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Alternative Frameworks in Conceptions of Sound: A Historical Evolution

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Abstract

This article reviews and discusses the historical development in the scientific conceptualization. It follows key debates and conceptions of sound through an evolutionary process leading to contemporary understanding of sound related phenomena. It is notable in the article that the raging debates among scientists of ancient Greece to seventeenth century interpreted and understood sound as either a substance or a wave. Consequently, sound related phenomena were explained based on the framework in which they were formulated. However, with evidence from scientific experiments and mathematical deductions, sound was eventually understood as a wave. Moreover, the sound-as-substance framework as shown in the historical development resembles some of students' preconceptions as demonstrated by numerous studies on conceptions of sound. It is hoped that this review of the historical development in the conception of sound can elucidate the way in which students learn and inform the nature of instructional activities that science teachers can design to promote student learning.

Key words: History of Sound, Teaching and Learning Sound.

Introduction

History of science has been widely accepted as a heuristic tool to promote students' learning of science. According to Matthews (1992), the history of science: motivates and engages pupils; humanizes the subject matter; promotes the better comprehension of scientific concepts; has intrinsic worth itself in understanding certain historical pivotal episodes; and demonstrates aspects of the nature of science. Moreover, it has been found that there are similarities between students' conceptions and those of early scientists (Espinoza, 2005; Gauld, 1991; Sequeira and Leite, 1991; Seroglou et al., 1998; Wandersee, 1985).

In other words, the past of science can illuminate the present of science learning (Matthews, 1989). With appreciation of these similarities, teachers can use the history of science to create learning activities that assist students to overcome their alternative conceptions.

However, including the history of science in classroom still has challenges. Teachers' knowledge of the history of science is one of those challenges (King, 1991). It is evident that even though teachers acknowledge and appreciate the benefits of including the history of science into curriculum, they can introduce the historical element only when it could be blended in their current instruction (Mash and Wang, 2002). Moreover, time pressure and difficulty in finding high-quality resources are main obstacles faced by teachers in integrating the history of science into classroom activities (McKinney and Michalovic, 2004). Therefore, in order to promote inclusion of the history of science in classroom activities, it is necessary to provide resources for teachers so that they can use such resources to design instruction, which includes the history of science.

Sound related concepts are among the key topics outlined in the Thai science curriculum (The Institute for the Promotion of Teaching Science and Technology [IPST], 2002). However, research on this topic is inadequate in science education literature when compared to other physics topics such as force, light, or electricity. Duit et al. (2006), for example, reviewed a number of publications on students' ideas in various physics topics. They found that there are only 28 out of 2,278 publications (1.23%) involving students' conceptions of sound. Moreover, when considering the inclusion of history of sound in classroom activities, McGinnis and Oliver (1998) found that only one article published in the 'School Science and Mathematics' journal during 1901-1998 periods showed sufficient attention paid to the history of sound. As a result, the authors have inspired to review the evolution of the conception of sound so that it can be used by teachers, in some particular ways, in integrating the history of science into their instruction.

This article describes how the ideas about sound have evolved over the centuries. It provides insight into debates regarding conception of sound among past thinkers and strategies they used to clarify the debates. However, to avoid what is called 'Whig history' (Brush, 1974: 1169), contexts where the conceptual development of sound the debates took place leading to some kind of scientific resolutions have been included as much as possible in a limited number of pages. Teachers and science educators can utilize this historical development of the understandings of sound, which have some key features that are similar those of present students, to design science instruction in order to assist students to overcome their alternative conceptions of sound.

The Organization of Article

Because of the overlap of the historical development of various ideas about sound, this article is divided into a couple of sub-sections to show the general development of each concept of sound. Each sub-section describes the development of a concept of sound in the contemporary period. Consequently, it is possible to refer to those who were involved in developing understanding of sound many times. Furthermore, it is important to note here that the notions of sound in early periods were rather developed by logical reasoning. Then through the development of scientific methods, the notions of sound involved more scientific experiments that attempted to manipulate the variables to generate empirical evidence for insights about sound. Moreover, the notions of sound were also clarified through the development of mathematics and its connections to empirical evidence. This led to the theoretical explanations about sound.

Thus the article begins with 'The Origin of Investigation of Sound' that describes how sound became an object of study. Then, main issues about sound in the past would follow. They include 'The Nature of Sound' that describes a discrepancy between views of sound as a substance and wave; 'The Production of Sound' that describes various perspectives on how sound is produced; 'The Propagation of Sound' that describes how sound travels from a source to other places; 'The Speed of Sound' describes attempts to measure the speed of sound in air; 'The Frequency of Sound' that details several notions about how the relationship between the pitches of sound and the frequency of vibrating sources have evolved over time; and 'The Theoretical Explanation of Sound' describes how the theoretical explanations of sound developed in response to questions resulting from centuries of debate about sound.

The Original of Investigation of Sound

Although there is no clear evidence showing when the first investigation about sound begun, there seem to be a general view that it might have originated during Babylonian and Egyptian period (Palisca 2003) or before the beginning of recorded history (Lindsay 1945). Most writers credit Pythagoras, a mathematician and philosopher in Greek era, as the earliest investigator of sound (Blood 2007; Caleon and Subramaniam 2007; Hunt 1978; Palisca 2003; Lindsay 1945, 1966). Based on a profound distrust in human sense and an obsession with numbers in the ancient Greek (Dampier 1961; Deutsch 1980), Pythagoras and his followers, who lost faith in the human sense, sought to interpret sound phenomena mathematically (Hunt 1978). However, sound was seen as a study of music rather than related to mathematics. It was also seen as a branch of art instead of being a study of science (Caleon and Subramaniam 2007; Lindsay 1945). From the ancient era to today, investigation of sound has evolved from using pure reasoning to a blend of both pure reasoning and more empirical based evidence (a study of physical properties by seeking empirical evidences) about sound. Contemporary investigation about sound is now a study with the realm of science, initially called 'acoustics' by Joseph Sauveur (Caleon and Subramaniam 2007; Lindsay 1966). However, historical development of acoustics was certainly influenced by the study of mathematics, classical mechanics, and wave mechanics.

About 580-500 B.C., the relations between pitches of sound and numbers were first revealed by Pythagoras (Caleon and Subramaniam 2007; Palisca 2003). Pythagoras observed sounds of hammers hitting anvils that are sometimes pleasant (consonant), and other times unpleasant (dissonant) (Caleon and Subramaniam 2007; Hunt 1978). He then found that the harmonious sounds were related to the weights of the hammers in the ratio of small whole numbers (Caleon and Subramaniam 2007; Hunt 1978; Palisca 2003). Pythagoras tested this with other materials such as glasses, vases, and strings and then drew a similar conclusion leading to his invention of a monochord consisting of a string stretched and fixed at both ends and a movable bridge dividing the string into two parts (Caleon and

Subramaniam 2007; Hunt 1978). He found the inverse proportionality between the pitch of sound and the length of a vibrating string (Mcginnis and Oliver 1998). Pythagoras also found that the length ratios of the two parts was 1:1, 1:2, 2:3, and 3:4 produced consonant sounds. This discovery by Pythagoras was a big step in the formal investigation of sound leading to empirical based assertions about sound.

The Nature of Sound

Some ancient thinkers considered sound to be a substance while others considered it to be a wave. These views influenced the development of sound related concepts. Each view employed approaches to explaining all the aspects of sound. These views continued to exist with different adherents until the wave theory was determined to be the most valid.

The notion of sound as a substance had been in existence since the Greek period, as implied by Democritus (460-370 B.C.) when he used the term 'fragments of sound'. According to Hunt (1978, p. 24), Democritus expressed that "the air is broken into bodies of similar shapes and rolls about with the fragments of the sound". This view is also implied in what Taylor (1999, p. 121) has discerned from Democritus's speech that "the air is split up into corpuscles of the same shape as the fragments of sound, and that they move about together". Similarly, Plato (about 428-347 B.C.) also referred to 'body of sound' when he expressed about hearing. Hunt (1978, p. 19) describes Plato as writing that "a great body of sound is loud, and small body of sound the reverse". Moreover, Epicurus (341-270 B.C.) used the word 'current' consisting 'homogeneous particles' for sound when he explained hearing. According to Cook (1996) and Chalmers (1936, p. 246), Epicurus wrote that "hearing takes place when a current passes from the object … which emits voice or sound or noise … This current is broken up into homogeneous particles, which at the same time preserve a certain mutual connection and a distinctive unity extending to the object … and thus cause the perception". This notion still persisted in the beginning of the Roman period.

During the Roman period, Titus Lucretius Carus (99-55 B.C.) explained voices, saying that sound has 'a corporeal form' shaped by organs such as the tongue and lip (Hunt 1978). According to Leonard (1997), Titus Lucretius Carus explained hearing that "a sound and every [other] voice … heard when, getting into ears, they strike the sense with their own body. For confess we must even voice and sound to be corporeal, because they're able on the sense to strike". The same notion also persisted in the period of Islam when Ikhwan al-Safa or Brethren of Purity, an organization of Arab philosophers during the tenth century, referred to 'collision and rest of sound'. It was noted that "hard, hollow objects … sound for a long time after they are struck because the tone repeats itself in their cavities and collides again and again until it comes to rest"(Hunt 1978, p. 57). Sound-as-substance framework was still in use until the sixteenth century. For instance, sound was referred to as, 'one of the subtlest pieces of nature' by Sir Francis Bacon (1571-1626) (Hunt 1978, p. 77), as 'invisible particles' by Pierre Gassendi (1592-1655), or as 'globules of sonic data' by Isaac Beeckman (1588-1637) (Caleon and Subramaniam 2007, p. 175).

On the one hand the discussion so far has described sound related conceptions that are based on the substantive nature of sound. On the other hand sound was understood as a wave by some ancient thinkers even though they did not understand fully the mechanism of sound. Although it is not clear who actually is the first person to employ the notion of wave for sound, it can be determined that this notion was basically generated from analogy of water wave. The Stoic, a school of philosophy in ancient Greece, used an explanation of a circular or spherical propagation of sound: “we hear when the air … suffers concussion, a vibration which spreads spherically and then forms waves …, just as the water in a reservoir forms wavy circles when a stone is thrown into it” (Kilgour 1963, pp. 282-283). The wave notion of sound proposed by the Stoic seemed to be the transverse wave.

Differently, Aristotle (384-322 B.C.) tended to imply the notion of the longitudinal wave when he expressed about the propagation of sound: “it [the air] is set in motion …, whether by contraction or expansion or compression … the air is at once driven forcibly on, thrusting forward in like manner the adjoining air, so that the sound travels unaltered in quality as far as the disturbance of air manages to reach” (Caleon and Subramaniam 2007, p. 174; Lindsay 1973, p. 23). Moreover, Marcus Vitruvius Pollis (about 80-25 B.C.) also distinguished the propagation of sound from that of water wave: “It [voice] is propagated in infinite numbers of circular zones, … as when a stones is thrown into a pool of standing water … but … in water the circles … are propagated horizontally only, while the voice is propagated both horizontally and vertically” (Hunt 1978, p. 24). In addition, Anicius Manlius Severinus Boethius (480-524) also held the wave view of sound: “when air is struck and produces a sound, it [the air] impels other air next to it and in a certain way sets a rounded wave of air in motion, and is thus dispersed and strikes simultaneously …” (Hunt 1978, p. 27).

The two views about the nature of sound certainly influenced understanding of the sound related phenomena. Indeed the phenomena were explained in diverse ways based on either substantive or wave view of the nature of sound. However, based on empirical evidence, sound was gradually explained using a wave framework. In the sound-as-substance framework, the production of sound was perceived as sticking of objects. This conception was gradually extended into sticking of air and then into movement of air. However, based on empirical experiments, the production of sound was eventually linked to the vibration of objects.

The Production of Sound

The question of how sound is produced preoccupied thinkers for over centuries (Lindsay 1966). However, after Pythagoras (about 580-500 B.C.) the relation between the pitch of sound and the length of strings producing the sound became well established. There exists recorded evidence that many ancient Greek thinkers held this understanding. Most of them basically showed that sound is produced by ‘striking of objects’. For example, Archytas (408-355 B.C.) expressed that “sound is impossible unless there occurs a striking of objects against one another” (Hunt 1978, p. 14). In the same manner, Aristotle (384-322 B.C.) showed an analogous idea that “what is required for the production of sound is an impact of two solids against one another and against air” (Hunt 1978, p. 23). However, Aristotle seemed to go further when he referred to the air influencing the production of sound, saying that “all sound arise either from bodies falling on bodies, or from air falling on bodies” (Hunt 1978, p. 26). This notion still persisted until the golden age of Islam.

The notion about the production of sound in Islam era was not much different from the Aristotle's notion. Sound was still produced by hitting of bodies. However, air seemed to be a necessary condition of the production of sound in this period. Many philosophers referred to air when they talked about how sound transmitted. For instance, Al-Farabi or Alpharabius (about 870-950 AD), a Muslim philosopher and musician, declared that "it is the air thrust away by the impact of two bodies which transmits the sound" (Hunt 1978, p. 49). In the same vein, Ikhwan al-Safa (about 893 AD) also showed that "sound … [is] generated in the air by the collision of objects" (Hunt 1978, p. 56).

In addition, the notion of the production of sound tended to be revised from the impact of bodies into movement of the air as Ibn-Rushd or Averroes (1126-1198) argued that "sound is produced by a passion [or an effect] of the air …" (Hunt 1978, p. 63). Moreover, Safi al-Din (1252 -1334) also explained about voice production by saying that "… the air applied a firm and violent impact to the cavities of the larynx; and this impact gives rise to a note" (Hunt 1978, p. 70). Furthermore, movement of air still seemed to be the main cause of production of sound in the late fifteenth century as Leonardo da Vinci (1452-1519) expressed that "there cannot be any sound when there is no movement or percussion of the air" (Hunt 1978, p. 76).

Until the period of scientific experiments, the production of sound was linked to the vibration of objects. Two experiments by Galileo Galilei (1564-1642) empirically verified the notion of sound-as-wave. The two experiments were consistently described by Hunt (1978) and Lindsay (1966). For the first one, Galileo Galilei fixed a glass goblet at the bottom of a large vessel filled with water almost up to the brim of the goblet. He then rubbed the edge of the goblet. The goblet vibrated and emitted a sound while there were ripples running across the surface of the water. Moreover, when he rubbed faster until the goblet sounded an octave, the ripples in the water were divided in two. The second one was accidental arising from when he scraped a brass plate with an iron chisel in order to remove some spots from it. Galileo realized that the scraping was accompanied by a sharp whistling sound of a definite musical character. He observed a long row of parallel fine streaks on the surface of the brass. He further observed that the distance between the streaks was constant or the same. In addition, he noticed that when he increased the speed of scraping, the pitch of sound produced increased and conversely, the distance decreased. These two experiments showed the connection between the production of sound and the vibrating motion.

More attention was paid to the vibrating motion of objects in order to determine how the vibration related to the pitch of sound (Lindsay 1966). Galileo also observed the vibration of pendulums having different lengths while Isaac Beeckman (1588-1637) investigated the vibration of strings (Lindsay 1966). Based on the experimental observation, Marin Mersenne (1588-1648) recognized that when other things were equal, the frequency of the vibration was inversely proportional to the length of a string, and directly proportional to the square root of the cross-sectional area (Lindsay 1966). Robert Hooke (1635-1703) indicated a way of associating frequency of vibration with the pitch of sound by allowing a cog wheel to run against the edge of a piece of cardboard (Caleon and Subramaniam 2007; Lindsay 1966). Joseph Sauveur (1653-1716) investigated the relation between frequency of strings and the pitch of sound (Caleon and Subramaniam 2007; Lindsay 1966).

Because the relation between the pitch of sound and the vibration of its source was clearly revealed, it implied that the vibration of objects led to the production of sound. However, there were no explanations about how the vibration of objects produced sound. Until Brook Taylor (1685-1731) could provide a strictly dynamic solution of the vibrating string by assuming that every point of the string would reach the horizontal position at the same time (Lindsay 1966). However, there was still need for the description of the vibrating motion in continuous medium. This led to further search for a theoretical explanation of the mechanism of sound that required understanding of mathematics and mechanics. The theoretical explanation of sound had to be compared with the empirical evidence in order to develop a valid explanation.

The Propagation of Sound

For many centuries, the nature of sound was perceived either as a substance or wave, and that propagation of sound had been consistently perceived as an activity of the air. This latter notion permeated thinking among Greek philosophers. However, the activity of the air was explained in different ways depending on how it was conceptualized. Despite this, attempts to understand the propagation of sound gradually pointed to the nature of sound as well.

The notion that sound as a kind of substance was conveyed in statements or thinking, which perceived sound as moving in a way similar to common physical substances (objects). Democritus (460-370 B.C.), for example, who used the term ‘fragments of sound’, offered that the fragments of sound were ‘rolled’ by bodies of similar shapes in air (Hunt 1978, p. 24). These fragments moved together as ‘birds of a feather flock together’ (Taylor 1999, p. 121). However, there still were no reasons for how the fragments of sound moved. In more details, Epicurus (341-270 B.C.) explained that sound passes from the source to listener as a ‘current’ of the homogeneous particles, which preserve a certain mutual connection and a distinctive unity extending to the object at the same time (Chalmers 1936, p. 246; Cook 1996). These particles were observed to be continuously displaced by the air like breath (Cook 1996).

However, Aristotle (384-322 B.C.), who did not agree entirely with the notion of certain shapes of the air, explained the propagation of sound wave-like in the air (Lindsay 1973). He explained that, when sound travels, the air is set in motion in the same way that bodies are moved. When the nearest portion of the air is struck, the air is driven forcibly on, thrusting forward in a manner like the adjoining air. Aristotle also used the term ‘disturbance of the air’ as well as ‘contraction’, ‘expansion’, and ‘compression’ of the air (Hunt 1978, p. 26; Lindsay 1973, p. 23). Because of this terminology, it is generally believed by many writers that Aristotle held the notion of sound as a ‘compressional wave’ (Lindsay 1966, p. 635) or a ‘longitudinal wave’ (Caleon and Subramaniam 2007, p. 174). But, it is not certainly clear that he held the wave-like propagation of sound view since he did not refer to the vibrational motion of the air molecules.

By using the analogy of water wave, many ancient thinkers employed the wave propagation for sound. Some of them directly referred to ripples of the air. For example, Chrysippus (280-207 B.C.), a Stoic philosopher who was credited by Hunt as a first person introducing the notion of spherical wave propagation for sound, referred to ‘undulating spherically’ of the air (Hunt 1978, pp. 23-24). Marcus Vitruvius Pollio (about 80/70-25 B.C.) also explained that sound “is propagated in infinite numbers of circular zones, exactly as when a stone is thrown into a pool of standing water” (Hunt 1978, p. 24). Both of them agreed that air ripples in all direction, both horizontal and vertical (Hunt 1978, p. 24, 56).

The continuous collision of air particles was also implied by some philosophers to explain the mechanism of the ripples of the air. Chrysippus, for example, explained that “the air between them [(colliding bodies)] is compressed, the particles composing it collide and disperse in a wave-like motion in all directions” (Hunt 1978, p. 56). Anicius Manlius Severinus Boethius (480-524), who also used an analogy of water wave to explain the propagation of sound, stated that “… it [air] impels other air next to it and in a certain way sets a rounded wave of air in motion, and is thus dispersed and strikes simultaneously …” (Hunt 1978, p. 27). Moreover, Al-Farabi or Alpharabius (about 870-950) proposed a model of the ‘layer of air’ to explain how sound is transmitted. He declared that “it [sound] moves the layer of air immediately adjacent with a motion similar to its own; the latter communicates this motion to the next layer, and so forth. The sound being in this way transmitted from one layer of air to another, reaches the air contained within the auditory tract, then the organ which is the seat of the auditory faculty” (Hunt 1978, p. 49). However, because the relation between the production of sound and the vibrational motion was still ambiguous; no one referred to vibrational energy transferring yet.

Although the notion of sound-as-wave was promising and still developing, the notion of sound-as-substance still persisted as well. For example, Adelard or Adelardus Bathensis (1080-1152) explained that sound could be heard when “a solid wall is interposed between me[(him)] and the hearers”, because “every metallic body or even anything more solid than that, if such exists, is full of porous interstices which afford a passage to so subtle a thing as air” (Hunt 1978, p. 62). Moreover, sound was also explained as odor transferred by wind. According to Hunt (1978, p. 63), Averroes or Ibn Rushd (1126-1198) suggested that “… it [sound] is also [like odor] impeded by the winds; … yet it does not follow from this that it is a body”.

Robert Grosseteste (1175-1253) introduced the notion of simple harmonics motion to explain the propagation of sound. He offered that, “… this motion [the simple harmonics motion] … which follows the local motion of the tremor, is sound, or the speed natural to sound. And when parts of the block shake, they move the air adjacent to them in a motion like theirs, and the motion travels to the same sort of air contained within the ears and produced there a pressure on the body …, and there results a sensation of hearing” (Hunt 1978, p. 66). During this period there was effort to build a law of physics that could be applied to both the simple harmonics motion and general waves. This was expressed by Leonardo da Vinci (1452-1519), who said that “the law of mechanics is the same in both instances! [both water wave and sound]” (Hunt 1978, p. 76) and also by Sir Issac Newton (1642-1722) who offered that if the law of the oscillating pendulum is true for one particle, it must be true for all adjacent ones (Lindsay 1966).

Sound-as-substance framework was still found in the seventeenth century. For example, Pierre Gassendi (1592-1655) attributed the propagation of sound to the emission of a stream of very small ‘invisible particles’ from the sounding body to the ears (Caleon and

Subramaniam 2007, p. 175; Lindsay 1966, p. 635). Isaac Beeckman (1588-1637), postulated that sound travels through air as ‘globules of sonic data’. He further stated that any vibrating object cuts the surrounding air into little spherical corpuscles of air. The corpuscles are then sent away in all directions by the vibrating motion of the source; perceived as sound upon reaching the ears (Caleon and Subramaniam 2007). The nature of sound was still vague or not understood in scientific terms. Moreover, the role of the air in the propagation of sound was also doubtful.

An experiment for producing a sound in a closed system evacuated of air was conducted by some scientists in order to determine whether or not air is necessary for the propagation of sound. Gian Francesco Sagredo (1571-1620) is credited as the first to introduce such experiment (Beyer 1999; Hunt 1978). Although there was still some air in the vessel, he nonetheless concluded that no sound was heard (Hunt 1978). This experiment was also conducted by Athanasius Kircher (1602-1680) and Otto von Guericke (1602-1686) (Hunt 1978). Both of them claimed that sound could be heard and then concluded that air is not necessary for the propagation of sound (Caleon and Subramaniam 2007; Lindsay 1966). However, Robert Boyle (1627-1691) repeated the experiment with an improved air pump and more-careful arrangements, and finally observed the decrease of the sound intensity when the air was pumped out. He then concluded that the air can transmit sound (Caleon and Subramaniam 2007; Lindsay 1966). This led to the conclusion that sound cannot propagate through a vacuum (Beyer 1999).

There were attempts to understand the mechanism of the propagation of a wave by building a mathematical model using data from empirical experiments. Sir Isaac Newton (1642-1727) is the first to offer a mathematic model about a wave theory of sound. He compared the motion of ripples on the surface of water (Lindsay 1966). Newton further explained that when a pulse is propagated through a fluid, the particles of the fluid always move in simple harmonics motion. He stated that particles of fluid “are always accelerated or retarded according to the law of the oscillating pendulum” (Lindsay 1966, p. 636). Moreover, he calculated the speed of sound in air by using his mathematical model that was not completely consistent with the empirical results (Caleon and Subramaniam 2007; Hunt 1978; Lindsay 1966). The next sub-section describes attempts to measure the speed of sound, which was then used to verify theoretical explanations of the propagation of sound.

The Speed of Sound

There was an alternative idea that the speed of sound depends on the pitch of sound. This idea, for example, was offered by Archytas (428-347 B.C.) when he said that sounds “which reach us quickly and powerfully from [a] source of sound seem high-pitched while sounds which reach us slowly and feebly seem low-pitched” (Hunt 1978, p. 14). This idea still persisted in Aristotle’s time (384-322 B.C.) who showed a sense of uncertainty when he said “some of the writers … assert that the sounds … do not reach us simultaneously, but [sounds] only appear to do so” (Hunt 1978, p. 15). However, the notion that the speed of sound is independent of its pitch was clearly shown by Theophrastus (372-288 B.C.). Theophrastus reasoned that “the higher note would not differ in speed [from the lower] … If there is concord, both notes are of the same speed” (Hunt 1978, p. 15).

By comparing the speed of light with that of sound, it was generally accepted that light was perceived earlier than sound when the two are emitted at the same time. Aristotle, for example, wrote that "we see it [lightning] earlier because sight is quicker than hearing" (Hunt 1978, pp. 21-22). By observing a woodman laboring with an axe, Titus Lucretius Carus (99-55 B.C.) similarly expressed that "the falling blows are seen before the sound comes to the ear", so "we see lighting ere the thunder hear" (Hunt 1978, p. 22). Pliny the Elder or Galius Plinius Secundus (23-79) also clearly recorded that "it is certain that when thunder and lighting occur simultaneously, the flash is seen before the thunderclap is heard (this [was] not being surprising, as light travels more swiftly than sound)" (Hunt 1978, p. 22). The difference between the speed of sound and that of light was clearly expressed by Al-Biruni (973-1048). Based on his observation, he wrote that the speed of light is incomparably greater than that of sound (Hunt 1978).

The notion that the speed of sound could be measured, was proposed by Leonardo da Vinci (1452-1519) when he concluded from his observations of echoes that the wave motion of sound has a definite finite velocity of propagation (Hunt 1978). Francis Bacon (1561-1626) also proposed a way to determine the speed of sound, even he did not perform the experiment, by timing the interval between seeing that flash and hearing the sound at a known distance (Hunt 1978). However, there still was a problem of measurement of time and distance that required reliable instruments.

Marin Mersenne (1588-1648) devoted his attention on the problem of time measurement and also concerned about the experimental error (Hunt 1978). He conducted an experiment to determine the speed of sound by measuring the time delay between the emission of a sound and its echo from a reflecting surface at a known distance (Hunt 1978). His method about the measurement of the echo's time delay was later modified by others (Hunt 1978). Pierre Gassendi (1592-1655), by modifying the Francis Bacon's method, helped to determine the speed of sound in air using firearms and assuming that the light of the flash is transmitted instantaneously. Gassendi's value was about 478.4 m/s while Mersenne's was about 450 m/s (Lindsay 1966). Both of them seemed to be too high.

In 1650 Giovanni Alfonso Borelli (1608-1679) and Vincenzo Viviani (1622-1703) together tried to do the same type of experiment and obtained 350 m/s (Lindsay 1966). However, Leopoldo de Medici (1617-1675), planned an experiment with gunfire six years later to re-determine the speed of sound and gave the plan to Borelli and Vincenzo to implement (Hunt 1978). Borelli and Vincenzo then got the speed of sound to be about 361 m/s (Hunt 1978). Giovanni Domenico Cassini (1625-1712), Jean Picard (1620-1682), and Olof Romer (1644-1710) as a team of the Academic des Sciences also undertook to measure the speed of sound and got a value of 356 m/s (Hunt 1978). The discrepancy between these measurements could have been due to lack of consideration for temperature, humidity, and wind velocity (Lindsay 1966).

The lack of consideration of wind velocity was detected when Gassendi noted that the wind did not affect the measured speed of sound (Lindsay 1966). However, after making extensive measurements of the speed of sound, William Derham (1657-1735) concluded that the speed of sound is independent of all environmental conditions except wind (Lindsay 1966). This conclusion was also offered by Giovanni Lodovico Bianconi (1717-1781). Based on his measurements, which he made in winter and summer, he concluded that the speed of sound in air increases as the temperature rises (Hunt 1978; Lindsay 1966).

By 1738 the Academy of Sciences of Paris became the first to measure the speed of sound without wind by using a cannon as a source of sound at 0 ºC and got the speed of sound to be 332 m/s (Hunt 1978; Lindsay 1966). This seemed to be the most reliable measurement of the speed of sound and the most valid during the eighteenth century (Hunt 1978). These empirical results were used as evidence to verify the theoretical explanations developed by latter scientists.

The Frequency of Sound

Pythagoras (about 580-500 B.C.) expressed that relation between the pitch of sound and the lengths of strings as previously mentioned. However, it is not clear that Pythagoras completely understood the relation between the pitch of sound and the vibration of strings (Hunt 1978). This relation was then implied by Archytas (428-347 B.C.) and Eudoxus (about 408-347 B.C.). As cited by Hunt (1978, p. 14), they explained that "a rapid motion responding with a shrill tone, because it strikes and goes through the air more rapidly and continuously, and a slow motion answering with a deep tone, because it is more sluggish". Although this might be confusing, the word motion meant either the vibrational motion of a source or the propagation of sound, which was confirmed by another Archytas's conclusion that "high notes are in swift motion, low notes in slow motion …" (Hunt 1978, p. 14-15). However, Euclid (330-275 B.C.) revealed that 'an amount of motion' could influence the pitch of sound. He expressed that "some sounds are higher pitched, being composed of more frequent and more numerous motions … lower pitched [sound is composed of less frequent and less numerous motions.] [To reach] required … the required pitch … [is] by an increase in the amount of motion" (Hunt 1978, p. 17). Unfortunately, this seminal notion seemed to have been ignored in the years that followed.

The pitch of sound was often associated with both some physical property of air and that of sources producing it. Al-Farabi or Alpharabius (about 870-950), for example, who proposed the model of 'layer of air', stated that, "the highness or lowness [of the pitch] of sound generally depends on the degree of compression given to the molecules of the layer of air which rebounded under impact" (Hunt 1978, p. 50). In this case, the 'degree of compression' might be referred to as the compressibility of the air. Moreover, he also related the pitch of sound to some properties of source when he stated that, "the harder and smoother the body which is hit, the higher the sound produced" (Hunt 1978, p. 50). Similarly, Ikhwan al-Safa (about 893) said that, "the tones of smooth objects are smooth because the interfaces common to them and to the air are smooth" (Hunt 1978, p. 56).

However, Ikhwan al-Safa appeared to have been the first to distinguish the attributes of sound designated by intensity, pitch, and, quality when he said "tones are stronger or weak; rapid or slow; fine or thick; heavy or light" (Hunt 1978, p. 56). The term 'fine or thick' was used by Hunt to mean 'high- or low-pitch' while the term 'rapid or slow' referred to 'succession of impacts'. The difference between loudness and the pitch of sound might have been clarified by Safi al-Din (1252-1334) when he said, "it would be more correct to say that the sound is more intense, instead of more high pitched, when the impact is firmer" (Hunt 1978, p. 70).

Moreover, when considering the pitch of a vibrating string, Safi al-Din seemed to go beyond Pythagoras's notion that the pitch of sound depends on the length of strings. He argues that not only is the pitch of sound related to the length of strings but also tension of strings. According to Hunt (1978, p. 71), Safi al-Din offered that, "you will sometimes observe that the sonority of a relatively thin and short string is graver [lower pitched] than that of another which is thicker and longer. This can be caused by a greater tension of the longer string and by a greater relaxation of the shorter one. Nevertheless it remains true that a relatively thinner and shorter string lends itself better to high-pitch sounds".

Safi al-Din's notion of the relationship between pitch of sound, tension in the string, and length of the strings was then confirmed by Vincenzo Galileo (1525-1591) and his son, Galileo Galilei (1564-1642). Vincenzo Galileo conducted an experiment and determined that the pitch of sound applied in relation to the length of strings while Galileo Galilei showed that sound produced by a string could be determined more precisely in terms of 'frequency' of sound (Caleon and Subramaniam 2007). According to Caleon and Subramaniam (2007, p. 176), Galileo Galilei noted that frequency is the number of pulse of air waves generated by a vibrating source. Moreover, he pointed out that "if the pitches sounded by two similar strings had been altered by changing the tension of one of them instead of its length, or by selecting strings of different diameters, the pitch would have been found to vary directly or inversely with the square root of these quantities" (Hunt 1978, p. 81). Thus, based on his two experiments (rubbing the edge of a goblet in a vessel filled with water and scraping a brass plate), the connection between the pitch of sound and the frequency of vibrational motion was confirmed.

Marin Mersenne (1588-1648) determined the actual number of vibrations per second of a particular musical note by counting the number of returns of a string sounding in unison with the note and then comparing this number of returns with the number of returns of a longer string, slow enough to count (perhaps one return in one second). According to Hunt (1978, pp. 90-91), Mersenne explained that "there is no difficulty in finding the number of returns for each string proposed, … to note exactly the number of these returns, one to count the returns while the other counts the seconds, whence if one divides the number of seconds into the number of returns, one will know how many it makes in each second". However, he noted that "ten vibrations [per second] are the limit of … counting by eye" (Hunt 1978, p. 91). He also made the first crude determination of the frequency of pitches (MSN Encarta 2007) even though it did not become scientifically valid (Wikipedia 2007).

Robert Hooke (1635-1703) tried to connect the frequency of vibration with pitch by allowing a cog wheel to run against the edge of a piece of cardboard (Lindsay 1966). When the cog wheel rotated, the teeth of the wheel stuck on the edge. The sticking produced sound with a frequency equal to multiples of the number of teeth and the number of cycles per second that the wheel rotated. For example, if a wheel with 30 teeth were rotated 2 cycles per second, sound produced by sticking between the teeth and the edge would be 60 Hertz. Moreover, this experiment was later used to determine the limits of human hearing by Felix Savart (1791-1841) (Ampel and Uzzle 1993; Beyer 1999).

Joseph Sauveur (1653-1716), who first used the term 'acoustics', simultaneously listened to two organ pipes having frequencies in the ratio of 15 to 16 and observed that there were six beats per second happening (Lindsay 1966). He considered this number as a difference between the frequencies of the pipes, later to be called ‘beat frequency’; he then found that the frequencies of both pipes were 90 and 96 cycles per second (Lindsay 1966). Sauveur also did this observation for the ration of 24 to 25 and got four beats per second (Rasch 1984). According to Rasch (1984, p. 25), Sauveur found that a higher-pitched pipe had a frequency of 100 cycles per second. This meant that the lower-pitched pipe had 96 cycles per second. He also proposed a frequency table of musical pitches (Rasch 1984). This is in a way presented a more valid relation between the pitch of sound and the frequency of vibration of source.

The Theoretical Explanation of Sound

The development of theoretical explanations of sound is complex since understanding of sound requires understanding of other fields (such as fluid mechanics, thermodynamics, elasticity, and electromagnetic) to explain it (Hunt 1978). Moreover, it requires advanced mathematical techniques such as calculus, which is an important tool that allows humans to profoundly understand the concepts of sound. Thus, understanding sound seems to have gradually developed along the development of other concepts. However, when chronologically compared with other physics concepts, it is rather clear that the theoretical understanding of sound has evolved more slowly than other physics concepts.

Although some phenomena under sound were empirically explained in predictable manner, the mechanism that underlies the phenomenon of sound was still ambiguous up until seventeenth century. It was generally understood as a wave traveling through a medium. Unfortunately, many questions (such as, how the medium particles are displaced when sound is transmitted?) were not clearly answered. However, after developing understanding of some physical properties (e.g., the elasticity of fluid, the force among particles, and the vibration of the string) and of calculus, the theoretical explanations of sound have gradually evolved from simple explanations to more complicated. An intelligible explanation in one situation might be reasonably applied or discarded in other situations. The construction, deconstruction, and reconstruction of the explanations have taken over one hundred years. This sub-section will describe how the theoretical explanations of sound related phenomena have evolved to date.

In 1678, Robert Hooke developed a theoretical explanation of physical properties of sound. It is only recent year that it became to be referred to as the theory of elasticity, which also became a basis for understanding the mechanism of sound. As excerpted by Moyer (1977, p. 267), Hooke explained that:

> “… in every springing body … the force or power thereof to restore itself to its natural position is always proportionate to the distance or space it is removed therefrom, whether it be by rarefaction, or separation of its parts the one from the other, or by a condensation, or crowding of those parts nearer together”.

This understanding was then applied to air. Based on experiments that Hooke used, two types of mercury-filled glass tubes containing columns of trapped air, he illustrated that “the elater [elasticity] of the air is reciprocal to the extension …” (Moyer 1977, p. 268). It was also confirmed by Robert Boyle (1627-1691) whom Hooke helped to construct the air pump in order to determine if air is necessary for sound to propagate (Caleon and

Subramaniam 2007). Boyle expressed that air could be bent or compressed and he also referred to the term 'spring of the air' (Hunt 1978; Moyer, 1977, p. 273). Although this understanding of elasticity seemed not to be relevant to sound, it appeared to be a basis for the understanding of elastic vibrations.

In 1678, Sir Isaac Newton (1642-1727) was the first to provide a theoretical explanation of the propagation of wave in fluids (Lindsay 1966). He explained the propagation of pulses in an elastic medium generated by a tremulous body:

> "… the parts of the tremulous body … (in going) urge and drive … parts of the medium that lie nearest, and … compress and condense them; and (in returning) suffer those compressed parts to recede … and expand themselves. Therefore the parts of the medium that lie nearest to the tremulous body move … (in like manner as the parts of the tremulous body itself do) … will … agitate others next to themselves; and these other … will agitate those that lie beyond them, and so on in infinitum"(Lindsay 1973, p. 78).

This explanation clearly showed the notion of wave theory. Moreover, Newton extended his explanation about displacement of the medium that "…parts of the medium … will not be all going and all returning at the same instant; but … some of them will be going while others are returning; and so on in infinitum" (Lindsay 1973, p. 78). In addition, Newton also concluded that there existed a relation between the number of pulses and the number of vibrations of the tremulous body. This led to a theoretical understanding of the relation between the frequency of a vibratory body and the pitch of its sound as he expressed that "it appear[s] that the number of the pulses propagated is the same with the number of the vibrations of the tremulous body" (Lindsay 1973, p. 83).

Based on an assumption that "if pulses are propagated through a fluid, the several particles of the fluid … are always accelerated or retarded according to the oscillating pendulum" (Lindsay 1973, p. 81), Newton also proved that the speed of the propagation of the pulses does neither depend on their amplitude nor their wavelength (Lindsay 1973). Instead, he proved that the speed of the propagation of the fluid is the square root of the ratio of the 'elastic force' to the density of their medium (Hunt 1978). As recorded, Newton concluded that, "the velocity of the pulses will be in a ratio compounded of the subduplicate ratio of the density of the medium inversely, and the subduplicate ratio of the elastic force directly" (Lindsay 1973, p. 151).

However, the term 'elastic force' of the fluid mentioned is a force among the elastic particles. It was assumed to be linearly proportional to its 'condensation' or pressure of the fluid (Hunt 1978; Lindsay 1973). Therefore, in the case of the propagation of sound in air, the speed of sound in air could be determined by the square root of the ratio of the atmospheric pressure to the density of air (Lindsay 1966). This was the first attempt to express the speed of sound in a mathematical form (Lindsay 1966) by calculating it using measurable physical properties (Caleon and Subramaniam 2007).

Newton, therefore, calculated the speed of the propagation of sound in air by using his formula and then got a value too low when compared to the empirical results (Ampel and Uzzle 1993; Caleon and Subramaniam 2007; Hunt 1978; Lindsay 1966). Even though he seemed to be satisfied with the calculated result (Lindsay 1966), there was a discrepancy between theoretically and experimentally determined values (Ampel and Uzzle 1993;

Hunt 1978). Because Newton assumed that air is homogeneous, and that all air particles isochronally vibrate, his theoretical explanation was criticized as being inadequate by others who are younger. However, it was recorded that Newton revised his calculation for the speed of sound by considering the impurity of air and got a value same as the experimentally determined one (Hunt 1978; Lindsay 1966). This was a big step in the acoustical development.

The vibration of strings seemed to be an easy way to investigate sound as Pythagoras had done with the monochord. In addition, it seemed to be a challenging problem to find a mathematical solution. Many mathematicians and physicists devoted themselves to solving this problem. Eventually, based on the assumption that all parts of the string are simultaneously on the same side of the equilibrium horizontal position (also called fundamental mode), Brook Taylor (1685-1731) became the first to provide a strictly dynamical solution to the vibrating string problem in 1713 (Lindsay 1966). He could determine the frequency of a vibrating string as directly proportional to the square root of tension force in the string and as inversely proportional to the square root of product of mass and length of the string (Lindsay 1973). Moreover, according to Lindsay (1966), the result was consistent with the experimental law of Marin Mersenne (1588-1648) and Galileo Galilei (1564-1642). This seemed to pave the way for more elaborate mathematical modeling, despite the fact that it could not be applied to general problems such as harmonics of sound produced by a vibrating string as observed by Joseph Sauveur (1653-1716) as well as John Wallis (1616-1703) (Lindsay 1966).

In 1727 Leonhard Euler (1707-1783) explained the elastic nature of the air by considering 'air as composed of infinitely small globules' that can be compressed by forces (such as weight of the atmosphere above) and able to resume their natural state when the forces are removed (Lindsay 1973). He also proposed the elastic compressibility of the medium that was interpreted as a measure of the deformability of these globules against the forces (Hunt 1978). This assumption about these properties of the air globules led to powerful, more valid explanations about sound. In general, he explained the propagation of wave as follows:

> "…one of the series of air globules is compressed … it will expand pushing against the adjacent globules and producing compression in them which push against still others in turn, so that for distant globules feel a certain small amount of compression" and "the original globules of air expanded cannot suddenly cease after this globule has reached the same state as the others; … it is then compressed again by the other globules. This again goes too far. Hence every globules situated not too far away the first one dilates and then contracts in a trembling motion" (Lindsay 1973, p. 106).

He then extended this explanation to the propagation of sound by saying:

> "…sound arises when a globule exposed to an outside force … it is necessary for the excitation of sound that a given globule should be alternately contracted and expanded" (Lindsay 1973, p. 106).

Moreover, Euler clarified that the loudness of sound depends on the amplitude of the vibrating globules of the air and the pitch of sound depends on the frequency of vibrating globules of the air (Lindsay 1973). Furthermore, he explained why sound heard from a longer distance is softer than from a shorter one in terms of the number of the latter globules increasing as the square of distance from the given globule (Lindsay 1973). In addition, Euler agreed with Newton's notion that neither the loudness of sound nor its pitch influenced the speed of sound (Lindsay 1973). In order to determine the speed of sound in air, Euler included an unexplained extra factor '4/π' into Newton's formula and theoretically predicted the speed of sound in air, which was in agreement with experimentally determined value (Hunt 1978).

The assumptions about the globules of air provided theoretical explanations for the production of sound in many cases such as sound produced by an impact of bodies, by strings, and by pipes. In the case of a sound produced by impact of bodies, Euler explained that, "…when air is subject to strong impact … the air is also compressed … after the compression the air … expands … hence the cause of the sounds … is the restoring of the air to its original state after compression" (Lindsay 1973, p. 113). In the case of a string producing sound, he offered, "when a string is oscillated it affects the globules of air, which are compressed … during … the oscillatory motion the globules of air continually suffer new compressions … hence, the air acts on the ear or the ear drum as often as the string goes through its oscillatory motion" (Lindsay 1973, p. 111).

Moreover, Euler understood the relation between properties of strings and their vibration by suggesting that both the length of strings and the transverse sections of the strings are inversely proportional to the frequency of their vibration (Lindsay 1973). Further still, he generated a mathematical expression that determined the frequency of the string. This solution agreed with the solution of John Bernoulli (1667-1748) and Brook Taylor (1685-1731). Euler explained his solution as follows:

> "… the frequencies [produced by different strings] varies directly as the square root of the tension of the string and inversely as the square root of product of the length of the string and its mass" (Lindsay 1973, p. 111).

He then applied this explanation to the sound produced by a pipe. Euler explained that in cases of a pipe the length of the pipe can be considered instead of the length of strings and the internal size of the pipe can be considered instead of the transverse sections of the strings (Lindsay 1973). He also exemplified how a tube produces sound as follows:

> "… when the air enters the tube, the air … will be compressed along its length … when this air expands again it goes too far and in turn is compressed again by the surrounding atmosphere, so that vibratory motion is thus produced in the tube … this vibration is the cause of the sound" (Lindsay 1973, p. 114).

Through the use of an analogy that an air column acts as a little bundle of aerial string stressed by atmospheric pressure, Euler applied the formula for determining the frequency of a vibrating string to determine the frequency of oscillation in any pipe. He found that the frequency of sound produced in pipes is inversely proportional to their lengths. Also, Euler found that neither the loudness of the sound nor the material of the pipe contribute to change in the pitch of sound produced (Lindsay 1973).

During the Euler period when calculus was growing at a fast rate, there were attempts to solve the general problems of vibrating strings using advanced mathematics. There were many mathematicians and physicists joining in this challenging enterprise of determining solutions mathematically. Euler's proficiency seemed to grow as he attempted to solve more challenging problems including solving mechanical problems of the motion of a vibrating string by assuming that the string consists of finite particles with no success (Lindsay 1966). Until in 1747 Jean le Rond d'Alembert (1717-1783) developed the partial differential equation of the vibrating strings in the form presently called the 'wave equation', which is the second time derivative of waves equal to the second space derivative of the waves multiplied by the square of the wave velocity (Lindsay 1966). He also commented that the wave equation could apply to sound (Lindsay 1966).

In 1755 the doubt about the harmonics of sound was resolved by Danial Bernoulli (1700-1782). He showed that it is possible for a string to vibrate in a way that a multiple of simple harmonics oscillations are present at the same time (Lindsay 1966). Bernoulli explained that each vibration contributed independently to the resultant vibration with the displacement at any point of the string at any instant being the algebraic sum of the displacements associated with the various simple harmonics modes (Lindsay 1966). He also proposed a principle of the coexistence of small oscillations referred to as 'the principle of superposition' even though he did not succeed in giving a proof for the principle.

In 1762 Joseph Louis Lagrange (1736-1813) offered a suggestion about the nature of the medium in order to explain or account for the discrepancy between the theory and the experiment (Hunt 1978). He suggested that the 'condensation' should not be linearly proportional to the pressure as Newton and Euler had offered. Instead, it should vary as '4/3' power of the density (Beyer 1999; Hunt 1978). Because of a lack of a plausible physical reason, Lagrange abandoned this hypothesis (Hunt 1978). Furthermore, using a mathematical analysis, he suggested that the particles of the medium should be considered isolated (discrete) without forming a complete continuum (Lindsay 1973). He assumed the string to be composed of a finite number of equally spaced identical-mass particles tied together by equal segments of a stretched weightless string. Lagrange solved this problem of the vibrating string and found that the frequencies were precisely the harmonic frequencies of the continuous string. Furthermore, he was able to predict theoretically the approximate harmonic frequencies of closed and open pipes (Lindsay 1966).

Lagrange's solution inspired Euler to again attempt to explain the fluid mechanics of the propagation of sound in 1766. With the knowledge of calculus and of discontinuous quantities, Euler mathematically solved the propagation of sound in a tube problem and got a solution in the form of the wave equation same with the vibration of a string (Lindsay 1973). Furthermore, he calculated the speed of sound in the air even though it was still too low when compared to experimentally determined value. He credited his success to Lagrange who introduced the discontinuous quantities factor in the calculation (Lindsay 1973).

The discrepancy between the theory and the experiment values for the speed of sound in the air was accounted for Pierre Simon Laplace (1749-1827), a mathematician who devoted himself in the field of physics including heat (Lindsay 1973). In 1816 Laplace suggested that it is more plausible to treat the nature of sound disturbances in fluid as adiabatic rather than isothermal (Lindsay 1973). The discrepancy between the values was occasioned by the heat generated through compressions and rarefactions of the air. Therefore, it seemed more reasonable to suppose that the compressions and rarefactions should follow the adiabatic law (Lindsay 1966). Consequently, Laplace revised Newton's derivation of the expression for the speed of sound in air by adding a ratio of the heat of the air at the constant pressure to the volume of the air (Lindsay 1966, 1973). Based on the adiabatic law, Laplace suggested that the ratio should be the square root of 1.5 of the resulting value of the speed of sound in air and found it to be 345.9 m/s at 6 ºC (Lindsay 1966, 1973). Moreover, there were later attempts to find a suitable ratio by others (Lindsay 1966). This eventually led to the agreement between the theoretically and experimentally determined values of the speed of sound in the air. This theory has been recently shown to be inadequate for very high frequency sounds passing through a gas at very low pressure (Lindsay 1973).

In the meantime besides the one-dimension vibration as the vibrating string had been broadly considered, there was more interest in the vibration in two and three dimensions. For example, Ernst Florens Friedrich Chladni (1756-1827) experimented with the vibration of a solid elastic plate in 1787. He used sand that was sprinkled on vibrating plates and then observed that the sand was thrown off from the vibrating portion of the surface often with considerable violence, whereas it remained at rest in lines on the places where there was no motion (Lindsay 1973). Euler had tried to extend his solution for the three dimensional vibration of the air without success (Lindsay 1973). Furthermore, these interests were later extended in non-linear acoustic waves (Lindsay 1966).

Implementation to Teaching and Learning Sound

As shown by its history, sound-as-substance framework is inadequate at explaining sound related concepts or phenomena. This inadequacy experienced by students at various levels of education when they attempt to develop understanding of sound related concepts (Barman et al. 1996; Boyes and Stanisstreet 1991; Eshach and Schwartz 2006; Hrepic et al. 2002; Linder 1992, 1993; Linder and Erickson, 1989; Mazens and Lautrey 2003; Menchen and Thompson 2004, 2005; Wittmann et al. 2003). In these studies, students were found to conceptualize sound as a substance or at least having some attributes of a substance. This outcome also confirms that there are some similarities between students' conception of sound and those in periods of its historical evolution. Tracing the historical development of conceptual understanding of sound related phenomena, is considered by the authors of this paper, as providing information necessary in formulating and implementing instructions about sound related phenomena from a historical perspective (Nashon et al. 2007). Thus, the authors of this paper have proffered a framework for planning and implementing such instructions.

To learn a particular scientific concept, students should be developed an appreciation and understanding of the challenges past thinkers encountered when they tried to make sense of natural phenomena. This can help students develop an attitude of persistence and patience when learning scientific concepts, especially when they realize that even early scientists also have thought in similar manners (Monk and Osborne 1997). In addition, exposing endeavors of early scientists to understand natural phenomena can help students to appreciate what they are studying (Caleon and Ramanathan 2007; Espinoza 2005). In cases of sound, the great long endeavor of past thinkers to understand the mechanism of sound can be used as an example to motivate students' learning of not only sound or physics but also science in general. From Greek to Roman to Islamic and then to present times, students can recognize that understanding of sound was also developed from basic reasoning to more and more complicated explanations. This can motivate students to develop their own uncompleted understanding of sound to an acceptable one.

The history of science can humanize scientific knowledge for students (Matthews 1992). Presenting both accomplishments and failures of a scientist can help students conceptualize the scientist as a normal general human being. For example, Isaac Newton is generally seen as a genius scientist who succeeded in mechanics (force and motion). However, he did not succeed to theoretically determine the speed of sound. In this case, it can help students appreciate that scientific knowledge is not a truth but instead it is constructed by common human beings with whom students can share a common background or interest (McKinney and Michalovic 2004). Moreover, interrelation among fields (such as mechanics, thermodynamics, and mathematics) can help students understand science as a human activity.

The history of science can be included in classroom activities. As suggested by Monk and Osborne (1997), for example, the historical ideas can be presented to students in order to build classroom discussion. For instance, teachers might ask students how the two Galileo's experiments (rubbing the edge of a goblet in a vessel filled with water and scraping a brass plate) linked sound to the concept of wave, what the evidence is, and whether or not the conclusions are reasonable. History-based questions can help teachers to elicit students' conceptions of sound. Moreover, historical ideas can be used by teachers as an analysis framework to diagnose students' alternative conceptions in order to seek ways to deal with them.

Although Espinoza (2005) and Heering (2000) recommended giving students to try experiments of past scientists with its historical introduction as a way of appreciating and overcoming their alternative conceptions, the authors of this paper suggest that caution must be taken not to give the students the impression that their understanding of things will necessarily follow the same path. However, the authors proffer that only carefully selected demonstration experiments could be used to illustrate the idea about the nature of science. Today's challenges are different from what the earlier scientists such as Aristotle and Newton faced. Because of the similarity between students' conceptions and those in the historical evolution, employing a Predict-Observe-Explain (POE) (White and Gunstone 1992) strategy can elicit some of the students' alternative frameworks, which can then be compared to those ideas that pervaded experiments such as those of Pythagoras, Galileo Boyle, and Hooke which can be demonstrated in a classroom. As guided by the history, teachers can prepare experiments including contexts where conceptual debates can be enacted.

The history of sound can provide some aspects of the nature of science. Durability and tentativeness of scientific knowledge, for example, can be presented through historical development of sound (Caleon and Subramaniam 2007). On the one hand, for the case of durability, the idea of Pythagoras about musical harmony related to simple ratios still remains in the present time in terms of the nature of resonance of sound, which expresses the frequencies of sound as limited to integer multiples of the fundamental frequency.

On the other hand, for the case of tentativeness, explanations about the production of sound have changed over time. Moreover, during conceptual debates between sound-as-substance and sound-as-wave, students can see that science needs evidence. Through many experiments students can appreciate the importance of scientific process. Moreover, through collaborative working, using the cases of both determining the speed of sound and explaining the mechanism of sound, students can be helped to appreciate and understand science as a human activity. An aspect of scientific community can be presented.

It is almost universal that, science curricula are placing empha sis on scientific literacy for all as one of the key aims, but lack explicit reference to teaching the history of science. For example, in Thailand, although the nature of science is emphasized as an important strand in the National Science Curriculum Standards (The Institute for the Promotion of Teaching Science and Technology 2002), the history of science is not explicitly included. To promote scientific literacy for all, the authors argue that inclusion of the history of science in the science curricula should be underscored and made explicit.

References

Ampel, F.J. & Uzzle, T. (1993). **The history of audio and sound measurement.** Paper presented at the 94th Convention, Berlin, New York, March 1993.

Barman, C.R.; Barman, N.S. &Miller, J.A. (1996). Two teaching methods and Students' understanding of sound. **School Sci Math. 96,** 63-67.

Beyer, R.T. (1999). **Sounds of Our Times: Two Hundred Years of Acoustics.** New York: AIP Press.

Blood, P. (2007). **Physics of Musical Instrument: A Brief History.** Retrieved October, 22,2007, from: http://www.dolmetsch.com/poshistory.htm.

Boyes, E.& Stanisstreet, M. (1991). Development of Pupils' Ideas About Seeing and Hearing—the Path of Light and Sound. **Res Sci Technol Educ. 9,**223-245.

Brush, S.G. (1974). Should the history of science be rated X? **Science 183,** 1164-1172.

Caleon, I. & Ramanathan, S. (2007). From Music to Physics: the Undervalued Legacy of Pythagoras. **Sci & Educ,** DOI 10.1007/s11191-007-9090-x.

Caleon, I.S. & Subramaniam, R. (2007). From Pythagoras to Sauveur: Tracing the History of Ideas About the Nature of Sound. **Phys Educ 42,** 173-179.

Chalmers GK (1936) Three Terms of the Corpuscularian Philosophy. **Mod Philol**, **33,** 243-260.

Cook, V. (1996). **Epicurus & Epicurean Philosophy: Letter to Herodotus.** Retrieved October 22, 2007, from:http://www.epicurus.net/en/herodotus.html.

Dampier, W.C. (1961**). A History of Science and Its Relation with Philosophy & Religion.** 4th ed. London: Cambridge University Press.

Deutsch, D. (1980). Music perception. **The Musical Quarterly, 66,** 165-179.

Duit, R.; Niedderer, H. & Schecker, H. (2006). Teaching physics. In Abell S.K.&Lederman N.G. (eds.). pp. 599-629. **Handbook of Research on Science Education.** New Jersey: Lawrence Erlbaum Associates.

Eshach, H. & Schwartz, J.L. (2006). Sound stuff? naïve materialism in middle-school students' conceptions of sound. **Int J Sci Educ, 28,** 733-764.

Espinoza, F. (2005). An Analysis of the Historical Development of Ideas About Motion and Its Implications for Teaching. **Phys Educ, 40,** 139-146.

Gauld, C. (1991). History of science, individual development and science teaching. **Res Sci Educ 21,** 133-140.

Heering, P. (2000). Getting shocks: teaching secondary school physics through history. **Sci & Educ, 9,** 363-373.

Hrepic, Z.; Zollman, D. & Rebello, S. (2002). **Identifying Students Models of Sound propagation.** Retrieved October 22, 2007, from: http://web.phys.ksu.edu/papers/2002/PERC_Sound_Prop.pdf.

Hunt, F.V.(1978). **Origins in Acoustics: The Sience of Sound from Antiquity to the Age of Newton**. New Haven: Yale University Press.

Irwin AR (2000) Historical case studies: teaching the nature of science in context. **Sci Educ, 84**:5-26

Kilgour, F.G. (1963). Vitruvius and the early history of wave theory. **Technology and Culture, 4**, 282-286

King, B.B. (1991) .Beginning teachers' knowledge of and attitudes toward history and philosophy of science. **Sci Educ, 75,**135-141

Leonard, W.E. (1997). **Nature of Thing: The Senses and Mental Pictures.** Retrieved October 22, 2007, from: http://www.worldwideschool.org/library/books/lit/poetry/Ofthenatureofthings/chap19.html.

Linder, C.J. (1992). Understanding Sound: So What is the Problem? **Phys Educ, 27,** 258-264.

_______ . (1993) University Physics Students' Conceptualizations of Factors Affecting the Speed of Sound Propagation. **Int J Sci Educ, 15,** 655-662.

Linder, C.J. & Erickson, G.L. (1989). A study of tertiary physics students' conceptualizations of sound. **Int J Sci Educ, 11**(Special Issue), 491-501.

Lindsay, R.B. (1945). A Historical Introduction. Pp. v-xxxii. In Strutt J.W. & Rayleigh, B. (eds.) **The Theory of Sound**. New York: Dover Publications.

_______ . (1966). The story of acoustics. **J. Acoust Soc Am, 39,** 629-644

_______ . (1973). **Acoustic: Historical and Philosophical Development.** Pennsylvania: Dowden, Hutchinson & Ross.

Matthews, M.R .(1989). A Role for History and Philosophy in Science Teaching. **Interchange, 20,** 3-15.

_______ . (1992) History, Philosophy, and Science Teaching: The Present Approachement. **Sci & Educ 1,** 11-47.

Mazens, K. & Lautrey, J. (2003). Conceptual change in physics: children's native representations of sound. **Cognitive and Development 18,** 159-176.

McGinnis, J.R. & Oliver, J.S. (1998). Teaching about sound: a select historical examination of research. **Sci & Educ, 7,** 381-401.

McKinney, D. & Michalovic, M. (2004). Teaching the stories of scientists and their discoveries. **The Science Teacher 71,** 46-51.

Menchen, K.V.P. & Thompson, J.R. (2004). Pre-service teacher understanding of propagation and resonance in sound phenomena. In Marx J, Cummings K, Franklin S (eds.) **Proceedings of the 2003 Physics Education Research Conference**, Madison, Wisconsin, August 2003.

_______ . (2005) Student understanding of sound propagation: research and curriculum development. In Marx J, Heron P, Franklin S (eds.) Proceedings of the 2004 **Physics**

Education Research Conference, Sacramento, California, August 2004.

Monk, M. & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: a model for the development of pedagogy. **Sci Educ, 81,** 405-424.

Moyer, A.E. (1977). Robert Hooke's ambiguous presentation of "Hooke's Law". **Isis**, 68, 266-275.

MSN Encarta (2007) **Sound.** Retrieved October 22, 2007, from: http://encarta.msn.com/encyclopedia_761560639_3/Sound.html.

Nashon, S.; Nielsen, W. & Petrina, S. (2007). Whatever Happened to STS? Pre-Service Physics Teachers and the History of Quantum Mechanics. **Sci & Educ.** DOI 10.1007/s11191-007-9085-7.

Palisca, C.V. (2003). **Dictionary of the history of ideas: music and science.** Retrieved October 22, 2007, from: http://etext.virginia.edu/cgi-local/DHI/dhiana. cgi?id=dv3-32. Rasch, R. (1984). **Joseph Sauveur, Collected Writings on Musical Acoustics** (Paris 1700-1713). Utrecht: The Diapason Press.

Seker, H. & Welsh, L.C. (2006). The Use of History of Mechanics in Teaching Motion and Force Units. **Sci & Educ 15,** 55-89.

Sequeira, M. & Leite, L. (1991). Alternative Conception and History of Science in Physics Teacher education. **Sci Educ, 75,** 45-56.

Seroglou, F.; Koumaras, P. & Tselfes, V. (1998). History of Science and Instructional Design: The Case of Electromagnetism. **Sci & Educ, 7,** 261-280.

Solomon, J.; Duveen, J. & Scot, L. (1992). Teaching about the nature of science through history: action research in the classroom. **J Res Sci Teach, 29,** 409-421.

Taylor, C.C.W. (1999). **The Atomists: Leucippus and Democritus** (fragments a text and translation with a commentary by C.C.W. Taylor). Toronto: University of Toronto Press.

The Institute for the Promotion of Teaching Science and Technology. (2002). **National Science Curriculum Standards: The Basic Education Curriculum B.E. 2544.** Retrieved October 22, 2007, from: http://kroo.ipst.ac.th/ipst/eng/ curriculum/ScienceCurriculum.pdf.

Wandersee, J.H. (1985). Can the history of science help science educators anticipate students' misconceptions? **J Res Sci Teach, 23,** 581-597.

Wang, H.A. & Marsh, D.D. (2002). Science Instruction with a Humanistic Twist: Teachers' Perception and Practice in Using the History of Science in Their Classrooms. **Sci & Educ, 11,** 169-189.

White, R.T. & Gunstone, R.F. (1992). **Probing Understanding.** Great Britain: Falmer Press

Wikipedia. (2007). **Pitch (music).** Retrieved October 22, 2007, from: http://kroo.ipst.ac.th/ipst/eng/ curriculum/ScienceCurriculum.pdf.

Wittmann, M.C.; Steinberg, R.N. & Redish, E.F. (2003). Understanding and Affecting Student Reasoning About Sound Wave. **Int J Sci Educ, 25,** 991-1013