daniel Raviv
Florida Atlanta University
ravivd@fau.edu

Adam Ginton
aginton3@gmail.com

Abstract

Effective science communicators are gifted in their capacity to take seemingly complicated and abstract subjects and present them in clear, engaging, and intuitive ways. Genuine learning is not achieved through memorization of formulas and rules, for even if a student is able to recite their textbook or teacher verbatim, the underlying logic and physical significance of what they are repeating may still be lost to them. Thus, educators must evaluate their teaching methods as well as the content to be covered in such a way that best serves their students. However, as circumstances differ from class to class and student to student, educators should also be aware that no one approaches to learning fits all. Teaching should also be adapted to meet different styles of learning.

It is therefore the purpose of this paper to present a visual and intuitive approach to teaching wave physics. Examples and analogies taken from everyday life are used to explain fundamental concepts, with the language that is used meant to make things as easy to visualize as possible. Some 'exotic' topics are also included, either to give some historical context of the physics, or if it relates to an aspect of waves yet to be discussed. Inclusion of extra information, such as stories and quotes by scientists, is meant to make the subjects of physics seem more socially relevant to students.

I. Introduction

This paper is concerned with the general state of physics education, including several of the most commonly cited problems that impede successful learning. We first review some of the recent academic research in physics education and student learning. Based on our findings from the literature, two distinct themes stand out which are to be investigated:

1. The subject material and course content, and

2. Students subjective experiences and views about a subject

The first of these topics is essentially about the effectiveness of a particular physics course. It addresses questions such as what aspects of physics do students have the most trouble with, and how different teaching methods compare with one another. The studies in this section often involved college students who were already enrolled in a physics class, and used a quantitative approach to obtain the data.

The second topic concerns how student's general attitudes and beliefs about physics factor into their learning. The research often looks at students who are not so interested in physics.

Based on the findings from the literature review, in section III we list several features of teaching that are easy to implement and which we believe can be effective in making any subject more accessible for the average student. We then present selections taken from our own ongoing manuscript that is meant to teach the physics of waves. Our aim is unequivocally *not* to replace any existing texts or course material. Rather, we simply want to address several of the most common obstacles that come up in physics education, and offer the average instructor with a broad set of ideas and resources to pick and choose from, and perhaps implement in their own classes.

We should point out that as our manuscript is still a work in progress, it has *not* yet been tested in an actual classroom, and thus don't have any data of our own. However, many aspects of our writing, as well as the suggestions outlined in section III, are based on previous research that does show the effectiveness of one method of instruction versus another. In the future, we hope to implement our approach in an actual physics course and compare how students learn.

The selections in the excerpt are meant to be accessible to the layman and physics major alike, and instill a more intuitive and visual grasp of physics concepts. We tried to make use simple language and a conversational tone. Rather than introduce a topic via a verbal or mathematical definition, we tried to describe how it manifests in a physical example or analogy. To make topics seem more relevant, we highlight how they may be related to daily experiences (for example, what distinguishes music from noise, and how to visually represent sound waves). More dramatic and exotic demonstrations of physics in action are mentioned to spark student's interest, and stories and quotations from scientists are included to make the subject seem more personal.

II. Literature Review

A. The Subject of Physics and Course Content

Perceptions of what makes physics difficult

Many studies have asked students about what makes physics difficult. These studies typically rely on surveys, questionnaires, focus groups, and/or individual interviews. From these reports, it appears that many students have difficulty coping with the wide range of representations in physics (e.g. graphs, formulas, verbal explanations, mathematical analysis, experiments, conceptual understanding), especially when they are asked to transform between these forms[1]. The fact that the same symbol may appear in different contexts (e.g. the symbol *W* for either work or watts) further exacerbates and confuses some students.

In a report titled, "An approach to conceptual difficulties in physics," Johns and Mooney write the following[2]:

… many students are unable to place the concepts in perspective. The result of this difficulty is that the students' knowledge and understanding of physics is frequently fragmented and compartmentalized and they never perceive a unity of the subject (p.356).

The gap between conceptual understanding and mathematical expressions: A common theme

A great amount of quantitative research has been made in order to determine the most frequent errors made by students, as well as gauge how effectively a student has learned. This type of research often involves pre/post testing. From these reports, it becomes apparent that many students have trouble developing a conceptual understanding of certain physics topics. Many teachers introduce topics by a verbal or mathematical definition, but never discuss the underlying logic or steps that are used to develop the idea. If true, it is understandable why many students have such a fragmented picture of physics. There is also often a gap between students conceptual and mathematical understanding, further supporting the notion that a main challenge lies in the translation between representations.

Fixing these problems may not be so straightforward. Kim and Pak found that conceptual difficulties tended to persist even when a student had solved a large number of traditional problems[3]:

The students did not have much difficulty in using physics formulas and mathematics. However, we found that they still had many of the well-known conceptual difficulties with basic mechanics, and there was little correlation between the number of problems solved and conceptual understanding.

Similar results were found in a separate study conducted by Byun and Lee[4].

Methods of teaching: traditional vs. reform

The “traditional” approach to teaching involves a single lecturer reciting the course information to a large, typically passive audience. The information may or may not come directly out of the course textbook and/or the lecturer’s notes. Critics of this method say that most lecturers are incapable of being engaging or even holding their students attention. Some have described this as though the lecturer were reciting a monologue to a room full of inattentive ears.

Student’s course grades are mostly determined by homework and exams. Many worry that students are more likely to focus on rote memorization of formulas and examples, and never develop independent thinking or the foundational understanding. Redish (1994) uses an analogy called “the dead leaves model”:

*…it is as if physics were a collection of equations on fallen leaves. One might hold s=1/2g*t^2, another F = m*a, and a third F = -k*x. The only thing one needs to do when solving a problem is to flip through one’s collection of leaves until one finds the appropriate equation (p.799).*[5]

Some suggest that teachers should put more emphasis on the process of setting up problems, which in turn makes students’ minds more responsive to the information that follows. Randall D. Manteufel of The University of Texas supports this idea in a report titled “Improving Teaching by Eliminating Student Dislikes”:

Example problems appear to be highly valued by students. Examples provide teachers with opportunities to explain solution strategies or provide critical insights into the material.[6]

Other research into student learning has been separately performed by Sadaghiani and Aguilera (2013) as well as Franklin et. al (2014). Sadaghiani and Aguilera compared the separate learning gains of students who were taught either with an emphasis on mathematical derivation of equations, followed by brief conceptual discussion, or through conceptual analysis, followed by a brief mathematical verification:

Results indicate that after the conceptual group and math groups achieved similar scores on the pretest, the conceptual group obtained a slightly higher normalized gain of 25% on the posttest, compared to the mathematical group's normalized gain of 16%.... Further, most students, even those in the mathematically-instructed group, were more inclined to give conceptually-based responses on posttest questions than mathematically-based ones.[7]

Another study by Franklin et. al, compared students taught in traditional, lecture-based classes to those taught using activity-based methods:

We show…students of both methods show equal short-term learning gains on a conceptual question dealing with electric potential. For traditionally taught students, this learning rapidly decays on a time scale of weeks, vanishing by the time of the typical end-of-term post-test. For students in reform-based classes, however, the knowledge is retained and may even be enhanced by subsequent instruction.[8]

B. Subjective Attitudes and Experiences of Students

Student beliefs regarding intelligence and ability

The research previously described only suggests why physics *as a subject* is commonly perceived as difficult. It does not address the subjective experiences of physics students, or whether attitudes influence how students learn.

Many have claimed that the key to successful learning is motivation. Unfortunately, this seems to be a double edged sword, especially for students who have initial difficulty with physics. These students may get frustrated and start believing they are inherently incapable of understanding the material. Research has suggested that these students are more likely to give up or withdraw quickly when facing challenging tasks.

One possible solution to the issue of motivation is for teachers to focus more on the historical and personal stories around the subject. A study conducted by Garcia, Hankins, and Sadaghiani involved the teaching of Newtonian Mechanics through its history and development since the time of ancient Greece. The researchers measures students' conceptual understanding and attitudes by giving pre/post tests using the Force Concept Inventory (FCI) and Colorado Learning Attitudes about Science Survey (CLASS), respectively. They found such methods, "increased our students' interest in physics and their sense making ability; further, at the end, students were able to draw a better connection between physical concepts and the real world."[9]

They go on to suggest that this approach to teaching may be especially useful, “for non-science majors who often don’t have a strong interest in math and science.”

Another study by Hong and Siegler (2011) looked at what happened when students were either informed about a scientists struggles, their lifetime achievements, or given no extraneous information at all:

> *We found that the achievement-oriented background information had negative effects on students’ perceptions of scientists, producing no effects on students’ interest in physics lessons, recall of science concepts, or their solving of both textbook-based and complex problems. In contrast, the struggle-oriented background information helped students create perceptions of scientists as hardworking individuals who struggled to make scientific progress. In addition, it also increased students’ interest in science, increased their delayed recall of the key science concepts, and improved their abilities to solve complex problems.*[10]

Nature of physics: everyday life and what is interesting

Many students believe the main purpose of physics is to understand the world and everyday phenomena. Ironically, many pupils rate “exotic” subjects like relativity, quantum mechanics, and astrophysics as more relevant to the everyday world than courses like mechanics, electricity, and waves.

Angell suggests that when pupils say “everyday world,” they are thinking about everyday conversations, as well as ones sense of place in the universe. Not only do concepts like time dilation and uncertainty fascinate students, but they are also seen as more relevant than concepts like acceleration, friction, and electric current.

III. Implementation and Excerpt of Manuscript

A. Tips and Strategies for Lecturers

Following the research findings as well as our own personal experience, we model our own writing using several strategies.

1. Relate the material to what has come before and what is still to come, so students may get better sense of the “big picture.”

2. Try to make the lessons sound more like conversations.

-Speaking in a more conversational style should make the material seem less intimidating to students, and perhaps more personal. Some wonderful examples of what we mean by conversational style can be seen in the writings of Richard Feynman (e.g., *The Feynman Lectures on Physics,* or *Feynman's Tips on Physics*).

3. Use physical examples that students are more familiar with, rather than something they've only seen on film or television. The more easily the example can be imagined, and the more senses that are involved, the better.
   -The Takoma Narrows Bridge collapse is commonly mentioned when discussing resonance. However, most students have never experienced a bridge collapse firsthand, and even though there is video footage of the vibrating bridge, it still may come across as a somewhat abstract or irrelevant example. A better example to initially discuss would be the experience of pushing someone on a swing set; to push someone as high as possible (e.g., to use your energy as efficiently as possible), you'd want to time your push just as the swing reaches its highest point and is about to fall back down.

4. Use simple language and shorter sentences when describing a physical problem, and explicitly state what any new terminology means.

   For example, compare the following two passages taken from actual textbooks:

a) *Suppose that we have a long string and stretch it…The tension in the string keeps the string straight. Next, we disturb the string by pulling the string upward a bit at a particular point along the string… What will happen next? The disturbance will move along the string as shown in the figure at one milli-second (1ms) intervals.*[11]

b) *A wave sent along a stretched, taut string is the simplest mechanical wave. If you give one end of a stretched string a single up-and-down jerk, a wave in the form of a single pulse travels along the string. This pulse and its motion can occur because the string is under tension. When you pull your end of the string upward, it begins to pull upward on the adjacent section of the string via tension between the two sections. As the adjacent section moves upward, it begins to pull the next section upward, and so on. Meanwhile, you have pulled down on your end of the string. As each section moves upward in turn, it begins to be pulled back downward by neighboring sections that are already on the way down.* [12]

5. Use simple analogies that can be easily pictured, and explain what feature of the analogy correlates to what concept.

6. Relate material to something from everyday life which students may take for granted (e.g., musical amplifiers) or something that is unusual and dramatic (e.g. electrons behaving like waves)

7. Include interesting historical stories that are relevant to the subject, or inspiring and/or humorous quotes by relating to material about to be discussed.

8. When making a passing statement, if there is a chance that the reader may not be certain what exactly you mean or are referring to, then immediately clarify the claim with a short example.

   -This may seem like a trivial point, but even seemingly obvious statements can often be easily and quickly clarified. For example, if you are discussing the difference between matter and waves, you will probably mention that matter cannot travel directly through other matter. As simple as this statement is, by adding an example of a ball thrown against a wall and bouncing back, any uncertainty of what you meant should be avoided.

B. Excerpt from *An Alternative Approach to Teaching Waves*

Matter has mass

All matter is made of atoms. Atoms can combine to form elements, which in turn can combine to form molecules such as H_2O, which in turn can combine to form different substances, such as ice, water, and steam. Each atom is itself made up of different combinations of subatomic particles - protons, neutrons, and electrons.

Matter is anything that has mass and takes up space. Even subatomic particles such as the proton and electron have *some* mass (approximately 1.67×10^{-27} kg and 9.11×10^{-31} kg, respectively). You, your friends, the planets, a bar of soap, a television, the ocean, a banana, – whether it’s moving or stationary, anything that you can conceivably *touch* is made of matter.

But there’s more to matter than meets the eye.

Energy

Energy is the inherent effort of every multiplicity to become unity.

— Henry Brooks Adams, 1904

A star is drawing on some vast reservoir of energy by means unknown to us. This reservoir can scarcely be other than the subatomic energy which, it is known exists abundantly in all matter; we sometimes dream that man will one day learn how to release it and use it for his service. The store is well nigh inexhaustible, if only it could be tapped. There is sufficient in the Sun to maintain its output of heat for 15 billion years.

— Sir Arthur Stanley Eddington, 1920

Energy is the measure of that which passes from one atom to another in the course of their transformations. A unifying power, then, but also, because the atom appears to become enriched or exhausted in the course of the exchange, the expression of structure.

— Pierre Teilhard de Chardin, 1955

For those who want some proof that physicists are human, the proof is the idiocy of all the different units which they use for measuring energy.

- Richard Feynman, 1964

In colloquial usage, the word “energy” is often associated with the capacity to perform an action. The nutritional information labels on certain packaged foods (particularly in Europe) may include something called the “Energy value.”

In physics, energy comes in many forms and is related to many things, such as the temperature, velocity, or color or an object. One of the most basic laws of nature is the law of the conservation of energy. It states that energy cannot be created or destroyed, but only converted from one form to another. A physicist might not be able to tell you exactly what energy *is*, but if something happens, then by making certain measurements and calculations they can tell you how much energy was involved, and what happened to it.

Thanks to Einstein, we also know that matter - you, your friends, the planets, a bar of soap, a television, the ocean, a banana,- has energy from its sheer *existence*. This follows from perhaps the most famous statement in all of science: $E = mc^2$.

Waves behaving like particles.

For a long time, physicists believed that particles (matter) and waves were unrelated phenomenon. Matter was what existed all on its own. Matter could not travel through other matter. If you throw a ball against a wall, the ball will bounce back. On the other hand, waves are able to interfere with (move through) one another. The most vivid demonstration of this is probably color mixing (e.g. overlapping red and green light produces yellow light).

But at the start of the 20th century, there was a particular phenomenon involving the interaction between light (a wave) and matter that baffled physicists, who were unable to explain it. This phenomenon is the *photoelectric effect*, and it was Albert Einstein who first successfully explained it (incidentally, it was for his explanation of the photoelectric effect and *not* Relativity that he won the Noble Prize in 1921). Einstein's revolutionary idea was to suggest that waves such as light could *sometimes* behave like particles.

Particles behaving like waves

Following on the notion that waves sometimes behaved like particles, a young Frenchman of noble birth named Louis de Broglie proposed that maybe particles could behave like waves. He suggested that there exists some sort of wavelength (a distinct *wave* property) that is associated with any kind of particle. Within five years, his idea was experimentally confirmed, when electrons (massive particles of finite size) were found to behave in a way that could only be explained using the de Broglie wavelength.

What have waves ever done for you?

The sound that we hear comes to us as waves. Most sounds are just vibrations of air molecules. If waves didn't behave the way they do, there would be no music. There would be no language! You'd try to say one thing to someone, but something entirely different would come out. Waves are responsible for earthquakes and Tsunamis and the beauty of the beach.

Light is a wave. The visible spectrum which includes all the colors in the rainbow is nothing more than an incredibly small slither of light waves. We utilize waves in our microwaves, radios, televisions, cell phones, and medical devices. Even the energy from the sun – the fuel of all life on Earth - comes to us as waves!

Mechanical waves: the basics

Waves transfer energy over a distance. Mechanical waves can only transfer energy through a physical medium. The matter in the medium is disturbed in a way that it "carries" the waves energy from A and B. You could say that the particles in the medium serve as some kind of "messengers" of the wave, transferring energy from place to place. If there is no matter, there would be no way to transfer energy. This is why there is no sound in the vacuum of space (hence, the tagline from the movie Alien: In space, no one can hear you scream.").

The two simplest forms of waves are transverse (perpendicular) waves and longitudinal (parallel) waves. An example of a transverse wave would be the audience wave often seen at sporting events. This is when successive groups of people briefly stand up, raise their arms, and sit back down. Each person stands up just as that person's neighbor stands up, with the overall effect as though a wave is rippling through the stadium. An individual person only moves vertically as they rise from their seats, but the overall disturbance propagates horizontally through the stadium.

Longitudinal waves are when the particles in a medium vibrate in the same direction (parallel to) the wave propagation. Sound is an example of a longitudinal wave. The sounds that we hear are produced by vibrating air molecules near our ears. When you speak, air is pushed out from your lungs, through your windpipe (trachea), and into your voice box (larynx). Your vocal folds then vibrate, alternately trapping air and releasing it. The air that you breathe out is the beginning of a sound wave, which carries acoustic energy along with it. The air you initially push out collides with nearby air molecules, which push them to collide with their neighboring air molecules, and so on (note this means that speech can only be produced if you are exhaling). This acoustic energy eventually makes it over to you, causing the air near your ear to vibrate, which causes your eardrum to vibrate. Your brain interprets these vibrations into the sounds you hear.

So as you listen to the sound of someone's voice, you are actually picking up some of the energy that they sent out. No air molecules actually travel from them to you. Each individual molecule only moves a little bit, but it causes a sort of domino effect that moves over large distances.

You might also be interested to realize that since sound is just a form of energy, and energy is related to temperature and heat, then it is therefore theoretically possible to warm up a cup of coffee by screaming at it. Of course, even in ideal conditions it would take around 9 years of non-stop screaming to heat up one cup of coffee, but still!

Speed of waves depends on medium

We have seen that the direction of motion of a wave's energy and the motion of the medium need not be in the same direction (transverse waves). It should make sense then that they also don't need to have the same velocity. For example, consider the audience wave found at sports events: The *wave* speed is associated with how quickly the disturbance travels through the *crowd* of people. If I am seated in aisle 1, and you are seated in aisle 250, and I start a wave, then the wave speed is associated with how long from when I stand until when you stand up. On the other hand, the speed with which each person stands up and sit down need not be related to the wave speed (how quickly the wave travels through the audience). Imagine that the wave is moving through the crowd very quickly, and there is an old man, who just as he stands up, pulls a muscle in his back, and takes a while to sit back down. The rest of the crowd probably doesn't even notice him, and so the wave travels at the same fast speed through the stadium.

In general, the speed of the wave is determined by the properties of the medium it is traveling in. Properties of a medium can include the spacing between neighboring particles, how strongly the particles interact, and the density of the medium.

If particles are very close together, then they will bump into each other more quickly than if they are far apart. Energy can this be moved more quickly, the closer particles are to one another. An analogy would be a game of telephone played by a group of turtles. This is the game where one person whispers a phrase into their neighbor's ear, who whispers it into their neighbors ear, and so on down the line. In this metaphor, the phrase is like energy, and the turtles are like particles. We assume that the turtles can speak at a normal rate, but move very slowly. Now suppose that the turtles are very close to one another, so that one turtle can whisper to his neighbor without having to move. Then the message will get sent from the first turtle to the last before long. But now imagine that each turtle is very far away from his neighbor. Each turtle has to walk over to his neighbor before he can whisper the message. It will obviously take much longer to get the message across. It is like this with waves as well. Thus, waves generally travel faster in solids than in liquids, and faster in liquids than in gases.

Another factor affecting wave speed is how rigid the material it is travelling in is, or how strongly the particles interact. We call this the *elastic properties* of the medium. A rigid material is one that maintains its shape very well, even when a force or stress is applied to it. Steel is a rigid material, as opposed to rubber or clay, which are more flexible. The atoms / particles in a rigid material tend to have tight chemical bonds, and consequentially feel a strong force of attraction with each other. As a result, when these particles are disturbed from their rest position, they will return quickly. These particles vibrate at higher speeds than those in a less rigid material. Therefore, mechanical waves like sound can travel faster in more rigid materials.

Another property that affects wave speed is the density of a medium. Things generally move slower through denser material (think of running in a swimming pool). Do not confuse the density of particles with the spacing between particles. Density is mass divided by volume. More density means more stuff packed into less space, and vice versa. A denser object becomes more difficult to move than a less dense object (assuming they have the same elastic properties). It's as if you were to carry an empty box versus that same box when it's filled with books; It will be more difficult to move with the denser (full) box than the empty one. Similarly, a wave will be slower while moving through a denser material, as neighboring particles are less responsive to one another.

This is also why your voice sounds higher after you breathe in helium. Sounds which move faster tends to sound higher (think of what happens when you slow down a recording of a person speaking - their voice sounds lower). Helium is less dense than air (that's why Helium balloons float), and so sound waves travel much faster through helium than in normal air. Conversely, if you breathe in a gas denser than air, your voice sounds lower. This is also why the lighter strings on a guitar produce a higher sound than the lower ones (assuming they're placed under the same tension).

Waveform diagram

We have described what properties determine the speed of a wave, but have not yet mentioned what characterizes a wave – that is, its shape. The most commonly experienced mechanical wave is probably sound. However, due to the small size of air molecules, as well as the high speeds at which they travel, direct visual observation of mechanical waves becomes nearly impossible. However, with the help of technology, it becomes possible to visually represent a sound wave as an image.

We have seen that sound is produced by a chain event of vibrating air molecules bumping into one another. After a molecule moves forward and collides with another molecule, the space where it previously was is now empty, and is considered a relative low density area. The space where the molecules collide is a relative high density area, as there are two molecules where before there was one. Larger density corresponds to higher pressure, and vice versa.

An instrument can be used to measure and plot changes in air pressure over time. The result is a curve that represents the physical sound wave. The curve is usually plotted as a standard *x-y* graph, with the horizontal axis representing time and the vertical axis representing pressure, or displacement. The plotted figure is called the waveform, depicting the shape of the wave. The value of air pressure when there is no sound corresponds to the zero line or baseline. The points higher up on the waveform represent areas of higher density/pressure, and lower represents lower density/pressure. A waveform thus allows us to "see" sound.

Wave amplitude

Mechanical waves cause temporary displacements in the medium they travel in. For example, in an audience wave, each person is temporarily displaced from their seats as the wave passes through the stadium. The amplitude of a wave is a measure of how big a displacement it causes; Imagine doing a cannon ball into a swimming pool. As you hit the water, you cause some water to splash up and outwards. You can think of the maximum height reached by the splashed water as the amplitude; If a small child does a cannon ball into a swimming pool, he will create a modest splash, while if a sumo wrestler does a cannon ball into the pool, he creates a much larger splash. The water from the sumo wrestler's splash reaches much higher into the air than the childs. Water from the wrestler is displaced more, and so has a larger amplitude.

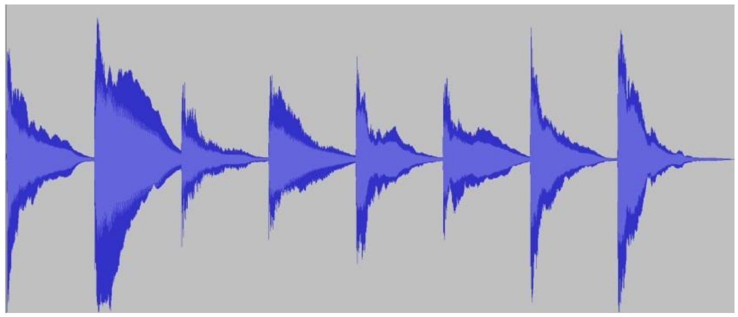
Sound waves travel by temporarily displacing the air molecules from their rest position. The amount of displacement that takes place has to do with the force of the collisions. More pressure equals more force equals more displacement. If your friend is across the room, then whether you whisper or scream at them, your voice takes the same amount of time to reach them. But if you whisper, each molecule is only slightly displaced, whereas if you scream, they are displaced much more.

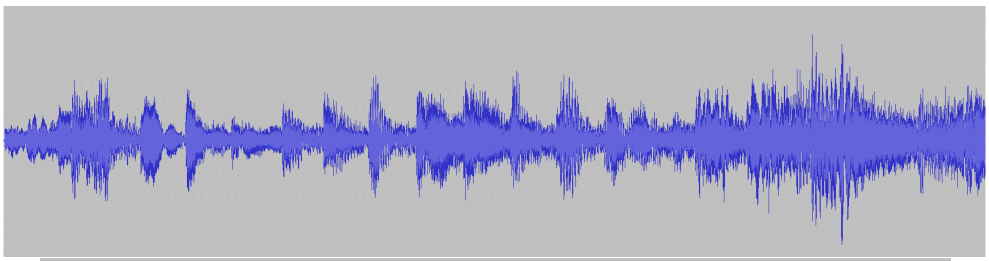
This fact explains how electric instruments and amplifiers work. Imagine the waveform produced when you pluck an electric guitar string – say, an open G - but with the amplifier volume set to zero. Now imagine what that waveform would look like if you slowly increase the volume. The waveform will look as though it's being stretched, but only vertically. As the volume increases, the amplitude of the wave increases, *but nothing else!* Anything else would change the pitch of the note. The G you played would no longer sound like a G! So the vertical axis of a sound wave tells us something about the loudness.

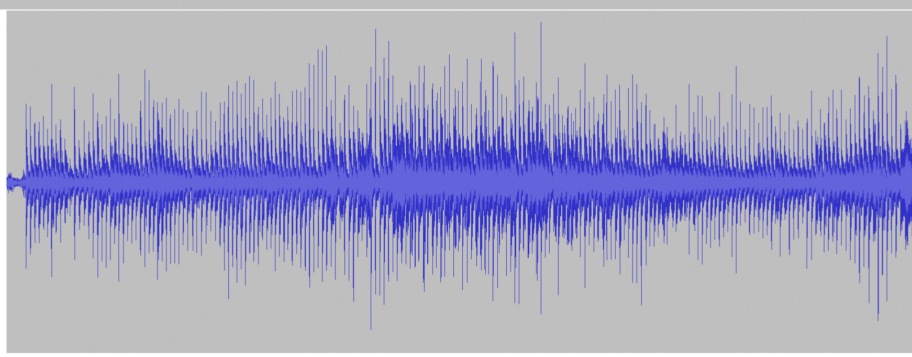
We actually have a scale used to measure degrees of loudness. This is the Decibel scale, named after Alexander Graham Bell, and it's based on human ears. The exact way in which this scale is set up involves some extraneous mathematics and physics concepts. There are some interesting ratings that are worth noting (following based on averages):

- 0 dB: threshold of human hearing (near silence)
- 15 dB: a whisper
- 60-65 dB: normal conversation
- 85 dB: City Traffic from inside car
- 110 dB: Car Horn
- 120 dB: Rock Concert or Jet Engine
- 125 dB: Pain begins
- 140 dB: when permanent damage begins

Music and noise

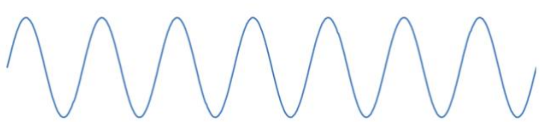






The figures above are the actual waveforms of three different sounds. The top waveform was taken from the sound of a C-major scale played on a standard piano. The middle waveform was taken from the opening bars of a piece of avant-garde music (Invention, by György Liget). The bottom waveform comes from the sounds of a jackhammer.

The shape that is usually shown when talking about waves is a sine curve:



This makes sense, because the shape of a sine curve is smooth, uniform, and clearly repeats itself. On the other hand, none of our waveforms look so pretty. However, it is probably safe to say that the waveform of the jackhammer seems much more random and chaotic than that of the C-major scale. The Ligeti waveform seems more random than the scale waveform, but that's to be expected when you consider that it's taken from an actual musical composition, where the notes aren't in a clear order like in the scale. Also, the height of the peaks in the middle waveform seems more uniform than in the jackhammer waveform, which is all over the place.

There's a good reason for this: the first two figures involve music, while the third involves noise. Music is ordered. Noise is random. This is not a matter of philosophy or taste. There is a literal mathematical distinction between music and noise. Noise is an abrupt, complex sound with an irregular period and amplitude. Noises sound chaotic and disorganized, and inherently unpleasant to the ear. The sound of paper crumbling, or construction, or nails against a chalkboard are examples of noise. Although distinct musical languages naturally developed across different cultures throughout history, as far as we know, no society has ever considered noisy waveforms to sound musical.

Music includes those sounds that we tend to perceive as pleasant. The waveforms in music are generally smoother, more regular, and even than noise waveforms. They look more like the sine curve.

Whereas noise is produced by the vibrations of a non-periodic (irregular) source, music is produced by regular vibrations. In order to describe how something vibrates, we use the word *frequency*. Recall that sound is produced by vibrating air molecules, going back-and-forth, back-and-forth, as they collide with their neighbors. This motion can be thought of as a cycle; the length of the cycle is how long it takes a molecule to return to its previous position. Using another analogy, you can imagine someone yo-yoing; assuming the yo-yo only goes up and down, and moves at a constant rate, then the length of the cycle would be how long before the yo-yo is in the same position twice (say, at the very bottom, or somewhere in the middle).

We use the word *frequency* to describe how often something happens. It is particularly useful to describe anything involving cycles. The frequency of a person's birthday is one birthday a year. Vinyl discs are often played at 45 *rpm* (revolutions per minute), meaning the record spins around exactly 45 times per minute. Frequency can also be used to describe how quickly something vibrates. If a waveform looks to be very nearly regular and uniform, then the frequency is approximately constant. Tuning forks produce sound waves with a constant frequency.

The standard unit of measuring frequency is in Hertz, Hz, which represents #cycles/second. 1 Hz means 1 cycle per second. When it comes to music, frequency is related to pitch. Middle C – the middle note on an 88-key piano – has a frequency of 261.6 Hz. This means that when you strike middle C on a piano, the piano string is vibrating 261.6 times per second. No one ever said, "the frequency of 261.6 Hz will from now on be known as middle C." We've just come to use that as the standard by which we tune our instruments.

As it turns out, the human ear is more sensitive to the relative difference between frequencies (pitches), rather than any particular frequencies. This explains why musical scales are so useful. Most of the world's music involves scales. A scale is just a pattern used to produce different musical notes. It's like a "musical ladder" that can be transposed to any key. Western scales are based on frequencies produced by 12 equally spaced intervals. A scale tells us its not the specific frequencies that are important in music, but the ratio of frequencies that is important. For example, a major chord consists of a root, third, and fifth. So a C-major chord consists of the notes C (261.6 Hz), E (329.6 Hz), and G (391.9 Hz), while an F-sharp major chord consists of F-sharp (739.9 Hz), A-sharp (932.3 Hz), and C-sharp (1108.7 Hz). You can check and see that ratio of notes in each chord are equal.

III. Conclusion and Future Work

In this paper, we have tried to create a vivid description of the general physics classroom by reviewing several of the most commonly cited problems that result from the course content and method of instruction.

We realize that without having implemented our project in an actual classroom or obtaining any data of our own, we cannot make any new conclusions. However, by describing a broad set of issues as well as simple solutions, we hope to offer the average teacher with at least one new idea to try and use with his or her own students.

This process is in the preliminary stages, and we would like to implement our project somehow in the upcoming school year. In addition to the manuscript, an effort is being made to convert the manuscript into an interactive, web-based manual. This will include links to video demonstrations, applets, projects and activities that can be performed, and other supplementary material for the interested student.

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