A Matter of Scale

Jim Charlton
Carrick High School

"Science … means unresting endeavor and continually progressing development towards an aim which the poetic intuition may apprehend, but which intellect can never fully grasp."

Max Planck (1854 – 1947)

"To call Divinity music is to speak to the sound that all beings are making: All atoms are busy vibrating and making music in the universe."

Hildegard von Bingen (1098 – 1179)

Overview

This unit is intended to enhance the students' understanding of the nature of music by using ideas conventionally thought of as associated with physics, specifically particle physics and superstring theory, as a metaphor for the dynamic processes by which music lives as an expressive, affective art. But, reciprocally, the same assertion could be made in the reverse; that musical processes are the most vital metaphor for the concepts that are recently evolving regarding the research being done around superstrings and M-theory.

Musical analysis is a vital and fundamental part of any serious study of music. At times, however, musical analysis (particularly in the high school curriculum) can take the form of mundane labeling of intervals, chords, themes, forms, and so forth. It's my belief as a musician, as well as my experience as an educator, that these strategies don't do the music justice in terms of illuminating the profound inner workings of this most expressive art. Cataloging the features of musical works is a start in understanding the expressive potential of music, but not a satisfying investigation. When students begin to listen for the interactions of tones and rhythms, to listen with sensitivity to how and why their ears are being drawn through the structure of the form, and to listen with an awareness of how the music creates an environment of dynamic interactions that stimulate their emotions and intellect, then musical analysis becomes a vital endeavor.

The first focus of study in this unit will be on a phonological level; investigating the nature of music from an acoustical perspective. The students will be introduced to the harmonic series and its relationship to tone color, temperament, pitch (frequency) and harmony. Concepts of wave-form, resonance, harmonics, and the Pythagorean ratios will be emphasized. The elemental vibrating source as the building block of more complex structures is the unifying concept in this part of the unit, highlighting the idea that the form and characteristics of the vibrating source determine how it is perceived and how it relates to and combines with other resonant sources to make more complex perceived structures. Parallel with this aspect of study, the students will be introduced to some of the basic, general ideas in superstring theory. Emphasis will be placed on those aspects of the theory that are most congruent to the musical foundation concurrently being studied. The student will be introduced to basic terms, and the concept that, like music, the wide variety of particles and fundamental force-carriers we observe in nature are the manifestations of various resonant forms of elemental strings of energy.

The second focus of study in this unit will be on a syntactical level; investigating the tendencies of tone and rhythm to combine to create meaningful, expressive musical units (phrases, chords and chord progressions) and how these structures develop into complete musical works. Musical examples that demonstrate qualities of melody, internal repetition, motific development, variation, modulation, contrapuntal procedures, and basic forms will be examined. Emphasis will be placed on the influences of chromaticism and diatonicism as opposing forces in music. The students will be introduced to the idea that a piece of music is a "system" with "rules" that are influenced by the composer's style, philosophy, expressive intentions, and temperament. Throughout, references to the physics of strings and the speculations of how they interact to generate more complex structures (various generations of matter, force carrier particles, and ultimately atoms, molecules, etc.) will be used to illustrate the similar nature of music (and vice-versa).

The unit's third focus will be on the semantic level; an examination of the evocative nature of music. This is the real goal of the unit, but to arrive at this point with a deeper grasp of music's underlying structure will profoundly enhance the students' ability to examine musical expression and meaning.

Rationale

An ancient Egyptian creation myth asserts that everything in the universe came into existence by an act of combining visualization with uttered sounds. The "primeval waters", a poetic description of a formless mass of energy, was the source of all things. Vibrations of the words of Amen-Ra poured into these waters and created ripples and currents that formed complex patterns of geometrical forms. Matter sprang into existence as a result of the interactions of these "opposing" resonances. As the god spoke the names of things, those things formed from the primordial energy. [1]

Throughout history music has been the metaphor for much of the descriptions of the physical world and the processes that drive it. Recent developments in superstring theory seem to allow the notion that music is more than just a poetic metaphor, but possibly an analogous environment. The behavior of the vibrating strings of musical instruments is often used to explicate the speculated behavior of strings. Brian Greene refers to the “notes” of superstrings and raises the possibility that working out the allowed resonances of strings will enable the explanation of observed properties of elementary particles and force carriers. [2] “The apparently distinct fundamental quarks and leptons, gluons and gravitons are the varied resonances of … identical strings. Spacetime and matter unify as the intrinsic notes of a complex melody whose score is string theory…” [3]

Many concepts in physics can be illustrated through musical relationships. The vibrating loop of energy that appears, because of its resonant properties, to be a particle is analogous to the vibrating string of a violin. The perceived tone of that vibrating string is the function of the complex shape of its wave-form (its resonant pattern, so to speak). Changing the wave-form changes the perceived tone and pitch, creating a different musical entity. Moreover, anybody who has ever held their eye next to a vibrating violin string immediately understands the concept of a vibrating medium appearing to the observer to be a solid thing taking up more space than its actual at rest filament, and also appearing to be both here and there at the same time. The interrelationship of tones, intervals, chords, phrases, themes, and movements depend on the tendencies of individual tones (resonant form and frequency) within the system of characteristics ascribed to them. “The most musical explanation of creation … vibrating strings of energy, a different ‘note’ for each different particle” [5]

Those of us in arts education find ourselves in the midst of a national movement toward inclusion of the arts with other academic disciplines. Using the arts to support the teaching of other subjects is becoming an increasingly important part of the overall planning and implementation of arts programs. Moreover, in the Pittsburgh Public Schools there is a mandated emphasis on literacy and mathematics, with structured programs to infuse these disciplines into the teaching of all subjects. All teachers are developing ways to support the mathematics and literacy standards within our discreet areas. While it may be true that more easily made connections to other subjects are available, I want to pursue my personal interests as well when developing multi-disciplinary activities for my students. Physics, particularly the work of the twentieth century relating to time, space, and the nature of things, has been an avocational interest for most of my life. The connections between the science to be discussed throughout the unit and music are not artificial or contrived at all, however. The objectives of the curriculum unit are a logical intersection of the two disciplines, this view reinforced I believe by the growing body of literature emphasizing the relationships between the two disciplines. In this curriculum unit I hope there will be a benefit to combining concepts in physics and music; that is to use the study of musical form and organization to help illustrate concepts in physics as well as to rely on the students' grasp of physics to help them understand the complex subtleties of musical organization, form, and syntax.

Primarily, the unit will emphasize parallels between the recent theories of the underlying orderliness in the physical world and a new perception of the nature of reality as discussed in *The Elegant Universe*, as well as in several related texts, and the organic structural nature of music. The unit will attempt, by drawing analogies between the two fields, to increase the students' understanding of both. In this unit, it is hoped that the students will develop an awareness of the hierarchies of musical structure and physical structure, and realize the similarities between the two; that the differences between the perceived world of music and the unimaginably small world of particles and superstrings are just a matter of scale.

Further, the unit will use music to illustrate how perceptions of reality are influenced by context. It may seem a reach to assert that music can help students understand concepts like relativity or the uncertainty principle, but during the unit the students will be introduced to numerous examples of how music can create and maintain a context within its own framework, at least for the temporary duration of the piece, while the same basic musical elements can be reordered in another piece to create completely different contextual feelings.

Throughout the unit the students will be introduced to musical works that attempt to create expressive worlds that arise directly from the subjects of modern physics. As in most periods throughout history, new discoveries in science are reflected in the arts. Music has responded to the new physics through the exploration of the use of electronics (providing both a wider palate of sounds and random generation of tones and tonal structures), new concepts of time and rhythm, layering techniques in musical form, and a wider definition of dissonance. Relying heavily on the work of contemporary composers such as Steve Reich, Georgy Ligeti, Luciano Berio, Bill Douglas and George Crumb along with the "ambient" music of composers such as Peter Mameluk and Brian Eno, the unit will encourage students to explore the times and places that presently can only be imagined by both artists and physicists.

This unit is designed not so much as a tightly sequential series of lessons to be completed within a defined period of time but as a more broadly inserted series of enhancements to lessons already included in the course of study.

Objectives

Principally I would like the students to be able to listen and respond to music with a more developed awareness of the underlying organization and workings of the tonal and rhythmic structure, as well as to have a deeper understanding of how musical syntax affects music's ability to evoke meaningful and expressive responses in the listener. At the same time, I hope to increase the students' awareness of the structure of nature as described by current superstring theories.

Students will be able to describe the characteristics of tone in terms of waveform, frequency, amplitude, and the harmonic series of upper partials, and relate these to more conventional musical identifiers based on perception (volume, tone color, pitch, etc.) The students should be comfortable and fluent using both the musical and the acoustic vocabularies when describing musical sounds. The students should also be able to identify and describe ways in which the physical/mathematical properties of musical sounds affect their functioning in the context of a musical composition or stylistic paradigm.

Students will be able to describe the movement of tones and rhythmic patterns from points of tension to points of repose, to identify melodic and rhythmic patterns that are used as materials to build up into more complex structures, and to describe the processes by which this occurs within specific musical works as examples. Students should be able to identify chord tones, non-chord tones, passing tones, etc., as well as motives, phrases, sequences, melodic development, and harmonic rhythm

The students will also be able to identify and describe the fundamental particles of matter including quarks, bosons, and force carrier particles and to describe how current string theory relates the various generations of matter and force carriers to various resonances of fundamental strings of energy. Students will also be able to relate, in broadly general terms, the properties of various particles to more complex structures and processes found in nature.

Students will be able to use various analytical tools in order to describe the workings of music, including traditional theoretical labels for intervals, chords, keys, and forms. In order to describe the interrelationships of tones and chords, and the musical sense of flow through points of tension and instability to points of repose and closure, the students will use some of the very basic techniques of Schenkerian analysis, and relate them, again in a broadly general way, to the diagrams used to describe the interactions and scattering of atoms and particles developed by Feynman and others that are in use in the students' science classes.

The students will understand concepts of dissonance and consonance less as labels attached to formulaic constructs that vary with stylistic periods and more as conditions of relative stability and instability within the flow of the music; events influencing the energetic movement forward through time and the structure of music. Hopefully, students will begin to hear music as a dynamic and expressive process, with points of tension (instability) moving through varied and interesting tonal paths to points of repose (stability), rather than as merely patterns that please the senses in some visceral way. The students should begin to understand the choices that composers make, and relate those choices to expressive results, and how manipulating or altering those musical choices alters the expressive results. Eventually the students should be able to discuss emotion and meaning in the music to which they listen in an informed and sophisticated manner, speaking with understanding and authority in terms of the manipulation of musical elements; the phonological, syntactical, and semantic elements found in the music.

Strategies

Most students' appreciation and understanding of music is limited to an "entertainment" paradigm. That is to say, the student perceives music in terms of its entertainment value, which is, of course, shaped by subjective taste, peer culture, and the media. It's difficult, because of this perspective, for the student to approach music objectively; to appreciate it in its own cultural and expressive context, to listen analytically, or to isolate perceptions regarding the elements of music in qualitative ways. At times students can exhibit tenaciously closed minds; an unwillingness to consider music, or any of the arts for that matter, as having any other purpose than that of glazing their senses in a subjectively pleasing way. The inclusion of concepts from other subjects often will more successfully facilitate a student's development of some objectivity by shifting the context in which a student listens to and thinks about music. It's been said that the "best way to 'know' a thing is in the context of another discipline." [6]

Music continually has evolved along with the culture and technology of the times, and an understanding of what a composer is trying to express or explore is necessary to understanding the means that composer may have developed to do so. Styles have changed throughout history because of this dynamic process of influences. As what the composer expresses becomes more complex, so do the techniques employed in that expression. This tendency can be observed throughout the ages: the changing concepts of consonance and dissonance during the Medieval period, the rise of functional harmony in music and unified point perspective in painting alongside the humanism of the Renaissance, the emphasis on form and symmetry in the music of the Enlightenment, the mathematical and philosophical symbolism of the motives in the works of Richard Strauss at the beginning of the twentieth century, and so on. In the twentieth century, in many works in the repertoire, the compositional and production techniques employed are direct analogues to the extra-musical subject of the composition. In this unit particular focus will be placed on demonstrating that the way music is created and perceived is in many ways a metaphor for the physical processes that recent physics and mathematics have identified. While contemporary trends in music composition and performance highlight many of these processes to a great degree, the contrapuntal techniques and processes of motific dissolution, theme and variation, and thematic development throughout the traditional historic periods of musical development are rich in possible examples. Even at a fundamental level, the musical system of basic tones and intervals that are combined to create chords and more complex tonal progressions that in turn create the listener's perception of the movement of music through time and over distance are a useful analogy to the processes a growing number of the scientific community are embracing.

Classroom Activities

This unit will be integrated at various points into a curriculum already being taught and so much of the class activity will continue as it already is, but with the introduction of information about string theory and emphasis on the hierarchical structure of music and nature.

The first area of activity will emphasize the basic phonology of music and investigation of the physical nature of musical sounds.

Included in the range of classroom activities will be discussion/investigation of the characteristics of a waveform, emphasizing the mathematical ratios that are the basis of the overtone series, the relationship of the fundamental to its upper partials, and how these ratios are the foundation for the chromatic tones used in western music as well as other scale systems and the diatonic key system of tonal relationships and tendencies music relies on. The students and teacher will experiment with the effect on pitch and tone of varying the length, thickness, and tension of a variety of vibrating sources, including but not limited to the guitar, violin, piano, harp, percussion and generally any available observable vibrating source of sound. Additionally, the students should complete the activity "A New Building Block", downloadable from the PBS website "Teachers' Guide for The Elegant Universe: Einstein's Dream". [7]

The teacher should explain the Pythagorean ratios derived from dividing the length of strings into whole-number segments and their relationship to pitch. The students will use the Pythagorean ratios to calculate frequencies of various pitches and to generate the circle of fifths. The teacher should also introduce the concept of an overtone series simultaneously sounding with a perceived fundamental pitch (demonstrating by using electronic instruments if available, or by using the damper system and pedal of a piano) and to relate this phenomenon to differences in tone color of various instruments. The teacher may also discuss/demonstrate closed and open pipes, again depending on the receptivity of the students and availability of resources. At this point in the unit, the students should investigate the link "Resonance in Strings" found in the "Slideshows and Interactives" section of the PBS website "The Elegant Universe". [7]

Transitional activities to move the students from phonology to syntax should include "Particle Puzzle Pieces" and "Forces of Nature", two more of the downloadable activities from the PBS website aforementioned. [7] These activities familiarize students with the fundamental particles and force carriers described in the Standard Model. The students should, at the same time, be introduced to pitches used in combinations and discuss the perceived effects of combining pitches in different ways. The teacher should demonstrate this in a number of ways. For example, a simple series of pitches – the tones of a major triad – could be played melodically as a musical unit/gesture. Varying this basic structure by changing the quality of the triad, or changing the underlying harmony of the last pitch (i.e. harmonized by the other two tones of the major triad, contrasted with harmonized as the root of a first inversion augmented triad, contrasted with harmonized as the seventh of a dominant seventh chord, contrasted with harmonized as the seventh of a diminished seventh chord, etc.). The teacher is encouraged to use as many varied examples as imagination allows, reinforcing the basic premise of this part of the unit. The students should be encouraged to freely discuss their reactions to the different musical gestures, even assigning suggestive imagery or alluding to non-musical subjects. [8] All of this is intended to start the students thinking about music structurally, as well as to encourage the students to understand how combining tones produces various evocative results. Sidebar discussions should encourage the students to relate the recombination of basic musical tones to the various expressive results to the way fundamental particles combine to create atoms and molecules, as described in the two science activities done in conjunction with this part of the unit's musical activities.

The students should also listen to a number of musical examples emphasizing a variety of tonal environments at this point, including, but not limited to works such as the Brahms, Penderecki, Crumb, Douglas, Lygeti, Tallis, Ives, McGlaughlin, Mameluk, Eno, Tschaikowsky, Bach, Webern, and Mozart examples listed in the appendix.

The students will examine how concepts of consonance and dissonance have evolved in different cultures and relate these to the physical properties of sounds. The students will also investigate the parallels between scientific thought in different periods of history and the stylistic characteristics of music during those periods.

The teacher will have students listen to and analyze melodies in order to be able to describe melodic structure, identify and apply concepts of melodic construction (including voice-leading, step-wise and intervallic motion of tones, sequence, motive and phrase organization). An introductory activity in this regard may be a graphing strategy, particularly if the students are not quick with their utilization of standard notation at this point. Essentially an ear-training tool, the students should begin by noting on paper the relationship between two tones, indicating which is higher or lower. Gradually the teacher introduces three tones, then four, and so on, as the students' skill in comparing the relative pitch of tones increases. Have the students do this task without the use of a conventional staff at first, but by drawing a continuous line that rises and falls, shadowing the rise and fall of the pitches. As their skill improves, the students should be prompted to be more accurate with the distance their 'graphs' indicate pitch change (i.e. how does the third pitch compare to both the first and second, not merely the second and so on). Ultimately, the students' graphs of pitch movement should begin to resemble the contour of notes on the staff. At this point the staff should be introduced (if the students are not already familiar with it) but as a system that is a graphic analogy to the perceived sound, not merely as a set of lines and spaces to be memorized out of context of its application. Through this procedure, the students are already sensitive to contour, the rise and fall of pitch, and patterns of internal sequence and repetition since these aural perceptions are visually noticeable in their 'graphs'. The teacher is encouraged to use the musical suggestions listed in the appendix, along with any other appropriate examples.

As the students analyze various melodies, they should also identify points of tension and repose within melodies, and relate this organization to the syntax of language. The students should be encouraged to find ways to graphically show the movement of the melody through points of tension to points of repose. Terms like cadence and phrase should be introduced with this activity.

Students will also listen to and analyze melodies within a harmonic framework, and identify the differences harmony introduces. As their experience increases, they should apply concepts of cadence, progression, texture and density, harmonic rhythm, and functional and coloristic effects to the music they are experiencing. Throughout their analysis activities, the students will gradually be introduced to, and encouraged to use, more of the Schenkerian techniques to describe the music along with traditional theory terms in order to focus their analyses on the interactions of tones and rhythms. The students should begin to understand and recognize that certain tones are unstable and serve to ‘draw the music’ forward in time to other tones that are ‘points of repose’. The students should attempt to analyze music in this fashion; a graph or a flow chart of the musical score, reducing it down to its basic compelling elements. The students need to be reminded that these graphs are not substitutions for the music, but representations of the flow of movement through a piece. Many of the students will have been introduced to similar techniques to visualize processes of the interactions and recombination of fundamental particles. If practical at this point, a discussion of the similarities and differences of musical analysis and the symbols used to show particle and charge interactions and scatterings should be led by the teacher, reinforcing with the students the idea that neither actually depict what’s happening, but summarize the interactions on an abstractly symbolic level in both disciplines.

There is an ongoing debate in music as to whether the evocative characteristics of tone are nature or nurture, in a sense. Many musicians and theorists (from Zarlino in the Renaissance & Rameau in the 1700’s to Hindemith, Bernstein, et al in the present) believe that there are musical tendencies that are ‘universal’, being a function of either physics (in the case of Zarlino, Rameau, and Hindemith) or a shared human predisposition to music that is analogous to the linguistic theories of Noam Chomsky in the sense that there are certain universal ‘utterances’, both linguistic and musical, that aren’t bound by culture or historic period (Leonard Bernstein was an enthusiastic proponent of this idea [4]). Tonal movement, certain intervals, certain rhythmic tendencies, concepts of dissonance and consonance pervade the music of all cultures and times regardless of surface appearances. Music is, from this point of view, the expression of qualities implicit in the natural order of things. On the other hand, a similar cadre of musicians and theorists support the idea that musical tendencies are not innate but are the result of cultural context. We create and respond to music based on principles that are arbitrary and ingrained in us through exposure and repetition. This school of thought asserts that musical expression is a function of the human need to impose orderliness on our environment. Proponents of this idea cite human fascination with complex patterns and a need to “decorate the world.”

Either way, the concept still stands that music is a ‘system’ with ‘rules’, and the expressive potential of music depends on the manipulation of those tendencies and the expectations on the part of the listener based on them, regardless of the origins of those tendencies. The unifying idea of this unit is the hierarchical and organic nature of music; extended and complex works grow from fundamental tonal resources manipulated and developed by composers. That the expressive and technical features of complex musical works are a logical outgrowth of that organic process of building up from basic musical elements, and that this quality of music is profoundly illustrative of how contemporary physics views the elemental process of matter and energy. Furthermore, recent thought and investigation in string theory seems to provide an even deeper connection between music and physics.

Annotated Bibliography / Resources

Barrow, John. *Pi in the Sky: Thinking, Counting, and Being*. Little, Brown & Company, 1992

An exploration of mathematics and human culture. The author raises questions regarding the nature of mathematics, whether it is a human invention or inherent in nature, as well as the infusion of mathematics into a variety of human endeavors from politics to theology.

Bernstein, Leonard. *The Joy of Music*. Simon & Schuster, 1980

Bernstein, Leonard. *The Unanswered Question.* Harvard University Press, 1976

Bernstein, Leonard. *Young People's Concerts*. Doubleday, 1962

The three Bernstein books are collections of essays on a variety of musical topics. Of the most interest to my unit are the chapters on musical form, the organic structure of musical composition, pattern recognition, and expression and meaning in music.

Bronowski, Joseph. *The Ascent of Man*. Little, Brown & Company, 1973

A history of the development of science. The chapters 'The Music of the Spheres' and 'The Majestic Clockwork' are of particular interest to this unit in terms of how scientific thought on the orderliness of the universe and artistic expressions of those concepts have evolved along parallel lines.

Dallin, Leon. *Techniques of Twentieth Century Composition*. Wm. C. Brown, 1964

A standard reference work in the evolution of composition styles and techniques in the twentieth century. The text is profusely illustrated with musical examples from what was the avant-garde of the time of the book's publication.

Eger, Joseph. *Einstein's Violin: A Conductor's Notes on Music, Physics, and Social Change.* Most Tarcher/Penguin, 2005

A world-renowned conductor discusses music and science, drawing upon both disciplines to make assertions about world issues.

Feynman, Richard. *QED: The Strange Theory of Light and Matter*. Princeton University Press, 1985

A collection of lectures on quantum electrodynamics.

Funes, Donald & Munson, Kenneth. *Musical Involvement.* Harcourt Brace Jovanovich, Inc., 1975

A study of the universality of musical elements throughout a wide range of styles and cultures. The author focuses on the underlying organic structure of music and the consistent similarities of certain features of music regardless of style, culture, or historic period.

Hansen, Peter. *An Introduction to Music in the Twentieth Century*, Allyn and Bacon, Inc., 1961

Also a standard reference work on the techniques of contemporary musical composition. The author spends a great deal of time emphasizing various permutations of basic scales and intervals found in a range of styles of composition.

Hawking, Stephen. *A Brief History of Time*. Bantam Books, 1988

Hawking, Stephen. *The Universe in a Nutshell*. Bantam Books, 2001

The two Hawking books are explanations of a number of theories of the "new" physics, oriented to the lay reader.

Hoffer, Charles. *A Concise Introduction to Music Listening*. 2nd ed., Wadsworth Publishing, 1979

This text on musical analysis focuses heavily on pattern recognition and the inner workings of motific dissolution and thematic development. The notion of more complex structures built up from basic motives is fundamental to this unit.

Hofstadter, Douglas. *Godel, Escher, Bach: An Eternal Golden Braid*. Random House, 1979

A series of essays on the relationships between the visual arts, music, and mathematics. The author illustrates how work in all three disciplines share common concepts, problems, and perspectives. Perceptions of reality and a more concise definition of intelligence are at the core of the author's work.

LeShan, Lawrence & Margenau, Henry. *Einstein's Space and Van Gogh's Sky*. MacMillan; 1983

Co-written by a physicist and a psychologist, this book explores the links between the theories and discoveries of the new physics and human consciousness, the limitations of conventional views of reality, and the nature of reality. The authors argue that traditionally precise and literal systems to explain reality were developed to accommodate the human need to control the environment, but fall short by not taking into account non-physical experience.

Ratner, Leonard. *Music the Listener's Art*. McGraw-Hill, 1977

A text on musical form emphasizing pattern recognition and identification, and developing the ability to hear and perceive the development of basic musical ideas into more complex structures.

Salzer, Felix & Schachter, Carl. *Counterpoint in Composition*. McGraw-Hill, 1969

Salzer, Felix. *Structural Hearing; Tonal Coherence in Music Volumes I & II*. Dover Publications, 1962

Both of the Salzer texts on Schenkerian are applications of the ideas of the musical theorist Heinrich Schenker. The emphasis is to develop the ability to identify, in one's hearing and performing of music, the flow from points of repose, through points of increasing and decreasing instability, to other points of repose, through time, and to develop the ability to identify the hierarchical underlying structure of music.

Storr, Anthony. *Music and the Mind*, MacMillan, 1992

Storr describes similarities and differences between mathematics and music in this text that examines both subjects in terms of our perceptions of reality, will, theology, and the innermost workings of the world. While emphasizing pattern recognition and the human tendency to look for orderliness as a common characteristic of both music and mathematics, he draws distinctions between the logical inevitability of mathematical arguments and the aesthetic inevitability of musical structures. The author draws heavily from a wide range of work, including that of Schopenhauer, Nietzsche, Gauss, Freud, Jung, Leonard Meyer, Howard Gardner, and Roger Penrose.

Yeston, Maury, editor. *Readings in Schenker Analysis and Other Approaches*. Yale University Press, 1977

A collection of essays by various authors on the theories and process of Heinrich Schenker. Schenker's work has been both influential and controversial among musicians. His basic premise, that the surface details of any musical work are related to an underlying fundamental structure, has caused a great deal of reevaluation of previously accepted ideas about both the technique of musical composition, and the expressive qualities of music.

Zuckerkandl, Victor. *Sound and Symbol: Music and the External World*. 2nd ed., Princeton University Press, 1973

The author presents music as an instrument of philosophical study. Through examining musical experience and a recognition of its essential properties, the author proposes a set of fundamental concepts which could serve as a framework for an understanding of the world, concepts that are congruent with some of the ideas of modern physics – particularly, tonal organization as an image of time.

Partial list of musical works to be used as examples/illustrations throughout the teaching unit:

Bach, J. S. *English Suite in G Minor*.

Bach, J. S. *Goldberg Variations*

Bach, J. S. *Well-Tempered Clavier Book I, various*.

Bach, J. S. *Well-Tempered Clavier Book II, various*.

Bach, J. S. *A Musical Offering, Ricercare a' 6*

Barber, Samuel. *Sonata for Piano Op. 26*.

Beethoven, Ludwig van. *Sonata for Piano in C Minor, Op. 13*.

Beethoven, Ludwig van. *Fur Elise*

Beethoven, Ludwig van. *Symphonies #1, 3, 5, & 7*

Bolcom, William. *The Graceful Ghost*

Chopin, Frederick. *Nocturnes Op. 9 #2, Op. 27 #2*.

Copland, Aaron. *Piano Variations (1937)*

Crumb, George. *Ancient Voices of Children*

Debussy, Claude. *Preludes Book II, various*

Douglas, Bill. *Deep Peace*

Douglas, Bill. *Earth Prayer*

Eno, Brian. *Thinking Music*

Glass, Philip. *String Quartet #3 "Mishima"*

Glass, Philip. *Incidental Music for "Dracula", various*

Ives, Charles. *Central Park in the Dark*

Ives, Charles. *The Unanswered Question*

Ives, Charles. *Symphony #3*

Hancock, Herbie. *Maiden Voyage*

Handel, George Frederick. *Chaconne and Variations in G Major*

Haydn, Joseph. *Andante con Variazioni in F Minor*.

Hendrix, Jimi. *Purple Haze* (original version by the composer and the transcription for string quartet performed by the Kronos Quartet)

Hindemith, Paul. *Sonaten fur Piano (1936)*.

Machaut, Guilliame. *Kyrie II*

Mameluk, Peter. *Traveling Without Moving*

McGlaughlin, John. *Birds of Fire*

Mendelssohn, Felix. *Variations Serieuses Op. 54*.

Mozart, Wolfgang Amadeus. *Symphony #40 in G Minor*

Parker, Charlie. *Au Privave*; transcription of saxophone improvisations from Verve recordings 8010, 4949, & 2515

Penderecki, Krystof. *Threnody: To the Victims of Hiroshima*

Prokofieff, Serge. *Sonata #3 for Piano Op. 28.*

Rachmaninoff, Serge. *Variations on a Theme of Chopin Op. 22.*

Reich, Steve. *Music for Mallet Instruments, Voices, and Organ*

Shostakovich, Dimitri. Symphony #5

Stravinsky, Igor. *The Firebird*

Stravinsky, Igor. *Octet for Winds*

Strauss, Richard. *Thus Spake Zarathustra*

Tallis, Thomas. *Spem in Alium*

Tchaikowsky, Peter. *Symphony #4*

Webern, Anton. *Variations for Piano Op. 27*

Internet references:

Anatomy of a Detector, Fermilab, 30 May, 2005
<quarknet.fnal.gov/run2/boudreau.shtml}>

The Elegant Universe Homepage, PBS, 31 May, 2005,
<http://www.pbs.org/wgbh/nova/elegant/>

The Elegant Universe:Einstein's Dream, Teachers' Guide, PBS, 31 May, 2005
<http://www.pbs.org/wgbh/nova/teachers/activities/images/3012_elegant_particles.gif&imgrefurl=http://www.pbs.org/wgbh/nova/teachers/activities/3012_elegant.html&h=445&w=300&sz=27&tbnid=TreGIGzBtIcJ:&tbnh=123&tbnw=83&hl=en&start=1&prev=/images%3Fq%3Dsubatomic%2Bparticles%2Band%2Bstrings%26hl%3Den%26lr%3D>

SLAC Virtual Visitor Center, Stanford University, 30 May, 2005
<http://www2.slac.stanford.edu/vvc/Default.htm>

The particle Adventure, Particle Data Group, Department of Energy/National Science Foundation, 31 May, 2005 <http://particleadventure.org/particleadventure/index.html>

Hyperphysics, Georgia State University, Department of Physics and Astronomy, 30 May, 2005 <http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>

Content Standards for the Pittsburgh Public Schools

The following content standards are addressed in this unit:

Fine Arts

1. All students describe meanings they find in various works from the visual and performing arts and literature on the basis of aesthetic understanding of the art form.
2. All students evaluate and respond critically to works from the visual and performing arts and literature of various individuals and cultures, showing that they understand important features of the works.
3. All students relate various works from the visual and performing arts and literature to the historical and cultural context within which they were created.

Communications

2. All students read and use a variety of methods to make sense of various complex texts.
3. All students respond orally and in writing to information and ideas gained by reading narrative and informational texts and use the ideas to make decisions and solve problems.
4. All students write for a variety of purposes, including to narrate, inform, and persuade.
7. All students listen to and understand complex oral messages and identify the purpose, structure, and use.

Science and Technology

1. All students explain how scientific principles of chemical, physical, and biological phenomena have developed and relate them to real-world situations.
4. All students explain the relationship among science, technology, and society.
5. All students construct and evaluate scientific and technological systems using models and to explain or predict results.

Mathematics

1. All students use numbers, number systems, and equivalent forms (including numbers, words, objects, and graphics) to represent theoretical and practical situations.
3. All students evaluate, infer, and draw appropriate conclusions from charts, tables, and graphs, showing relationships between data and real-world situations.

Notes

[1] *Einstein's Violin*, p 32

[2] *The Elegant Universe*, p 146

[3] *How The Universe Got Its Spots*, p 199

[4] *The Unanswered Question*, throughout

[5] NY Times editorial "String Theory: Trying to Visualize Many Dimensions of Weirdness". Dennis Overbye

[6] *The Unanswered Question*, p3 Bernstein quoting David Prall

[7] PBS, The Elegant Universe:Einstein's Dream, Teachers' Guide http://www.pbs.org/wgbh/nova/teachers/activities/images/3012_elegant_particles.gif&imgrefurl=http://www.pbs.org/wgbh/nova/teachers/activities/3012_elegant.html&h=445&w=300&sz=27&tbnid=TreGIGzBtIcJ:&tbnh=123&tbnw=83&hl=en&start=1&prev=/images%3Fq%3Dsubatomic%2Bparticles%2Band%2Bstrings%26hl%3Den%26lr%3D

[8] For additional examples of this classroom activity see *The Unanswered Question*, Chapter 2. Mr. Bernstein includes a number of usable illustrations as part of his lecture on syntax.