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Introducing ``Physics of music'' to students using free software

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Abstract: Many consider physics to be a highly mathematical oriented subject to study. To break this opinion and also to generate a deep interest in physics, a course on 'Physics of Music' can be introduced at any level of a curriculum. We present a simple and practical way of introducing this topic even for school level students. Teachers, along with students, can visualize and feel physics all time throughout the course.

Keywords: Physics of music; Sound; Pitch; Rhythm

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Introduction

Learners find more ease in learning topics or subjects which they experience in their daily life. It is due to the fact that most students enjoy and actively participate in language classrooms when their mother tongue is taught. The conventional tools available to teach concepts in physics in classrooms are derivations and equations. In topics like mechanics, many concepts are experienced by the learners in their daily life. But while studying concepts in solid-state physics like phonons or particle in a box in quantum mechanics, students often find it difficult to relate them with real-life experience. An area of physics that can be introduced to the students and taught with real-life experience and examples is the physics of music topic. Students can learn and enjoy physics better since the simple introduction of the physics of music helps to present basic concepts in physics like waves, energy, pressure, simple harmonic motion, types of waves and many more (G. Ramsey, 2015; G. P. Ramsey, 2015).

Many topics across subjects are often taught without the active participation of the learner. There is a huge divide between many concepts taught in the classroom and the opportunity to experience them by the learner. The general public and many students consider music as art but, there are many physics concepts in the generation of music. Conventionally, physics and music are introduced as separate subjects to the students, thus they are unaware of interrelating physics with music or vice versa. Considering the fact, an interdisciplinary approach is favorable to reduce this barrier.

More effective learning is possible by the combination of the resources of physics and music along with modern technology (Hechter & Bergman, 2016). Using software to create the Fourier components of sound and hard wares to do lab experiments engages the learner effectively in classrooms (Black & Magruder, 2017; de Winter, 2019; Jaeger, 2020; Neilsen et al., 2020). Studies on physics and music help the learner to find that there is a common platform for both physics and music where each of its concepts are correlated and the physics concepts help to understand music in a more scientific manner (Mullen et al., 2019). Thus introducing of physics of music in a curriculum may help the learner to acquire concepts from real life and classroom experiments.

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The physics of music topics can be taught to any discipline or age group and it is possible to incorporate experts like musicians, instrumentalists, and doctors from the society to share their concepts (J. Dostal, 2017; J. A. Dostal, 2020). Many possible methods and tools can be used for the introduction of the physics of music in the classroom like musical instruments and simple experiments (Piacsek, 2012; G. Ramsey, 2012; Worland, 2012, 2020). We can use free software like Audacity to introduce the basic waveforms for audiences from any educational background (Jaeger, 2017). In this paper, we introduce the use of software for frequency and waveform analysis of different musical sounds and introduction of basic concepts.

Methods

In this paper, we use some methods like visualization of the audio sound samples to introduce the physics of music to the students. Along with theoretical lessons, the practical assignments and live demonstrations are suitable to gain the attention of the learner. The audio samples of the musical instruments are collected and saved in a folder on a computer. For plotting the waveforms and for obtaining the frequency spectrum, Sonic Visualizer and Audacity are used. The windows of these software are shown in Figure 1 and Figure 2.

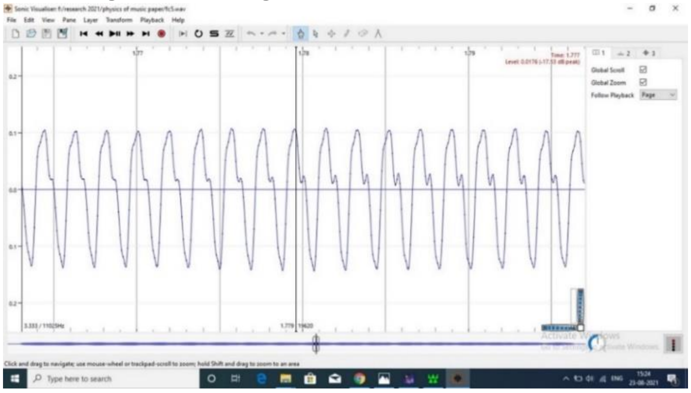

Figure 1. A representation of Sonic Visualiser window

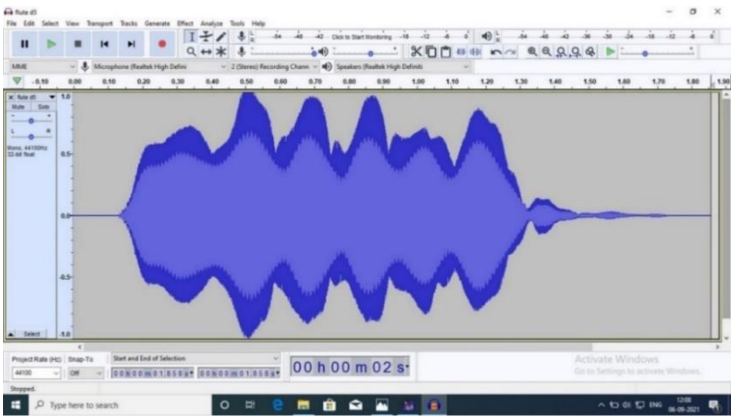

Figure 2. A representation of Audacity window

These softwares are freely downloadable from the internet. Double click on the executable files downloaded and follow the steps given below to install the software. The software Sonic visualiser is opened by double-clicking the icon on the desktop. The following options are chosen from the menu to plot the audio waveform.

File $\longrightarrow$ Open

The audio waveform of the file chosen from the folder appears on the main screen of the software. To save the image the following option is used from the same menu

File $\longrightarrow$ Export Image File

The frequency spectrum of audio files of musical instruments is plotted with Audacity. For plotting the following options are used.

File $\longrightarrow$ Open

Analyze $\longrightarrow$ Plot spectrum

A new window with a frequency spectrum is generated. In this window, all the parameters are kept as chosen by the software. When the mouse pointer is placed on each peak in the spectrum, the frequency value of the peak has appeared in the lower section. The frequency ratio is calculated for different samples.

Results and Discussion

Sound and light are the basic phenomena we come across in our daily life. Unlike light, the sound is only capable to propagate in some medium (Spieser & Bailly, 2020). In a medium, the mechanical vibrations of some body or source lead to the production of sound (Howard & Angus, 2017).

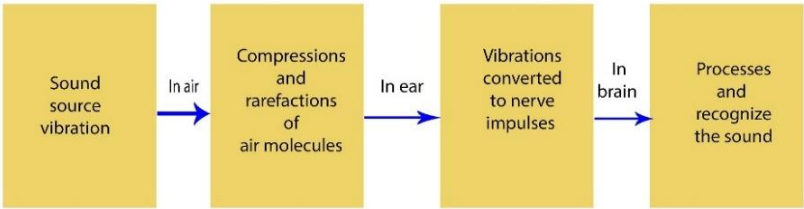

Figure 3. Graphical representation of sound and its propagation

These vibrations are transferred to the surrounding air molecules and move away from the source of vibration. In our body, we have a vibrating source to produce the sound which is termed as vocal cord. The vibrations generated by our vocal cord also move away through the mouth and reach the atmosphere.

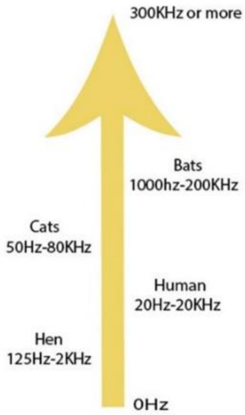

Figure 4. Graphical representation of sound and its audiable range in different species.

Sound and propagation

In the air, when the air molecules vibrate, some of them come closer and creates regions of high pressure called compressions and some other molecules move away from each other and creates regions of low pressure called rarefactions. The resultant wave consisting of compressions and rarefactions moves in the same direction as the vibrations of the air molecules and hence the sound wave is a longitudinal wave. These waves through the air reach our ears and we hear the sound. A pictorial representation of the process is given in Figure 3. Sound waves are produced in a wide range of frequencies, but humans can hear only a small range of them (Harder-Viddal, 2019).

Frequencies outside the human audible range are utilized in many fields like medical diagnosis and industry (Tallon et al., 2020; Weiss et al., 2013). A representation of the audio range of different species is given in Figure 4.

Classification of sound

Sound is broadly classified into noise and music. A sound produced by irregular vibrations and unpleasant to hear is termed noise (Frank Fahy, 2015). For a noise sound, the amplitude of the sound changes instantaneously.

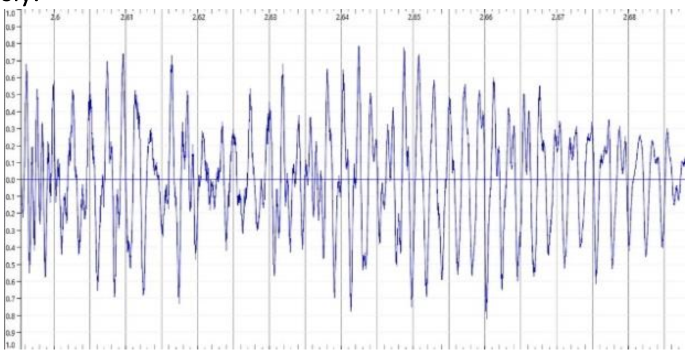

Figure 5. Waveform of the sound of a barking dog

The waveform of the sound of a barking dog and an ambulance are the best examples of noise, which are given in Figure 5 and Figure 6.

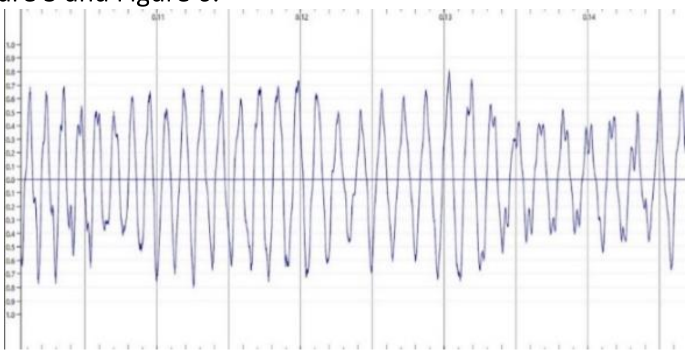

Figure 6. Waveform of the sound of an ambulance

As noise show irregular nature and it is difficult to get parameters or properties associated with a noise. A musical sound is different from a noise in many aspects.

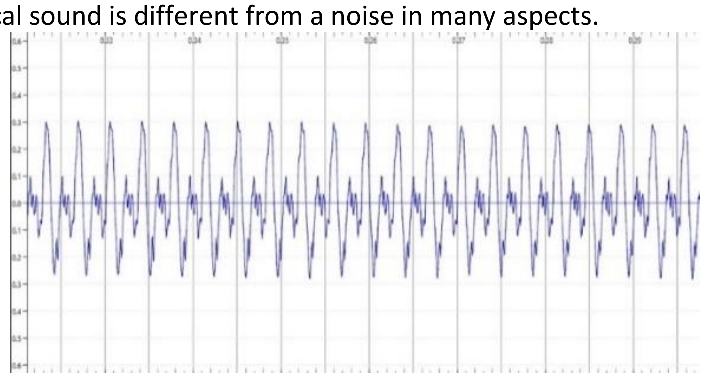

Figure 7. Waveform of the sound of a Violin

It has a regular waveform and is produced by regular or ordered vibrations. Musical sound is pleasing to hear and a particular wave shape is repeated over and over. The Violin and Flute wave forms are given in Figure 7 and Figure 8. The regular and ordered character allow us to define many parameters associated with musical sound. These parameters help in the study of musical sound in comparison with noise.

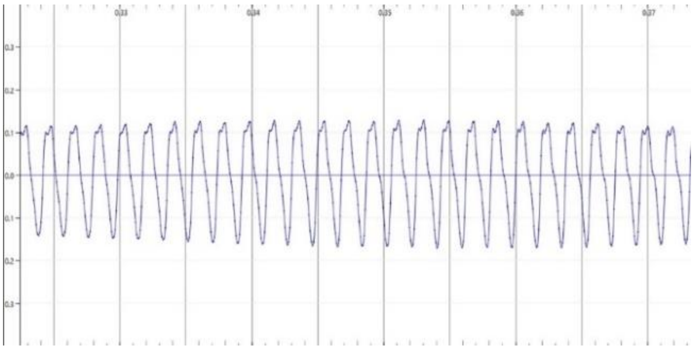

Figure 8. Waveform of the sound of a Flute

Properties of musical sound

For a musical sound, the basic parameters are pitch, rhythm, loudness and timbre. They are represented in Figure 9.

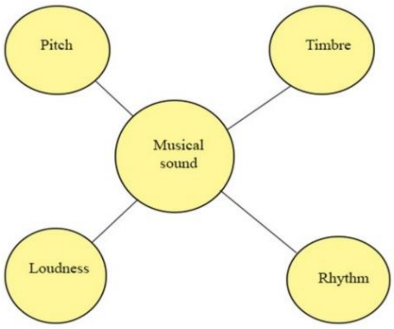

Figure 9. Basic parameters of musical sound

Even though many of these parameters are subjective in nature, we can relate them with physical quantities associated with the waveform of sound (Konz & Ruiz, 2018; Vurma et al., 2011).

Pitch

In a musical sound, there is a large number of frequencies, the lowest frequency is called fundamental and higher frequencies are termed overtones and together they are called harmonics. Figure 10 represent the note played on Violin with the lowest peak with frequency 445 Hz and higher. We get integer values when we divide each overtone frequencies in a musical sound with the lowest frequency which reveal their relation.

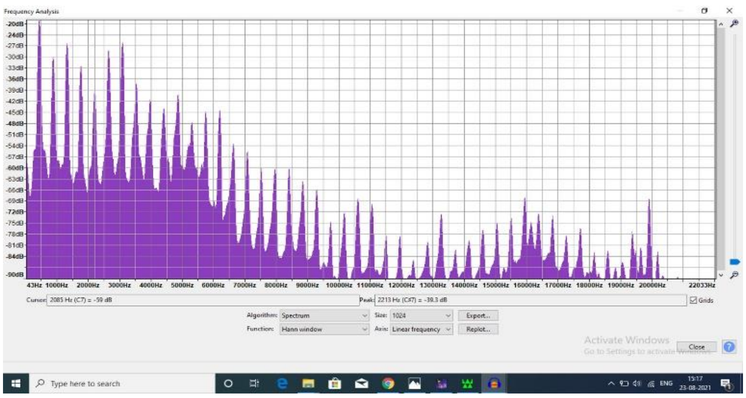

Figure 10. Frequency spectrum of the sound of a Violin note

The frequencies and their ratio with the lowest frequency of the Violin note in Figure 10 are given in the Table 1.

Table 1. First five frequencies and their ratio of a Violin note

Peak	Frequency (Hz)	Ratio
1	445	1.00
2	882	1.98
3	1331	2.99
4	1774	3.98
5	2213	4.97

Integer multiple frequency ratio is seen for Violin and many other instruments in string family but it is not the case of percussion drums which are known to produce indefinite pitch. Table 2 and Table 3 show the frequency ratio of drum heads with different shapes (Nishanth et al., 2019).

Table 2. Frequency ratio of the modes of rectangular and square membrane

Mode	Rectangular	Square
(1,1)	1.00	1.00
(2,1)	1.3867	1.5811
(1,2)	1.7541	1.5811
(2,2)	2.00	2.00
(3,1)	1.8605	2.2361
(1,3)	2.5570	2.2361
(3,2)	2.3533	2.5495
(2,3)	2.7316	2.5495
(3,3)	2.9999	3.00

Table 3. Frequency ratio of the circular membrane

Mode	Circular
(0,1)	1.0000
(1,1)	1.5934
(2,1)	2.1356
(0,2)	2.2954
(3,1)	2.6531
(1,2)	2.9173

Unlike rectangular and square membranes, circular membrane produces a wide range of frequencies and the frequency ratio approaches more close to the integer values in comparison with other shapes. But still, circular drums cannot generate harmonics. Certain methods like adding weight at the middle region of the drum head, changing the tension on the drum head while playing the instrument are used to produce definite pitch in many Indian drums like Mridangam, Tabla, Edakka, etc. (Dubey & Krishna, 2021; Nishanth & Udayanandan, 2020b). The frequency ratio of the first six modes of Mridangam is given in Table 4.

Table 4. Frequency ratio of the Mridangam

Mode	Ratio
(0,1)	1.0000
(1,1)	1.9496
(2,1)	2.9666
(0,2)	3.0723
(3,1)	3.9930
(1,2)	4.1237

The sound produced by many musical instruments have interrelated harmonics with fundamental slightly higher than one or absent in the spectrum (Datta et al., 2019). We hear the correct pitch in such cases also and is called virtual pitch or missing fundamental (Su & Delgutte, 2019; Suits, 2019). In many musical instruments, the sound is produced with missing fundamental like in Timpani and Kim (Boedts, 2020; Thangprasert, 2015). There are many reasons for missing fundamental in instruments, for example in Timpani air loading generates missing fundamental and in Indian drums like Tabla the striking method by the artist creates missing fundamental (Rossing, 1977; Tiwari & Gupta, 2017).

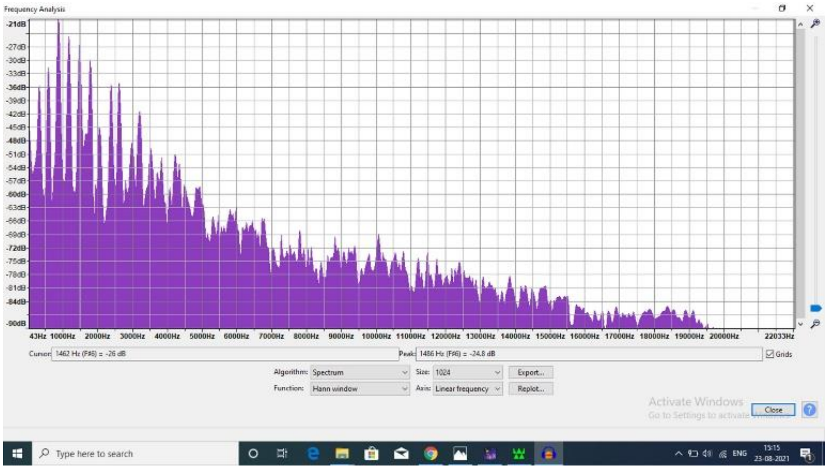

Figure 11. Frequency spectrum of the sound of Tabla

Figure 11 shows the frequency spectrum of the note played on the Indian drum, Tabla, with harmonics and here the lowest peak is not in harmonic relation with other peaks. When the fundamental is missing, these harmonics are processed by the primary auditory cortex in the brain and we get the sense of pitch (Alho et al., 2012). The processing of missing fundamental is represented in Figure 12.

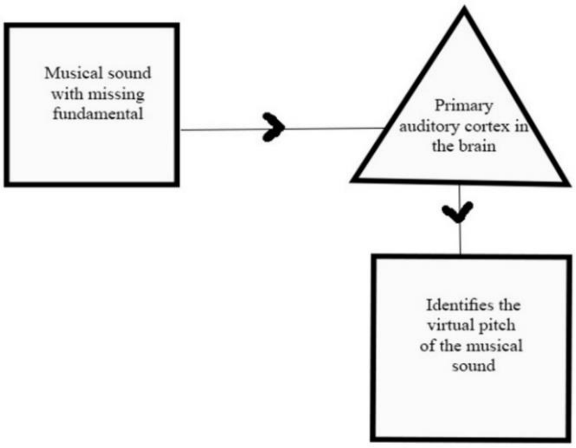

Figure 12. Representation of how virtual pitch is identified in a musical sound

In such cases, we hear a pitch at almost half the frequency of the second peak and the frequency ratio of different peaks are given in Table 5. In musical instruments, the pitch is determined from the duration of the sound produced and physical factors such as length, thickness, etc. (Bucur, 2017; Gilbert & Willy, 2008).

Table 5. First five frequencies and their ratio of Tabla

Peak	Frequency (Hz)	Ratio
1	323	1.10
2	587	2.00
3	880	2.99
4	1180	4.02
5	1486	5.06

For drums, the circular shape of the drum head helps to make lowest possible pitch in comparison with other shapes such as rectangular drum head (Nishanth & Udayanandan, 2020a).

Rhythm

There are different kinds of drums and a stroke by the player makes their circular membrane drum heads to vibrate in many modes. The initial shape of the membrane or its initial velocity does not change the modes of vibration and hence they produce a characteristic set of frequencies that are not interrelated as the multiple of the lowest frequency (Nishanth & Udayanandan, 2018). In such drums, a specific pattern of strokes over time is maintained and they attract the attention of the audience. These patterns are repeated over and over as the time progresses and attracts the attention of the audience again and again and are called rhythm (Deva, 1967; Jones, 1993). In general one best example of rhythm is the patterns of our heartbeat we all experience in our daily life. In our pre-school or early school days we have been taught rhymes like “twinkle twinkle little star”, “Baa baa black sheep” and many more. Due to their rhythm and order, they are popular at any time and are at our mouth even after many years. Studies show that students with a better ability to understand and perform rhythmic music have improved ability in their language and grammar skills (Chern et al., 2018; Lee et al., 2020). In live performances, ensemble of drums are used to create rhythmic sound and when they are played in a certain rhythm, the activities of the brain takes place at a similar rate to the strokes on the drum heads.

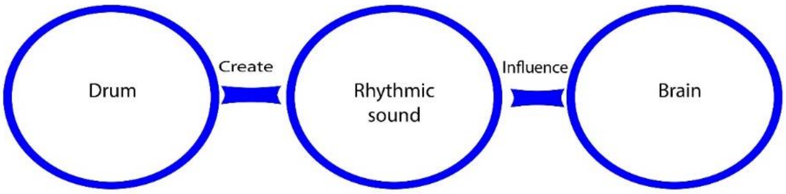

Figure 13. A representation showing interrelation between the drum and the brain

Many studies show that musical rhythm has ability to influence the activities of our brain in the regions associated with movement and generates more neurotransmitters associated with pleasant feelings (Salimpoor et al., 2015; Trost et al., 2014). Hence on hearing popular rhythmic music on television, mobile, or at some stage performance, many of us or our friends make movements and we find ourselves and others get involved. When there is a large audience, gradually each person attains a similar level of pleasantness and makes body movements like the other. So, good rhythmic music engages a large audience and there are similar levels of interpersonal coordination in movements and pleasant emotions which makes the large audience attract towards rhythmic music (Kim et al., 2019). Hence rhythm is an important pillar of music and more fundamental compared with other parameters. Figure 13 shows the relation between the drum sound and the brain.

Loudness

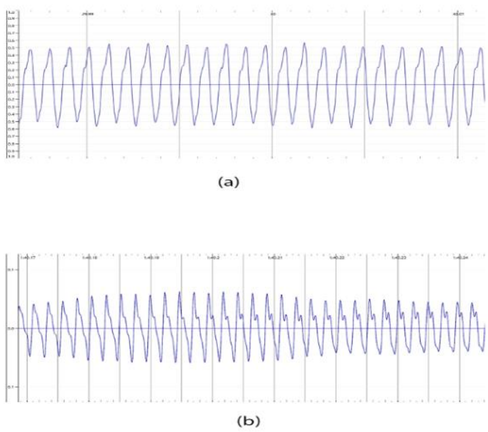

Figure 14. Waveforms of flute with (a) high loudness (b) low loudness

Loudness is the parameter in the musical sound related to the amplitude of the waveform. The studies about loudness are important as it helps the studies on hearing loss, overall understanding of hearing mechanism etc (Florentine et al., 2011). The loudness is closely related to other parameters such as timbre, pitch, and when we hear high pitched instruments they sounds loud (Beament, 2003). In Figure 14, waveform of flute with amplitude around 0.5 and 0.05 are given and the sound with amplitude 0.5 is louder in comparison with sound with amplitude 0.05.

Timbre

Timbre is a parameter of a musical sound represented by a unique set of frequencies possessed by each sound (Fabiani & Friberg, 2011). When the same note is played on Indian drums Tabla and Mridangam, we identify them as different since the sounds have the same pitch but the frequency of different overtones are different. We can separately identify the two sounds with same pitch, duration and loudness as two different sounds because of the parameter timbre (Siedenburg et al., 2019). The timbre of a sound is highly related to the shape of the waveform of that sound and the characteristics of the waveform.

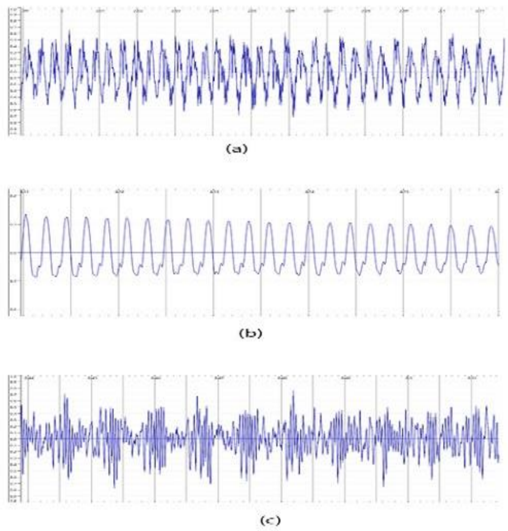

Figure 15. Waveforms of (a) a Guitar (b) a Flute and (c) a Sitar

In Figure 15 waveforms of three instruments are given and each has different shapes. When these instruments are played with the same pitch and loudness for the same duration, the difference in their wave shapes gives them distinct identification. When we struck a drum, the amplitude of its waveform rises to a maximum value in a certain initial time and remains at the same high amplitude for a certain more time and then decay to the minimum which makes the overall shape of the waveform. The initial portion of the waveform at which the amplitude raises to its maximum is termed as attack region, followed by sustain region and decay region. The sound produced by different instruments have changes in the size of these regions which makes different timbre for those sounds (Berg & Stork, 2005). The overall change in the amplitude from the initial point to the end of the waveform of a sound is called its envelope and for different instruments, the changes in the shape of the envelope create the difference in their timbre even when the same note is played on those instruments (Gunther, 2012). Timbre is a parameter that helps the listener to identify characteristics of the waveform of a sound (Jannereth & Esch, 2021). Hence it is interrelated with all other parameters of the waveform such as pitch, loudness, etc.

Conclusions

The methods by which topics in physics are communicated in the classrooms are very important. In this paper, we suggest that the course on the physics of music can be introduced in a very lively way with demonstrations and active participation of the learners. The method of collection of samples, observation of frequencies, and waveforms was promoted including the technique to distinguish music from noise.

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